NATIVE AND EXOTIC ANTS (HYMENOPTERA: FORMICIDAE) OF GEORGIA: ECOLOGICAL RELATIONSHIPS WITH IMPLICATIONS FOR DEVELOPMENT OF BIOLOGICALLY-BASED MANAGEMENT STRATEGIES

by

REID MATTHEW IPSER

(Under the Direction of Wayne A. Gardner)

ABSTRACT

The red imported fire ant, *Solenopsis invicta* Buren, is an invasive species that causes medical and economic problems, endangers domestic animals and wildlife, displaces native species, and disrupts natural habitats. This pest ant species now occupies much of the southeastern U.S., parts of the southwestern U.S., and has invaded southern California. This study was undertaken to define selected ecological relationships and competitive interactions of this invasive ant to serve as a basis for development of biologically-based management strategies.

Red imported fire ant occurrence, activity, and interactions with native ant species were compared in canopied and uncanopied habitats at two central Georgia locations. Fire ant density and activity were significantly greater in open than in canopied habitats. Native ant species were numerous and competed with fire ants via predation of reproductive alates and foraging for food resources in the canopied habitats.

A statewide survey for ground-dwelling ants expanded the list of taxa occurring in the state to 144. Of these, three are undescribed species belonging to two genera, *Myrmica* and *Stenamma*. Native species that compete with *S. invicta* were collected from the majority of the sites surveyed, thus, indicating the potential for competitive interaction with *S. invicta*.

Laboratory choice assays determined the bait particle size preference of *S. invicta*, the Argentine ant (*Linepithema humile* (Mayr)), and four native ant species. Particle size preference was positively correlated with worker ant head capsule width with large particles being preferred by those species with wide head capsules. Results indicate that particle size preferred by *S. invicta* overlap those of *Aphaenogaster fulva* Roger, *A. lamellidens* Mayr, and *Formica pallidefulva* Latreille. *Pheidole dentata* Mayr preferred a small particle size. Competitive interactions between *S. invicta* and the four native species for bait particles resulted in dominance of the laboratory foraging arena by *S. invicta*.

Field testing at Griffin, Georgia further determined that single broadcast applications of hydramethylnon bait and fipronil granules at recommended rates in early summer reduced fire ant mound density and fire ant worker activity in treated areas. The effects of fipronil were longer-lasting that those of hydramethylnon. Neither hydramethylnon nor fipronil reduced populations of native ant or other ground-dwelling arthropod species in this study.

INDEX WORDS: Argentine ants, bait particles, bait preference, competition, fipronil, fire ants, ground-dwelling ants, hydramethylnon, insecticide, nontarget, species diversity, survey.

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DEDICATION

For the new myrmecologists.

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Deyrup (Archbold Biological Station, Lake Placid, FL) verified species identifications, and Cecil Smith of the Georgia Natural History Museum supplied equipment and allowed access to ant specimens housed in the museum.

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PREFACE

The red imported fire ant, *Solenopsis invicta* Buren, is the most serious economic pest ant species in Georgia. Since its introduction into the Mobile Bay, Alabama, area in the 1930's, it has spread throughout the southeastern and some parts of the southwestern U.S. With its sting, aggressive behavior, ability to proliferate, and the ecological and economic damage it causes, *S. invicta* has become the most studied pest ant species in the U.S.

Historically, various chemical insecticides formulated as granules, liquids, wettable powders, and baits have been used in control programs or in area-wide eradication efforts against *S. invicta*. While some agents provide temporary control, reinfestation generally occurs within 4 to 8 weeks primarily through establishment of founding colonies following nuptial flights. A more comprehensive and multi-faceted approach involving biologically-based tactics and strategies are needed to achieve long-term and satisfactory control of this pest ant. The study reported herein focuses on native ant species which might effectively compete with *S. invicta* given suitable conditions.

The second chapter of this dissertation explores ecological relationships and competitive interactions occurring between *S. invicta* and native ant species in habitats infested with *S. invicta* (open uncanopied, frequently disturbed) vs. habitats with relatively little *S. invicta* activity (canopied, undisturbed). The objectives of this component of this study were to compare (1) occurrence of ground-dwelling ant species; (2) foraging activity of ground-dwelling ant species, and; (3) the natural predation of *S. invicta* reproductives in the two different habitats.

A second component (Chapter 3) of the study identified and catalogued native ground-dwelling ant species in Georgia. Thus, the distribution and occurrence of those native species that effectively compete with *S. invicta* were defined. A taxonomic key of ground-dwelling ant species collected in Georgia is included in the Appendix.

The fourth chapter examined foraging and recruitment activities of *S. invicta*, *Linepithema humile* (Mayr), and four native species in laboratory choice tests. It also examined competition among these species. The objectives of this component of the study were to (1) determine particle size preference of these species and correlate particle size with head capsule width; (2) determine effects of ambient temperature on the foraging activities; (3) examine competitive interactions between species, and; (4) measure recruitment rate and intensity to a food source for each species.

The final chapter addressed the impact of two commonly used insecticides - hydramethylnon and fipronil – on fire ant occurrence, activity, populations of native ant species, and populations of other ground-dwelling arthropods. Changes in arthropod abundance were quantified after single applications of both insecticides.

CHAPTER 1

A REVIEW OF THE SCIENTIFIC LITERATURE ON THE BIOLOGY, ECOLOGY, AND FORAGING STRATEGIES OF TWO INVASIVE ANT SPECIES IN NORTH AMERICA[1]

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Abstract

The red imported fire ant, *Solenopsis invicta* Buren, and the Argentine ant, *Linepithema humile* (Mayr), are economically important pest ant species that are not indigenous to North America. Historically, methods for control of these pest ants have primarily focused on chemical insecticide tactics in their expanded ranges. However, management programs should be increasingly biologically-based. Scientific literature on the ecology, biology and behavior of these two species is presented herein to establish a basis for further identification, development and implementation of such biologically-based strategies that could provide long-term sustainable management of these invasive pest ant species.

Introduction

The red imported fire ant, *Solenopsis invicta* Buren, and the Argentine ant, *Linepithema humile* (Mayr), are native to South America. *Linepithema humile* reportedly invaded North America in coffee shipments through New Orleans in 1891 (Foster 1908), while *S. invicta* entered the U.S. through Mobile, AL, on several occasions between 1933 and 1944 (Rhoades 1977). Both species have since expanded their respective ranges to include the southeastern U.S., parts of the southwestern U.S., and states along the Pacific coast (Korzukhin et al. 2001, Vega and Rust 2001).

In the U.S., *S. invicta* causes medical problems (Rhoades 1977, Adams and Lofgren 1982, Lofgren 1986), endangers domestic animals and wildlife (Mount 1981, Holtcamp et al. 1997, Allen et al. 2001), damages agricultural crops and equipment (Adams 1986), and interferes with biological control programs (Brinkman et al. 2001). Pimentel et al. (2000) estimated damage and costs of control in the U.S. to exceed $1.6 billion per year; however, these estimates may have been low due to the lack of factoring indirect and non-market costs (Lodge and Schrader-Frechette 2003). Varlamoff et al. (2001) further determined that use of insecticides exceeded that of herbicides among Georgia homeowners primarily because of treatment of *S. invicta* infestations in home lawns.

Linepithema humile lacks the aggressive behavior and the sting of the *S. invicta* workers. Yet, it is a nuisance pest in and around urban settings, and it is a true agricultural pest in citrus, almonds, and other crops where workers actively tend homopteran insects in classic ant-insect mutualistic associations (Rust et al. 2003).

In addition, these two invasive pest species cause ecological problems that are not factored into economic or medical damage estimates. In their expanded ranges, they directly or indirectly compete with native species resulting in their displacement from the ecosystem. This may lead to reduction of species abundance and richness in the affected habitats. Furthermore, a range of native species may be affected. This is especially significant when a species is dependent upon the displaced species for survival. For example, in South Africa, certain Proteaceae plants depend upon seed dispersal by the native ant *Pheidole capensis* Mayr. Bond and Slingsby (1984) predicted the extinction of these Proteaceae in habitats where *L. humile* has competitively displaced the native *P. capensis.* While *L. humile* workers harvest the plant seeds, they do so more slowly than the native species, and they do not store seeds below the surface where they are protected from other seed harvesters.

Historically, control or management programs for *S. invicta* and *L. humile* in the U.S. have focused on insecticidal-based tactics and strategies (Drees and Gold 2003, Rust et al. 2003). However, comprehensive management strategies must be developed for these invasive pests and should include a mixture of tactics that are biologically-based as well as chemically based. Thus, the objective of this review is to collect and assimilate pertinent research-based information on the biology, ecology, and behavior of these invasive pests that might serve as a foundation for development and implementation of biologically-based management strategies.

The review is organized so as to address the properties and characteristics of these two pests that enable them to be successful invasive species in North America, the characteristics of habitats that are successfully exploited by these species, interactions of the invasive species with native ants, the current and potential use of natural enemies against these pests, and foraging strategies and behavior of each species. Preservation or restoration of natural habitats, conservation of native ant species, and continued development of natural enemies as biological control agents are explored as bases for development of biologically-based management programs for these pest ants.

Invasive Properties

Solenopsis invicta and *L. humile* possess several attributes that enable them to successfully invade and become established in their expanded North American ranges. Both species are r-strategists (Markin 1970b, Holldobler and Wilson 1990, Majer 1994, Tschinkel 1998), have fertility and fecundity rates that are higher than those of native ant species (Tschinkel 1988a, 1993a,b, Holldobler and Wilson 1990), and are omnivorous allowing them to shift among different food resources (Taber 2000, Vega and Rust 2001). In addition, the aggressive behavior and the sting of *S. invicta* allow this species to overwhelm vertebrate and invertebrate competitors and to repel them from food resources (Vinson 1994).

The lack of natural enemies (i.e., predators, parasites, and diseases) in their expanded ranges also insures the success of both species (Wojcik 1983, Patterson 1994, Orr et al. 1995, Orr and Seike 1998). Williams et al. (2003) report that more than 30 species of natural enemies of *S. invicta* have been discovered in its native range in South America. Yet, these natural enemies are absent from its expanded range in North America, where only two protozoan diseases reportedly occur naturally in imported fire ant populations (Pereira et al. 2002, Williams et al. 2003). Natural enemies of *L. humile* have been sought as early as 1918 without much success (Vega and Rust 2001).

Within-colony relatedness has also contributed to the successful invasiveness of both species. Holway et al. (1998) reported that because of the unicolonial formation of *L. humile* in the U.S., intraspecific competition is reduced thereby resulting in large populations of the pest ants extending across extensive geographic areas. In northern California, multiple colonies are connected by trunk trails allowing brood, queens, and food resources to be exchanged and shared among separate nesting sites (Tsutsui et al. 2000, Tsutsui and Case 2001). This phenomenon does not occur in its native range in South America where *L. humile* exhibits pronounced intraspecific competition and aggression. The absence of intraspecific aggression in its expanded range has been attributed to a lack of recognition cues and the breakdown of nestmate discriminatory ability resulting from high genetic relatedness among the colonies (Holway et al. 1998, Tsutsui and Suarez 2003).

Solenopsis invicta is also losing genetic diversity in its expanded range (Tsutsui and Suarez 2003). Ross et al. (1996) report that nonindigenous populations introduced into North America contain fewer alleles than populations from their native range. The polygyne forms are believed to be reinforced by reduced genetic diversity and greater nestmate recognition abilities (Ross and Keller 1995, Ross et al. 1996).

Polygynous *S. invicta* forms disperse and found colonies primarily through budding; monogynous forms disperse and found colonies by nuptial flights and claustral founding (Vargo and Porter 1989). Polygynes do produce nuptial flights thereby supporting the hypothesis that this form exhibits two methods of colony reproduction and formation, i.e., budding and independent queen founding (Vargo and Porter 1989). Newly-mated queens of both monogyne or polygyne forms can found colonies either alone (haplometrosis) or by joining with other newly-mated queens (pleometrosis) following nuptial flights (Tschinkel 1998).

Although nuptial flights occur in *L. humile,* the primary method of colony reproduction and founding is budding (Newell and Barber 1913, Markin 1970a,b). *Linepithema humile* reportedly executes 90% of the queens, or 8% of the total biomass of the colonies, prior to the colony reproductive season, thereby increasing available food resources for workers while reducing inhibition of the production of new reproductives (Keller et al. 1989).

Exploited Habitats

Abiotic conditions, habitat characteristics, and interactions with native species are key factors governing successful establishment and subsequent population growth of an invasive species (Diamond and Case 1986, Orians 1986, Lodge 1993, Holway 1998). *Solenopsis invicta* prefers moist conditions in its expanded range, while *L. humile* prefers drier conditions with access to free water (Taber 2000, Vega and Rust 2001). Furthermore, Vega and Rust (2001) postulate that the continuously wet environments resulting from the high levels of rainfall in the temperate rainforests of the U.S. Pacific Northwest will limit expansion of *L. humile* in that region. *Solenopsis invicta,* on the other hand, prefers wet habitats that are characteristic of its native range in South America (Taber 2000).

Holway (1998) noted that the expansion rate of *L. humile* in riparian woodlands of the lower Sacramento River Valley of northern California averaged 16 m per year where permanent stream flow occurs. However, where stream flow is intermittent, the range was actually decreasing at 6 m per year. By comparing survey data with those of previous surveys (Tremper 1976, Ward 1987), Holway (1995) concluded that *L. humile* was expanding its range in riparian vegetation along permanent creeks and was absent from surrounding habitats.

Solenopsis invicta and *L. humile* infestations in their expanded ranges are often associated with habitats that have been ecologically disturbed. Both species rapidly establish in disturbed areas such as grazed pasturelands, managed recreational sites, and areas disturbed by fire or foresting activities (Erickson 1971, Vinson 1994,). Tschinkel (1988b) reported that clearcut areas in the Apalachicola National Forest in Florida contained high densities of *S. invicta. Solenopsis invicta* prospers in these disturbed habitats (Buren et al. 1978), even in its native South American range (Wojcik 1986).

Linepithema humile also exploits disturbed habitats in its expanded ranges, where its numbers may comprise as much as 80% of the total ant community (Majer 1994). *Linepithema humile* is capable of successfully invading undisturbed habitats as well (Human and Gordon 1996, 1997); however, exploitation of undisturbed habitats depends largely upon their ability to use and move from adjacent disturbed areas, usually associated with urban development (Crowell 1968, Human and Gordon 1997, Kennedy 1998, Suarez et al. 1998).

Porter et al. (1992, 1997b) reported that *S. invicta* was more abundant along roadsides, lawns, and grazed areas in the U.S. than in similar areas in Brazil. It has been hypothesized that this is due to a lack of natural enemies in its expanded range (Wojcik 1983, Porter et al. 1997b, Williams et al. 1998). Majer (1994) also noted that he had not observed *L. humile* in undisturbed, pristine areas of western Australia and concluded that habitat simplification resulting from ecological disturbance allowed for the success of *L. humile* in disturbed habitats. Furthermore, Suarez et al. (1998) credit the destruction and ecological simplification of natural scrub habitats in San Diego County of southern California for the successful invasion and establishment of *L. humile* in that region.

Native Ant Species

Solenopsis invicta and *L. humile,* as invasive species, aggressively compete with native species for ecological niches and, thus, competitively displace native ant species leading to a significant reduction in species abundance and richness in affected habitats. Camilo and Phillips

(1990) reported a negative correlation of *S. invicta* population density with the number of coexisting species of native ants. In that study, 21 ant species occurred in undisturbed areas that were not infested with *S. invicta,* while 14 species occurred in disturbed habitats that were not infested with *S. invicta.* In areas infested with *S. invicta,* nine ant species were collected from undisturbed plots, and only five species were collected from disturbed plots. They postulated that *S. invicta* out-competed native ant species, citing two granivorous ant species, *Pheidole tepicana* Pergande and *P. crassicornis* Wheeler, as being displaced from food resources.

Porter and Savignano (1990) also found a significant negative correlation between populations of polygynous *S. invicta* with the number of coexisting native ant species. An average of 16 species of ants was collected in pitfall traps from sites not infested with *S. invicta* compared to an average of five species collected from infested sites. Other sampling methods yielded similar results with 16 species extracted from leaf litter gathered from uninfested areas compared to six species extracted from litter from infested sites. Also, seven species were collected on baits placed in uninfested sites compared to one species collected on baits placed in infested sites.

Pasfield (1968) reported that *L. humile* displaced neighboring native ant species 300 m^2 per year in Australia. *Pheidole megacephala* (F.), a nonindigenous species to Hawaii, was also displaced by *L. humile* between 66 to 100 m^2 in Hawaii (Fluker and Beardsley 1970). Cole et al. (1992) also noted that *L. humile* negatively impacted invertebrate fauna in the highlands of Hawaii where gastropods, araneids, collembolans, dermapterans, hemipterans, coleopterans, dipterans, hymenopterans, and lepidopterans were reduced in areas infested with *L. humile.* They also observed a reduction in populations of nonindigenous ants and hypothesized that complete competitive exclusion had occurred. In North America, Holway (1998) and Human and Gordon (1996) concluded that *L. humile* was proficient at exploitive and interference competition against native ants in the lower Sacramento River Valley and the Jasper Ridge Biological Preserve in California.

Although Banks and Williams (1989) reported that *S. invicta* effectively competes with other ant species for resources in its native range in South America, they note that additional studies are needed to categorize and quantify competitive interactions with other native species in South America. Such studies could identify species that are successful competitors against *S. invicta* and *L. humile* in their native range and provide information on mechanisms, such as foraging strategies that structure ant communities in South America that might be applied to their expanded ranges in North America.

Competitive interactions between invasive species and native ant species primarily involve competition for the same food resources. *Solenopsis invicta* effectively displaces other ant species from the same food resources (Baroni-Urbani and Kannowski 1974, Banks and Williams 1989, Camilo and Phillips 1990, Porter and Savignano 1990, Jusino-Atresino and Phillips 1994). However, Banks and Williams (1989) reported that when *S. invicta* and *Paratrechina longicornis* (Latreille) compete for the same food resource, *P. longicornis* discovered the resource first and dominated the resource with many workers and foragers for 30 min, recruiting 275 workers to three baits within 20 min. Although *S. invicta* was slower in recruiting to the same baits, they eventually recruited more workers than did *P. longicornis.* Within 40 min, *P. longicornis* was completely displaced from baits by *S. invicta* workers.

Linepithema humile will monopolize and secure available food resources as well as control the remaining foraging areas (Holway 1999). Human and Gordon (1996) reported that *L. humile* discovered and recruited to baits in higher numbers than native ants and displaced native species in 60% of the encounters in a 450-ha biological reserve in northern California. Furthermore, Holway (1999) noted that *L. humile* discovered baits an average of 4 min faster than the native species *Aphaenogaster occidentalis* (Emery), *Dorymyrmex insanus* (Buckley), *Formica aerata* Francoeur, *F. moki* Wheeler, *Liometopum occidentale* Emery, *Monomorium ergatogyna* Wheeler, and *Tapinoma sessile* (Say). He further observed that *L. humile* recruited 3X more foragers to the baits within 3 h than did these seven native ant species.

Yet, native ant species also reportedly compete and/or coexist with *S. invicta* and *L. humile* in their expanded ranges. Holway (1999) reported that certain native ant species hindered the discovery time to baits by *L. humile*, indicating significant interspecific competition. Apperson and Powell (1984) found that, while *S. invicta* dominated baits in a North Carolina study area, the native ant *Lasius neoniger* Emery outnumbered *S. invicta* collections in pitfall traps. They suggested that *L. neoniger* can coexist and compete with *S. invicta*.

To succeed in areas infested with either *S. invicta* or *L. humile*, native species must exhibit some sort of resource partitioning strategy. Native species, such as *Prenolepis imparis* (Say), *Nievamyrmex* spp., and some *Aphaenogaster* spp., attain large population levels in habitats that appear unsuitable for *S. invicta* and *L. humile* (Holldobler and Wilson 1990, Tschinkel 1987, Gotwald 1995). In addition, heat tolerant species, such as *Forelius analis* (Andre) and *Paratrechina arenivaga* (Wheeler), build moderate population levels in habitats where *S. invicta* and *L. humile* prosper (Stimac and Alves 1994).

Due to their abundance and biomass, native ant species have the ability to compete for resources with invasive species, and priority effects could allow for a less competitive native species to dominate a bait in the presence of an invasive species. Torres (1984), for example, found that discovery and recruitment to a bait resource first was significantly correlated with dominance of the bait, thus imparting competitive advantage. In that study, 43 of the 46 species that first arrived at a bait dominated it regardless of the environmental conditions. Morrison (1996), in his study of ant communities in the Polynesian Islands, noted that the presence of one dominant ant species on a food resource precluded access of other ant species to the resource.

Priority effects have not yet been reported in the expanded ranges of *S. invicta* and *L. humile*. However, the coexistence of either *S. invicta* or *L. humile* with native ant species suggests regulation of these ant communities by some biotic or abiotic factor(s), such as moisture, nutrients, or habitat heterogeneity (Morrison and Porter 2003), as well as the possible involvement of priority effects.

Ecological disturbance of habitats disrupts native ant assemblages, thus allowing for the successful invasion and establishment of exotic ant species (Suarez et al. 1998). Human et al. (1998) observed that *L. humile* occurred in areas near the edge of the Jasper Ridge Biological Preserve in northern California; whereas, it did not occur in the center of the undisturbed preserve where native ant species were abundant. Suarez et al. (1998) also found *L. humile* inhabiting edges of large, undisturbed scrub habitat in California. They further noted that these undisturbed areas supported more native ant species than the disturbed areas. Simplification of habitats through ecological disturbance also simplifies ant communities, thus contributing to the successful invasion and establishment of *S. invicta* or *L. humile* (Majer 1994). Advanced community complexity yields advanced food webs which, in turn, produces high linkage density, cycles, loops, direct and indirect links, longer food chains, and compartmentalization of food webs (Morin 1999). These ecological features are advantageous to ant communities by creating food and temporal niches and resource-based population regulation factors (Kaspari 1996, 2000).

Natural Enemies

Williams et al. (2003) recently reviewed the status of natural enemies for *S. invicta*. More than 30 species of diseases, parasites and predators reportedly occur in its native range in South America (Allen and Buren 1974, Allen and Silveira-Guido 1974, Silveira-Guido et al. 1973, Jouvenaz et al. 1980, 1981a,b, Williams 1980, Jouvenaz 1986, Wojcik 1986), while only a few endemic species occur in its expanded range in North America (Jouvenaz and Kimbrough 1991, Williams et al. 1998, Pereira et al. 2002). Efforts to inoculate populations of *S. invicta* with the protozoan *Thelohania solenopsae* Knell are continuing (Williams et al. 2003); natural spread readily occurs in polygynous forms. In addition, two phorid fly parasitoids imported from South America are being systematically released throughout the southeastern U.S. (Williams et al. 2003). Recent releases of *Pseudacteon tricuspis* Borgmeier in north central Florida have led to their establishment (Porter et al. 1997a); spread into southern Georgia is expected. *Pseudacteon curvatus* Borgmeier has been released and successfully established in Mississippi, Alabama, and other states (Gilbert and Patrock 2002, Vogt and Streett 2003).

Explorations for potential classical biocontrol agents for *L. humile* were initiated in 1918 (Mally 1918, Vega and Rust 2001). To date, only the two phorids *Pseudacteon pusillum* Borgmeier and *Apocephalus silvestrii* Borgmeier are potential candidates (Orr and Seike 1998, Vega and Rust 2001). There are no immediate plans for introductions in North America or other expanded ranges.

Foraging Strategies

The competitiveness and the successful invasiveness of *S. invicta* and *L. humile* are largely dependent upon the foraging strategies and behavior exhibited by each species.

Solenopsis invicta is an efficient forager; workers often dominate other ant species in obtaining most food resources (Barnoi-Urbani and Kannowski 1974, Apperson and Powell 1984). After locating food resources, workers recruit foragers to the resource using temporary trunk trails. Foragers generally return to the nest via the temporary trunk trails, although solitary workers can retrieve food items without recruitment if the resource is small. Larger-sized *S. invicta* workers will guard smaller foragers during food resource retrieval (Wilson 1962, Holldobler and Wilson 1990). *Linepithema humile* workers also use temporary trunk trails in retrieval and recruitment (Human and Gordon 1996).

Solenopsis invicta workers are slightly polymorphic with head capsule widths ranging from 0.45 to 1.5 mm (Wood and Tschinkel 1981). As Oster and Wilson (1978) noted, polymorphic species are more likely to dominate a food patch when first encountered because of a higher initial removal rate associated with the size range of polymorphic worker ants. Wilson (1978) further reported a positive correlation of head capsule size of workers with the size of particles retrieved and carried by the omnivorous *S. invicta* and the seed harvesting *S. geminata* (F.). With continuous polymorphism characteristic of these two species, workers can match the size of food resource objects they retrieve and carry (Went et al. 1972, Wilson 1978).

In contrast, *L. humile* workers are monomorphic with a mean head capsule width of 0.54 mm (Hooper-Bui et al. 2002), and are more restricted than *S. invicta* in the sizes of particles that workers retrieve and carry. California populations of *L. humile* reportedly carry a maximum particle size of 1.0 mm in diameter (Hooper-Bui et al. 2002). Yet, *L. humile* compensates for this limitation by recruiting a large number of workers to a food patch (Markin 1968, Holway 1998). The unicolonial formation of *L. humile* colonies provides up to a 10-fold increase in the number of foragers, given the assumption that a sufficient number of inter-related colonies are attracted to the same food patch (Markin 1970a). Likewise, the polygyne *S. invicta* also recruit large worker forces to food patches (Bhatkar and Vinson 1987a, 1987b, MacKay et al. 1994).

Carroll and Janzen (1973) hypothesized that as individual worker ants become more familiar with a fraction of the foraging territory through random searching, the size of the foraging territory increases. Aron et al. (1990) observed that *L. humile* establishes continuous foraging trails resulting in mass recruitment and territory founding when new food patches are discovered. Fernandes and Rust (2003) also noted that *L. humile* repeatedly returned to the same food patch after discovery of the resource; however, only 11% of the originally-recruited workers returned to the resource 48 h after its discovery.

Other factors, including temperature and polyethism, affect foraging potential and activity. Porter and Tschinkel (1987) reported maximum foraging activity for *S. invicta* between 22 and 36ºC. Francke et al. (1985) reported temperatures exceeding 42ºC as lethal to *S. invicta* workers; yet, Porter and Tschinkel (1987) and Vogt et al. (2003) noted that workers continue to forage at temperatures >42ºC by using an extensive underground tunnel system that apparently protects workers from exposure to extremes of environmental conditions. The optimal foraging temperature for *L. humile* is 15 to 30ºC (Markin 1968), but workers are active between 10 and 35ºC (Markin 1970a).

Polyethism, or task allocation and specialization, occurs in ants with respect to individual morphology (caste) and age (Wilson 1953, 1971). *Solenopsis invicta* exhibits age and size polyethism, while *L. humile* exhibits only age polyethism. Smaller and younger *S. invicta* workers concentrate on brood care and other activities in the nest; older workers forage (Mirenda and Vinson 1981). These older workers are of various sizes and are usually around the nest periphery and the foraging territory. Older *L. humile* workers forage while younger workers tend to nest duties and brood care.

Biologically-Based Management

Historically, the management of these two pest ant species have relied almost totally upon chemical insecticide strategies and tactics (Williams et al. 2001, Drees and Gold 2003, Rust et al. 2003). While the use of insecticides is an important component in the management of these pests, biologically-based strategies and tactics must be identified, developed and implemented to achieve long-term and sustainable management of these invasive species.

Future management programs should include an ecological rationale focusing on natural enemies and the utilization of competitive native ant species. Williams et al. (2003) recently reviewed the biological control of *S. invicta*, noting that efforts are multi-faceted and incorporate classical biocontrol, augmentation, and microbial insecticidal approaches. Efforts at biological control of *L. humile* lag behind those of *S. invicta* (Rust et al. 2003).

Interactions of these invasive species with native ant species have largely focused on competitive displacement of native ants by the invading pests. Yet, some reports note that native ant species can compete with *S. invicta* and *L. humile.* Furthermore, habitat disturbance decreases species diversity and richness, simplifies the ecological infrastructure of the system, and eliminates native species. This, in turn, enhances the potential for successful establishment of invasive species such as *S. invicta* and *L. humile.*

Conservation or preservation of native ant species in the expanded ranges of these pests should be included in any biologically-based management program. This may involve habitat conservation or restoration, especially with *S. invicta.* Selective use of insecticides formulated as baits could focus on temporal, spatial, food preference, and particle size preference differences between native and invasive ant species to allow for preservation of native species while controlling pest species (Klotz et al. 1998, Kaspari and Majer 2000, Hooper et al. 2002, Silverman and Roulston 2001). Other factors that might enhance native species (i.e., environmental manipulation) should be explored.

Future management strategies for *S. invicta* and *L. humile* must be multi-dimensional. Approaches focused on one or two tactics will provide only short-term control, not long-term and sustainable management, as demonstrated by the use of only chemical insecticides (Apperson et al. 1984)

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CHAPTER 2

ABUNDANCE, ACTIVITY, DIVERSITY, AND SPECIES INTERACTIONS OF GROUND-DWELLING ANTS (HYMENOPTERA: FORMICIDAE) IN OPEN AND CANOPIED HABITATS IN CENTRAL GEORGIA[1]

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[1] Ipser, R. M. and W. A. Gardner. To be submitted to Environmental Entomology

ABSTRACT

The red imported fire ant, *Solenopsis invicta* Buren, and native ant species were studied in canopied and open uncanopied habitats in central Georgia. Population densities, native species diversity, and interactions were measured, quantified, and contrasted in the two types of habitats. Sampling methods involved pitfall traps, bait dishes, collection of leaf litter, and active searching. Fire ant population density was found to be lower in canopied habitats, where native ant species diversity was higher. Native ant species competed with fire ants more intensely in canopied habitats via predation of fire ant reproductives and foraging activity. The results suggest that native ant species can suppress fire ant population levels, and techniques for managing fire ants should include competition by native ant species.

Key Words: Ant species, biodiversity, interspecific competition, *Solenopsis invicta*, species diversity.

INTRODUCTION

The red imported fire ant, *Solenopsis invicta* Buren, is native to South America where its home range extends north along the Guapore River into Brazil and south along the Paraguay River into northern Argentina (Buren et al. 1974, Rhoades 1977). It was accidentally introduced into North America on multiple occasions between 1933 and 1941 through the Mobile, AL, area ports (Rhoades 1977). It has since expanded its range in the U.S. to include most of the Southeast and parts of the Southwest and southern California (Korzukhin et al. 2001).

Factors contributing to its successful range expansion in the U.S. include its reproductive strategies (Holldobler and Wilson 1990, Tschinkel 1998), its omnivorous feeding habits (Camilo and Phillips 1990), the relative lack of natural enemies to provide natural suppression in its expanded range (Wojcik 1983), and its aggressive behavior (Vinson 1994). Vinson (1994) noted that *S. invicta* rapidly establishes in disturbed areas such as grazed pasturelands, managed recreation areas, and areas cleared by fire, deforestation, or other events. Taber (2000) concurred, observing that in its expanded range, *S. invicta* occurs primarily in open and often disturbed areas rather than areas canopied with trees and other vegetation. Reasons for these observed responses to canopied vs. open areas have not been delineated. Therefore, the study reported herein compares the occurrence of ground-dwelling ant species, foraging activity of ground-dwelling ant species, and the natural predation of *S. invicta* alates in canopied vs. open habitats in central Georgia.

MATERIALS AND METHODS

Study Areas and Habitats

The study areas selected for this study were within two Georgia state parks in central Georgia. One was High Falls State Park that is approximately 20 km south of Jackson (Butts Co.), GA. It is 178 m above sea level and is characterized primarily by loamy/clay soils. The second, Indian Springs State Park, is approximately 5 km south of Jackson (Butts Co.), GA, and is 193 m above sea level. It also is characterized by primarily loamy/clay soils. Both parks contain over 100 ha of open uncanopied areas and more than 200 ha of wooded areas characterized as second-growth forests, comprised primarily of *Quercus* spp. and *Pinus* spp.

Study sites were established in canopied and open uncanopied areas within each park. There was 1 study area within each habitat in each park, each measuring 1000 m^2. Both plots within canopied habitats were at least 60 m from any adjacent right-of-way.

The dominant plant species and amount of plant cover were characterized for each sample site using five 20-m parallel linear transects established 10-m apart within each plot. Each transect served as a centerline for 200 quadrats of area, each 1 m^2 in size. Plant species were identified, and the area covered by these species was estimated (Meyers and Shelton 1980).

Ant Abundance, Activity, and Diversity

Ground-dwelling ant fauna were sampled using pitfall traps, bait dishes, collection of leaf litter, and visual searching as described by Bestlemeyer et al. (2000). The combination of these methods is ideal for biodiversity monitoring programs and comparing ant fauna among different habitats (Bestlemeyer et al. 2000). In each plot, 20 pitfall traps were placed at 1-m intervals along the transect. These traps were 40-ml plastic vials containing propylene glycol (filled 2/3) as a nontoxic preservative. Each was inserted into the ground to a depth so that the upper rim of the vial was level with the soil surface. After 7 d, each trap was removed from the soil, capped, and returned to the laboratory.

Bait dishes were plastic Petri dishes (35 x 10 mm) containing a 25-mm diam grade 1 Whatman filter paper disk covered with a thin layer of tuna in oil as described by Brinkman et al. (2001). Bait dishes were placed at 2-m intervals along each transect in each plot. Dishes were placed at 0900 (EST) during the warmer months and 1400 (EST) during the colder months. These dishes remained exposed for 2 h after which they were covered, sealed with Scotch™ transparent tape, and transported to the laboratory. If a bait dish was dominated by an individual ant species before the end of the 2 h time period, it was covered and sealed to collect as many ants as possible.

Litter samples were obtained at 5-m intervals along each transect. This involved hand collecting litter and humus in a 1-m^2 area and placing it in large trash bags. These were transported to the laboratory where sub-samples were placed into Berlese funnels. After 24 h, vials containing ants and other invertebrates were removed, and ants were separated.

Each canopied sampling plot also was visually searched for three man-hours during each sampling date for ant fauna. Litter, bare ground, tree trunks, foliage, decaying wood, and other surfaces were searched. Representative ants were collected and placed in 70% ethyl alcohol for transport to the laboratory.

All ants collected by these methods were initially identified by comparison with specimens housed in the University of Georgia Natural History Museum (Athens, GA). Identifications were made with keys by Bolton (1994, 2000), Buren (1968), Creighton (1950), Cuezzo (2000), DuBois (1986), Gregg (1958), Holldobler and Wilson (1990), Johnson (1988), MacKay (2000), Smith (1957), Snelling (1988), Snelling and Longino (1992), Taylor (1967), Trager (1984, 1988), Wilson (1955). Stefan Cover (The Museum of Comparative Zoology, Harvard Univ., Cambridge, MA) and Mark Deyrup (Archbold Biological Station, Lake Placid, FL) confirmed species identifications. Voucher specimens have been deposited in the University of Georgia Natural History Museum and the Museum of Comparative Zoology at Harvard University.

Each site was sampled at monthly intervals for 12 months from September 2001 through August 2002. An analysis of variance (Sokal and Rholf 1995) was used to determine differences in numbers of ants collected from the different sample sites by date. At each sample site location, the Shannon-Weaver's species diversity index (Southwood 1978) was used to measure ant species diversity based on species richness and evenness.

Fire Ant Reproductive Mortality and Predation

Solenopsis invicta reproductives (female alates) were placed individually in 20-ml plastic vials. The alates were collected from colonies maintained in the laboratory on the University of Georgia Griffin Campus. The alates were used within 1 day after collection. The lid of each vial was modified by cutting a hole (≈2 cm diam) through the center (Nichols and Sites 1991). Wire screen (1.66 mm^2 mesh) was placed over each vial opening and secured with the modified lid. This screen allowed workers of most ant species as well as other small arthropods to enter the vial while preventing the escape of alates (Nichols and Sites 1991). Control vials were similar but contained a 0.8-mm^2 mesh cover over the opening to exclude all arthropod predators. The bottom of each vial contained dental plaster that was moistened to prevent desiccation of the alate.

Openings in the soil for the vials were created with a drill bit 24 h before vial placement to reduce arthropod activity in response to soil disturbance. Ten vials containing the 1.6-mm^2 mesh and 10 vials containing the 0.8-mm^2 mesh were placed in the middle location within the 1000 m^2 plot. Each vial was placed vertically in the soil 2 m apart and 10 cm deep in the soil along a linear transect. Each was covered with a rock or piece of pinewood to simulate colony founding (Nichols and Sites 1991). Vials were checked each day for 7 d. After 7 d, alates that were not preyed upon were considered successful founders. Ants or other arthropods present in vials were collected, placed in 70% ETOH, and transported to the laboratory. Data were recorded as (1) preyed upon within 7 d (binomial distribution), and (2) the number of days until an alate was preyed upon within the 7 d period. Alates that perished due to adverse environmental conditions were not included in the analysis. All data were analyzed using Statistical Package for the Social Sciences (SPSS). A logistic regression (Sokal and Rholf 1995) was used to determine differences in alate mortality based on vial, habitat, location (state park), and sample date.

Foraging Activity

Ant foraging activity within each habitat was estimated at monthly intervals for the duration of the study. On each sampling date, 10 baiting stations were placed at 2-m intervals along a 20-m transect in each plot. The baiting stations were individual 7.5x12.5-cm index cards staked in the ground using two wooden dowels (Saks and Carroll 1980). An individual termite worker obtained from decaying wood was firmly pressed to each card. After placement in the plot, cards were monitored for removal of prey items for 1 h. Ant species preying upon the termite on each card were recorded until the prey item was either removed or 1 h had elapsed, whichever occurred first. Once a prey item was removed, it was not replaced. All data were analyzed using the Statistical Package for the Social Sciences (SPSS). Data were analyzed using a logistic regression (Sokal and Rholf 1995) to determine differences in predation in relation to habitat (open vs. canopied), location (state park), and sampling date. An analysis of variance was used to determine differences in the amount of time for predation to occur from placement of prey.

RESULTS

Plant Characterization

The dominant plant communities differed among the habitats sampled. The canopied area within High Falls State Park was a mature conifer forest dominated primarily by loblolly pine, *Pinus taeda* L., and short leaf pine, *Pinus echinata* Miller. A few water oaks, *Quercus nigra* (L.), and other understory trees and shrubs (Table 2.1). The overstory and understory vegetation created 100% canopy coverage at a height on 5 m above the soil surface.

The canopied area sampled in Indian Springs State Park was a second to third stage successional deciduous forest approaching climax community (Table 2.1). This community was dominated by southern red oak (*Q. falcate* Michaux), water oak (*Q. nigra*), American beech (*Fagus grandifolia* Ehrhart), yellow poplar (*Liriodendron tulipifera* L.), loblolly pine (*P. taeda*), dogwood (*Cornus florida* L.), and wild cherry (*Prunus* spp.). Due to the maturity of the forest and associated larger trees, this vegetative growth created 100% canopy coverage at a height of 8 m above the soil surface (Table 2.1). The open areas in each state park had no vegetative canopy above ground level and consisted completely of grasses, primarily fescue (*Festuca arundinaceae* Schreb.) and common bermudagrass (*Cynodon dactylon* L.).

Species Diversity

A total of 93,834 ants representing 24 genera and 54 species were collected during this study (Table 2.2). The Shannon-Weaver index of diversity calculated a higher diversity of species in the canopied habitats than in uncanopied habitats at both locations (Table 2.3), while the total number of ants collected was significantly ($P < 0.05$) greater in the open habitats than in canopied habitats.

During this study, *S. invicta* mounds were difficult to identify in all habitats and locations because *S. invicta* does not form their mounds into dome structures in central Georgia during hot and dry weather. However, collections of *S. invicta* workers in pitfalls and on baits provided indications of activity. Data from these collections indicate that *S. invicta* workers did not forage between October 2001 and April 2002 (Fig. 2.1). With September 2001, May 2002, June 2002, July 2002, and August 2002 being the months of highest *S. invicta* activity (Fig. 2.2). Activity, as indicated by numbers of workers collected, increased from May 2002 through August 2002. Over the entire study period, *S. invicta* was the most abundant species in terms of number of foragers collected from the open habitat at Indian Springs State Park, with 10,356 workers (88%) collected in August 2002 alone. However, over the entire study period, *Monomorium viride* Brown was the most active ant species collected in the open habitat at High Falls State Park, with 12,013 individuals collected for the duration of this study. *Solenopsis invicta* was not collected in canopied habitats for the duration of this study.

Numbers of native ant species collected at both state parks decreased in the winter months and increased in the spring and summer months (Fig 2.3). The largest numbers of native ant species were collected from the open habitat at High Falls State Park (Fig 2.3). The two most dominant native ant species in that area were *M. viride* and *Pheidole tysoni* Forel, with a total of 12,013 and 7,146 workers collected, respectively. The highest numbers of native ant species collected was in June 2002, when 4,707 individuals of *M. viride* were collected from bait dishes alone. While *S. invicta* occupied more baits, *M. viride* and *Ph. tysoni* occasionally recruited and occupied baits with higher numbers of workers than did *S. invicta*. At Indian Springs, *Forelius analis* (Andre) was the most abundant native ant species in the open habitat, with 6,166 individuals collected for the duration of this study, with September 2001, October 2001, April

2002, May 2002, June 2002, July 2002, and August 2002, being the months of highest native ant activity (Fig. 2.4).

A greater diversity of species was collected from canopied habitats than from open habitats at both locations, with the canopied habitat at Indian Springs supporting the highest species diversity (Table 2.3). *Prenolepis imparis* (Say), the *Aphaenogaster picea/rudis/texana* Wheeler complex, and *Ph. dentata* Mayr were the three dominant species collected from the canopied habitats at each state park. During the colder months, *Pr. imparis* became the single most dominant ant, but decreased in numbers during the warmer months, when workers of the *Aphaenogaster picea/rudis/texana* complex became the most abundant.

Numbers of ants in the canopied habitat at Indian Springs were substantially lower from September 2001 through March 2002 than from May 2002 through August 2002, with the highest number of ants collected in August 2002 (Fig 2.3). In the canopied habitat at High Falls, collections fluctuated slightly in September and October 2001 and from April 2002 through August 2002. The greatest number of ants was collected in September 2001. Collections of ants diminished in canopied habitats at both locations from November 2001 through March 2002.

Predation of Alates

The logistic regression analysis detected significant differences in predation rates in relation to vial type, habitat, and sampling dates. Alates placed in the vials from which predators were excluded were not preyed upon. Some natural mortality of these alates occurred, ranging from a mean of 1.4 to 9.3%. Mortality data of these alates were not included in the analysis.

Percent predation of alates varied according to sampling date. Predation diminished in open and canopied habitats at both locations during the winter months (Fig. 2.5). This was apparently due to lack of ant activity, as corroborated by the low numbers of ants collected during that period of time (Figs 2.1, 2.3). For example, in September 2001, all of the alates were preyed upon in the canopied habitat at both locations. However, from December 2001 through May 2002, predation diminished significantly in those habitats. Predation of alates in the open habitat at High Falls State Park did not occur until May 2002, with the highest levels in July 2002 and August 2002. Similarly, at Indian Springs State Park, predation of alates in the open habitat occurred in September 2001, November 2001, December 2001, and June 2002, July 2002 and August 2002, with highest levels of predation occurring in the latter two months.

Predation of alates was significantly (*P* <0.01) greater in canopied habitats than in open habitats (Fig. 2.5). For example, in September 2001, all alates were preyed upon in the canopied habitat at High Falls State Park, while no predation of alates in the vials occurred in the open habitat at that same location. Similarly, all alates were preyed upon in the canopied habitat at Indian Springs State Park, while only 20% of alates were preyed upon in the open habitat at that location.

From September 2001 through August 2002, predation of the alates remained significantly (*P* < 0.01) greater in the canopied habitats than in the open habitats at each location. During this period, a mean (± SEM) of 54.1 ± 5.4% of the alates were preyed upon in the canopied habitat in High Falls State Park, while only 20.0 ± 4.4% were preyed upon in the open habitat at that location. Similarly, 44.7 ± 5.5% of the alates were preyed upon in the canopied habitat at Indian Springs State Park, while only 14.1 ± 4.8% were preyed upon in the open habitat at that location. During the warmer months, coinciding with greater ant activity, mortality by predation was 84.4 ± 5.4% in the canopied habitat in High Falls State Park and 74.4 ± 6.7% in the canopied habitat in Indian Springs State Park. During this same time period, predation in the open habitats was significantly less (33.3 ± 7.6% at High Falls State Park and 46.5 ± 7.6% at Indian Springs State Park). During the late spring and the summer months, 100% alates were preyed upon within 24 h in the canopied habitats at both locations. This was not observed in the open habitats.

Ant predators preying on alates were observed, recorded, and collected when possible (Table 2.4). However, alates were usually dismembered and removed, rendering collection and recording of ant predator species at times impossible. Of those species found to be predators of alates, four had not been previously reported as predators of *S. invicta*. These are *Aphaenogaster picea* (Wheeler), *Pr. imparis*, and two Dacetine ants, *Pyramica ornata* (Mayr) and *Py. rostrata* (Emery). Among these, *A. picea* was most frequently observed in canopied habitats at both locations.

Foraging Activity

Foraging for termite prey was more intense in canopied than in open habitats, with 100% predation of the prey occurring at Indian Springs State Park within 60 min in September 2001, June 2002, and August 2002, and 100% predation occurring at High Falls State Park within 60 min in July 2002 (Fig 2.6). Foraging activity decreased in all habitats in the winter months. From September 2001 through August 2002, the mean (± SEM) time for the onset of predation of termites in canopied habitats was 39.1 ± 1.9 min at High Falls State Park and 31.7 ± 2.1 min at Indian Springs State Park. The mean time for the onset of predation of termites in the open habitats was greater at High Falls State Park (47.6 ± 1.8 min) and at Indian Springs State Park (47.8 ± 1.9 min). Predation time decreased in all habitats due to higher ant activity as mean daily temperatures increased. Within the warmer months, coinciding with increased ant activity, mean time for the onset of predation in the canopied habitat at High Falls State Park was 34.2 ± 2.7 min and 20.8 ± 2.5 min at Indian Springs State Park. Mean time in the open habitats was 45.4 ± 2.5 min at High Falls State Park and 41.2 ± 2.8 min at Indian Springs State Park. Lowest mean time for the onset of predation of termites was during September 2001, October 2001, June 2002, July 2002, and August 2002.

More species of ant predators were observed foraging on termites during the warmer months than colder months in canopied habitats at both locations (Table 2.5). Among these, *A. picea*, *Camponotus americanus* Mayr, *C. nearcticus* Emery, *Formica pallidefulva* Latreille and *P. imparis* were the dominant taxa that preyed upon the termites in the canopied habitats. *Camponotus americanus* was collected only from Indian Springs State Park. During the colder months, *P. imparis* was the only predator observed in canopied habitats. *Solenopsis invicta* remained the dominant forager in the open habitats at both locations throughout the study. In these studies, collections of individual ants were conducted when feasible. However, because foraging usually occurs within seconds, collections of individuals were limited.

During this study, a total of 140 termites (58% out of 240) were preyed upon in the canopied habitats as compared to a total of 68 (28% out of 240) in the open habitats. At High Falls State Park, 55% of the termites were preyed upon in the canopied habitat, while only 30% were preyed upon in the open habitat. Similarly, 62% of the termites were preyed upon in the canopied habitat at Indian Springs State Park, while only 27% were preyed upon in the open habitat at that location. Foraging activity and predation of termites decreased during the months with cooler temperatures, thus coinciding with the observations of predatory rates.

DISCUSSION

In central Georgia, canopied habitats as compared to open habitats support a greater diversity of native ant species that compete with *S. invicta*. Furthermore, native ant species diversity and *S. invicta* population levels appear to be inversely related regardless of habitat type. These results suggest that *S. invicta* population levels are at least partially regulated by varying degrees of competitive interactions that are also associated and positively correlated with native ant species diversity. These interactions are predation of *S. invicta* alates by native ant species and competition for food resources by foragers of native ant species. These competitive interactions occur more frequently and at a greater intensity in canopied habitats than in open habitats in central Georgia.

Solenopsis invicta activity was greater in open habitats than in canopied habitats in this study, thus, further supporting that *S. invicta* activity appears to be inversely related to native ant species diversity. Few native ants were observed to inhabit areas dominated by *S. invicta*. We found *Monomorium viride* Brown, *Paratrechina vividula* (Nylander), *Ph. dentata*, *Ph. tysoni* Forel, *Forelius analis* (Andre), and *S. molesta* (Say) in sufficient numbers in open habitats to indicate coexistence with *S. invicta* in those habitats. However, most other native ant species collected in open habitats were sporadically collected and were represented by only a few workers and apparently do not successfully coexist with *S. invicta* in these central Georgia habitats.

Predation of alates at each location was directly related to species diversity in the habitats. Hence, more predation of *S. invicta* alates occurred in the canopied habitats where species diversity was greater in comparison to the open habitats. While there were insufficient numbers of queens for this predation study, it was assumed that predation of the alates corresponded to that for founding queens. Indeed, predation of newly-mated *S. invicta* queens was found to be a significant factor impacting *S. invicta* founding success in northern Florida (Whitcomb et al. 1973, Nickerson et al. 1975). Bhatkar et al. (1972) and Whitcomb et al. (1973) discovered that *Lasius neoniger* Emery destroyed *S. invicta* alates in their claustral cells. Certain native ant species have reportedly preyed on *S. invicta* alates before they enter the soil. These include species *Ap. floridana* Smith, *So. geminata* (F.), *Ph. dentata*, *Ph. morrisii* Forel, *Fo. schaufussi* Mayr, *Ca. floridanus* Buckley, and *Paratrechina* spp. In addition, several species of the genus *Dorymyrmex* (=*Conomyrma*) have been documented to coordinate attacks with conspecific members, bringing *S. invicta* queens into their nest (Whitcomb et al. 1973).

Solenopsis invicta is also subjected to subterranean predation by ants of the subgenus *Diplorhoptrum* (Whitcomb et al. 1973, Buren 1983). Buren (1983) further indicated that in this way *Diplorhoptrum* species could potentially suppress *S. invicta* populations in the U.S. He noted that these ants have the greatest potential effect on regulating *S. invicta* populations because of their subterranean habits. In this study, the subterranean *Diplorhoptrum* ant species, *So. molesta* (Say), were observed preying on *S. invicta* alates. Furthermore, 5 additional ant species other than reported by Whitcomb et al. (1973), Nickerson et al. (1975), and Nichols and Sites (1991), which are not subterranean predators, were observed preying of *S. invicta* alates. *Pyramica ornata* (Mayr) and *Py. rostrata* (Emery) were observed preying on alates in canopied habitats. This is the first report of the genus *Pyramica*, considered to be specialist predators of Collembola (Holldobler and Wilson 1990), preying on another ant species.

Foraging activity at each location also was directly related to species diversity. Not only were more termites foraged upon in canopied habitats, but the time to discover the prey item was lower in canopied than in the open habitats. Torres (1984) reported that arrival at a bait resource first was significantly correlated with bait dominance. This allows poor or equally-dominant competitors to coexist in an area because first arriving species can recruit more workers than later arriving species (Torres 1984). This may be occurring in open habitats. *Monomorium viride* was observed on numerous occasions foraging on termites in the absence of *S. invicta*.

In the canopied habitats, species such as *Ap. picea*, *Ap. fulva* Roger, *Ca. pennsylvanicus* (De Geer), and *Fo. pallidefulva* were represented equally at the foraging stations. These fast recruiting species discovered prey items quicker than others. In addition, canopied habitats contained additional species of *Camponotus* and *Formica* whose workers also forage individually, thus also allowing for a quicker response time to individual prey items.

Canopied habitats in central Georgia support a high diversity of native ant species. These native ant species occurring in canopied habitats appear to be able to compete successfully against *S. invicta* for food resources and to significantly ($P = 0.05$) reduce *S. invicta* population levels. In open habitats, *S. invicta* is extremely competitive and becomes the dominant ant species. Ecological disturbance of habitats may reduce the number of possible niches for use by native ants via simplification of the environment that disrupts native ant assemblages and allows the successful invasion and establishment of *S. invicta*. There is evidence of similar ecological perturbations in California with the Argentine ant, *Linepithema humile* (Mayr), and in southwest Columbia with the little fire ant, *Wasmannia auropunctata* (Roger), whereby simplification of the environment produced more nesting sites for these invasive pest species (Armbrecht and Ulloa-Chacon 2003, Human et al. 1998, Suarez et al. 1998). Based upon the results of the study reported herein, conservation of habitats that support and sustain competitive native ant species assemblages will maintain high biodiversity of native ant populations and help reduce invasion of *S. invicta* into canopied habitat in central Georgia.

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Table 2.1. Plant communities in canopied habitats at High Falls State Park and Indian Springs State Park in central Georgia, 2002.

High Falls State Park

Cupressaceae:
Juniperus virginiana L. – red ceder

Fagaceae:
Quercus nigra L. – water oak

Hamamelidaceae:
Liquidambar styraciflua L. – sweet gum

Nyssaceae:
Nyssa sylvatica Marshall – black gum

Oleaceae:
Ligustrum sinense Lour – privit

Pineaceae:
Pinus taeda L. – loblolly pine
Pinus echinata Miller – short leaf pine

Rosaceae:
Crataegus spp. – hawthorn
Prunus spp. – plum, cherry

Vitaceae:
Vitis rotundifolia Michaux – muscadine
Vitis spp.

Indian Springs State Park

Cornaceae:
Cornus florida L. – dog wood

Fagaceae:
Fagus grandifolia Ehrart – american beech
Quercus falcate Michaux – southern red oak
Quercus nigra L. – water oak

Juglandaceae:
Carya spp. – shag bark

Liliaceae:
Smilax bono-nox L. – greenbrier
Smilax spp, - greenbrier

Magnoliaceae:
Liriodendron tulipifera L. – yellow popular

Pineaceae:
Pinus taeda L. – Loblolly pine

Rosaceae:
Crataegus spp. – hawthorn
Prunus spp. – plum, cherry

Ulmaceae:
Ulmus alata Michaux – winged elm

Verbenaceae:
Callicarpa americana L. – beauty berry

Vitaceae:
Vitis rotundifolia Michaux – muscadine
Vitis spp.

Table 2.2. Ant species collected in High Falls State Park and Indian Springs State Park from September 2001 through August 2002 in central Georgia.

Species	Collection Site
Aphaenogaster fulva Roger	1,2
Aphaenogaster lamellidens Mayr	1,2
Aphaenogaster picea/rudis/texana complex[a]	1,2
Brachymyrmex depilis Emery	1,2
Camponotus americanus Mayr	1,2
Camponotus floridanus (Buckley)	1
Camponotus pennsylvanicus (De Geer)	1,2
Camponotus subbarbatus Emery	1
Crematogaster ashmeadi Mayr	1,2
Crematogaster lineolata (Say)	1,2
Crematogaster minutissima Mayr	1,2
Forelius analis (Andre)	1,2
Forelius pruinosus (Roger)	1,2
Formica pallidefulva Latreille	1,2
Formica schaufussi Mayr	1
Formica subintegra Wheeler	1
Formica subsericea Say	2
Hypoponera opaciceps (Mayr)	2
Hypoponera opacior (Forel)	1,2
Lasius alienus (Foerster)	1,2
Leptothorax shaumii Roger	1
Monomorium minimum (Buckley)	1,2
Monmorium viride Brown	1,2
Myrmecina americana Emery	2
Myrmica americana Weber	2
Myrmica pinetorum Wheeler	1
Myrmica punctiventris Roger	1,2
Pachycondyla chinensis (Emery)	2
Paratrechina arenivaga (Wheeler)	1,2
Paratrechina faisonensis (Forel)	1,2
Paratrechina parvula (Mayr)	1
Paratrechina vividula (Nylander)	1,2
Pheidole crassicornis Emery	1,2
Pheidole dentata Mayr	1,2
Pheidole dentigula Smith	1,2
Pheidole tysoni Forel	1,2
Ponera pennsylvanica Buckley	1,2
Prenolepis imparis (Say)	1,2

Proceratium pergandei (Emery)	1
Pyramica ornata (Mayr)	1,2
Pyramica rostrata (Emery)	1,2
Solenopsis carolinensis Forel	1
Solenopsis invicta Buren	1,2
Solenopsis molesta (Say)	1,2
Solenopsis pergandei Forel	1,2
Solenopsis texana Emery	1,2
Stenamma diecki Emery	1,2
Stenamma impar Forel	1,2
Stenamma schmitti Wheeler	1,2
Strumigenys louisianae Roger	1,2
Tapinoma sessile (Say)	1,2
Trachymyrmex septentrionalis (McCook)	2

---

1 - Collected in High Falls State Park

2 - Collected at Indian Springs State Park

[a] *Aphaenogaster picea/rudis/texana* complex includes *A. picea* (Wheeler), *A. picea rudis* Enzmann, *A. texana* Wheeler, and *A. texana carolinensis* Wheeler (S. Cover, personal communication).

Table 2.3. Numbers and species diversity of ground-dwelling ants occurring in canopied vs. open habitats at High Falls State Park and Indian Springs State Park from September 2001 through August 2002 in central Georgia.

Location	Habitat	Total # of Ants	Shannon-Weaver Index
High Falls	Canopied	17,139	1.938
	Open	32,467	1.567
Indian Springs	Canopied	11,639	2.115
	Open	32,589	1.094

Table 2.4. Ground-dwelling ant species observed preying upon *S. invicta* alates in open and canopied habitats at High Falls State Park and Indian Springs State Park from September 2001 through August 2002 in central Georgia.

Species
Aphaenogaster picea[1]
Pheidole dentata
Pyramica ornata[1]
Pyramica rostrata[1]
Prenolepis imparis[1]
Solenopsis molesta

[1] New observation records of ant species preying on *S. invicta* alates.

Table 2.5. Ground-dwelling ant species observed removing termites in open and canopied habitats High Falls State Park and Indian Springs State Park in central Georgia from September 2001 through August 2002.

	High Falls S.P.		Indian Springs S.P.	
Species	Open	Canopied	Open	Canopied
Aphaenogaster fulva		x		x
Aphaenogaster p/r/t complex		x		x
Camponotus americanus		x		x
Camponotus nearcticus				x
Crematogaster ashmeadi		x		x
Formica pallidefulva		x		x
Monomorium minimum	x		x	
Monomorium viride	x		x	
Pheidole tysoni	x		x	x
Prenolepis imparis		x		x
Solenopsis invicta	x		x	

Fig. 2.1. Total numbers of *S. invicta* collected monthly in pitfall traps and bait dishes at High Falls State Park and Indian Springs State Park from September 2001 through August 2002 in central Georgia.

Fig. 2.2. Numbers of *S. invicta* collected during months of highest ant activity in pitfall traps and bait dishes at High Falls State Park and Indian Springs State Park.

Fig. 2.3. Total numbers of native ants collected monthly in pitfall traps and bait dishes at High Falls State Park and Indian Springs State Park from September 2001 through August 2002 in central Georgia.

Fig. 2.4. Numbers of native ants collected during months of highest ant activity in pitfall traps and bait dishes at High Falls State Park and Indian Springs State Park.

Fig. 2.5. Percent predation of *S. invicta* alates in open and canopied habitats at High Falls State Park and Indian Springs State Park from September 2001 through August 2002 in central Georgia.

Fig. 2.6. Percent predation of termites within 60 min in open and canopied habitats at High Falls State Park and Indian Springs State Park from September 2001 through August 2002 in central Georgia.

Figure 2.1

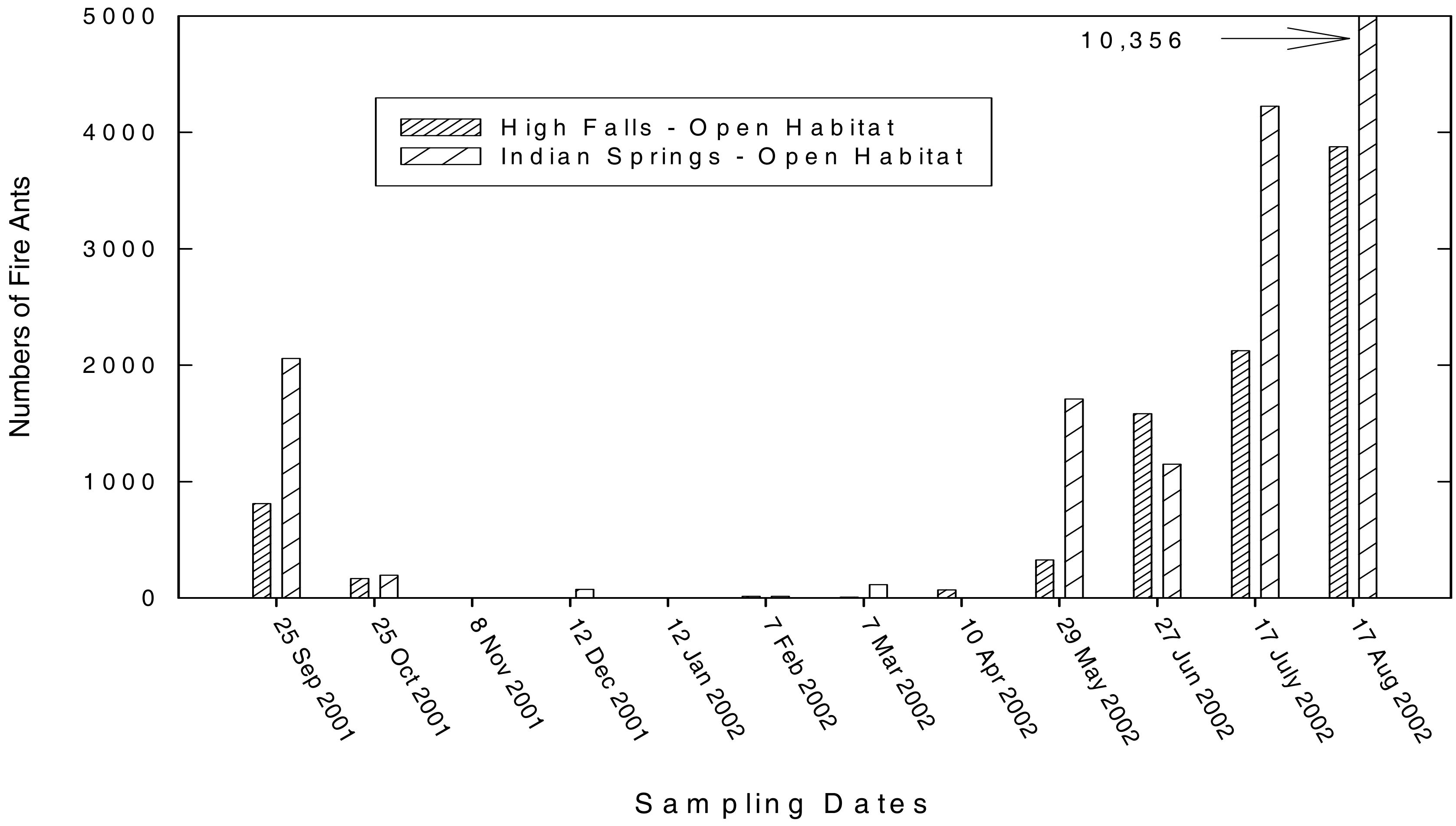
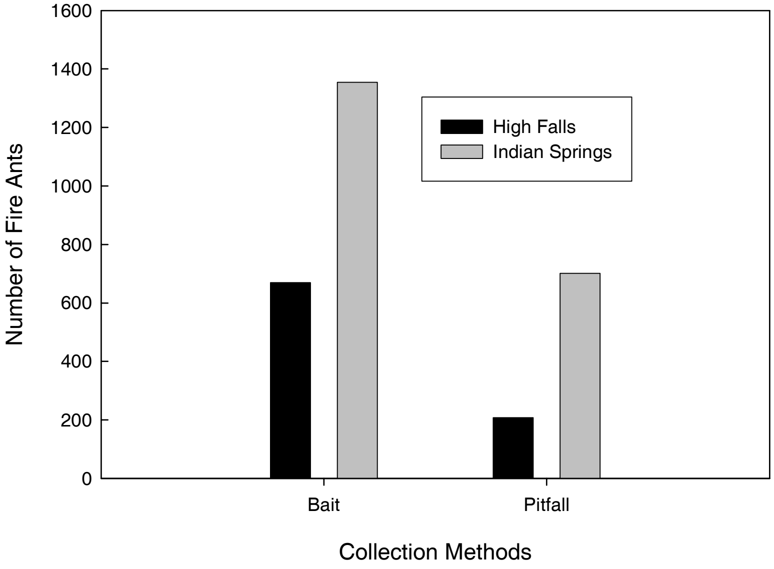
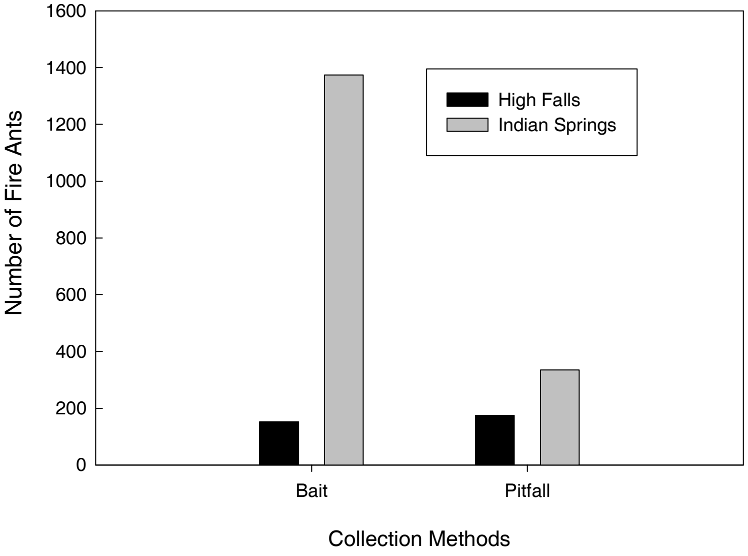

5000
4000
3000
2000
1000
0
Numbers of Fire Ants
High Falls - Open Habitat
Indian Springs - Open Habitat
10,356
25 Sep 2001
25 Oct 2001
8 Nov 2001
12 Dec 2001
12 Jan 2002
7 Feb 2002
7 Mar 2002
10 Apr 2002
29 May 2002
27 Jun 2002
17 July 2002
17 Aug 2002
Sampling Dates

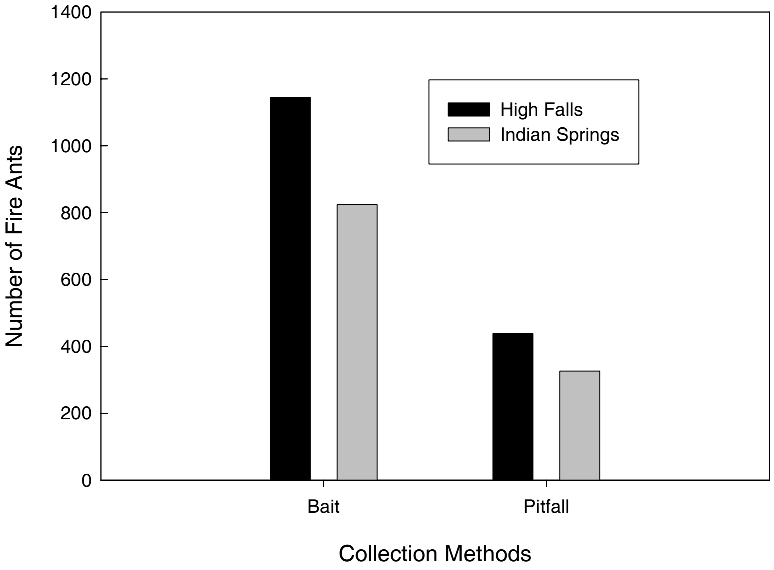
Figure 2.2

25 Sep 2001

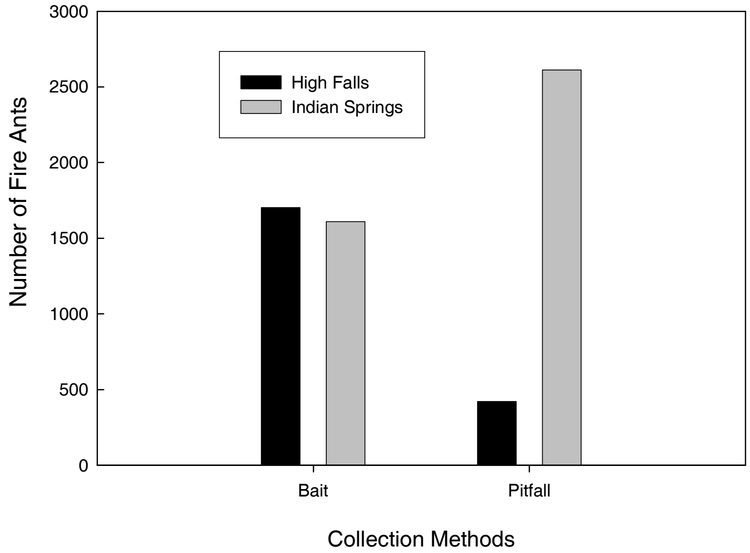


29 May 2002





27 June 2002



17 July 2002

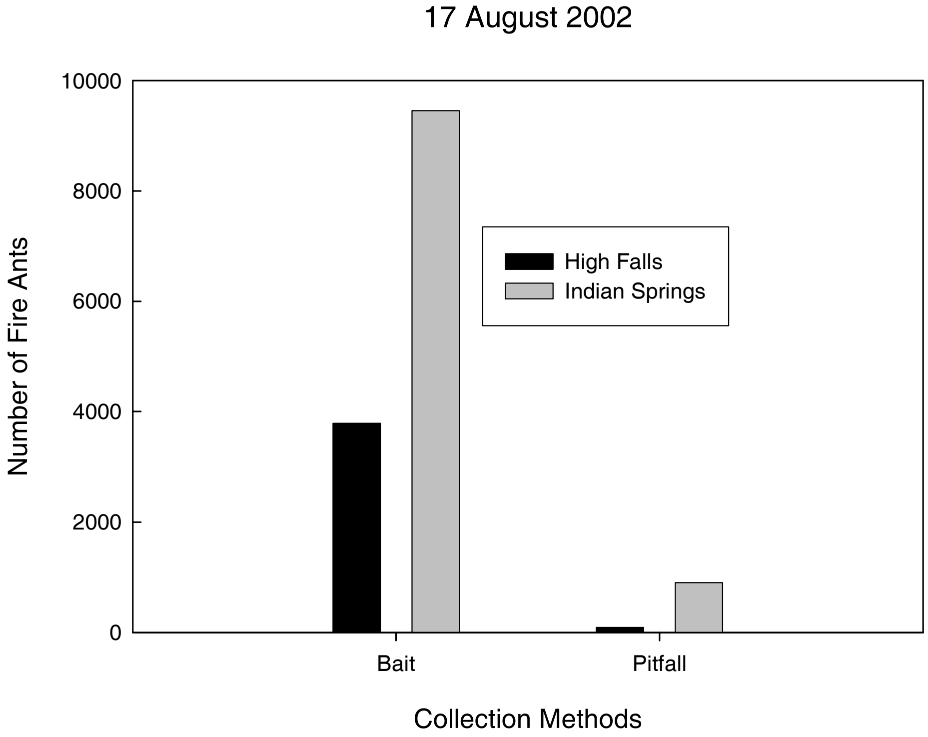
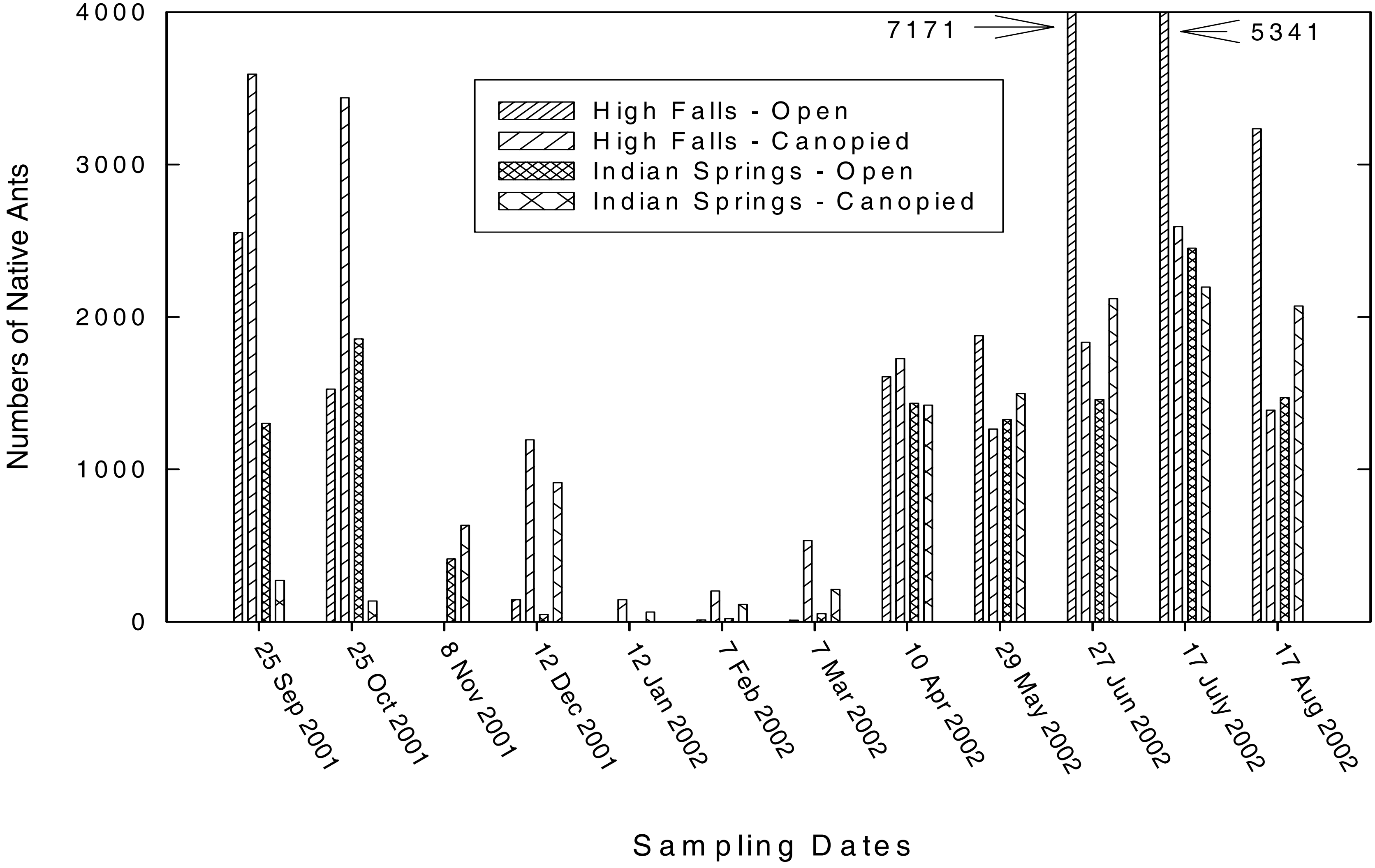

17 August 2002
Number of Fire Ants
10000
8000
6000
4000
2000
0
High Falls
Indian Springs
Bait
Pitfall
Collection Methods

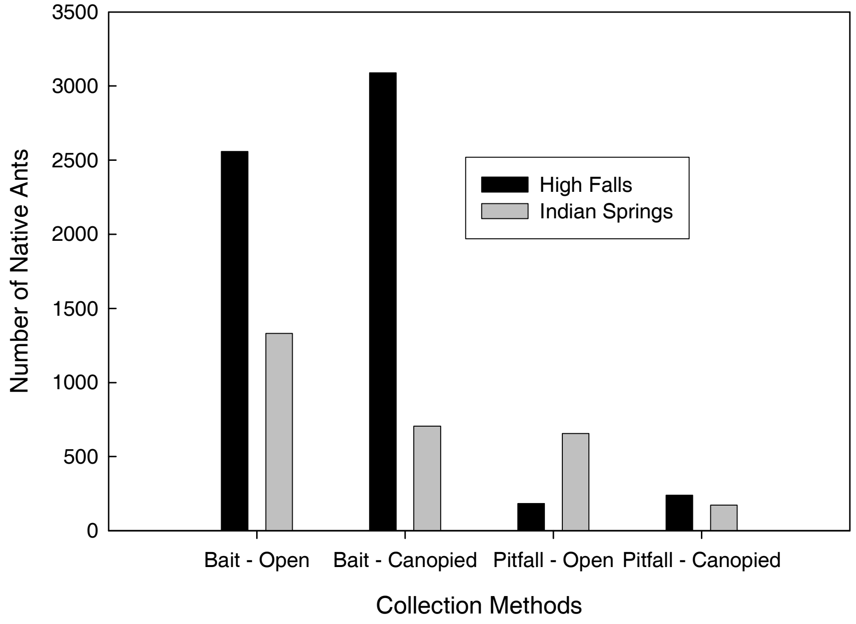
Figure 2.3



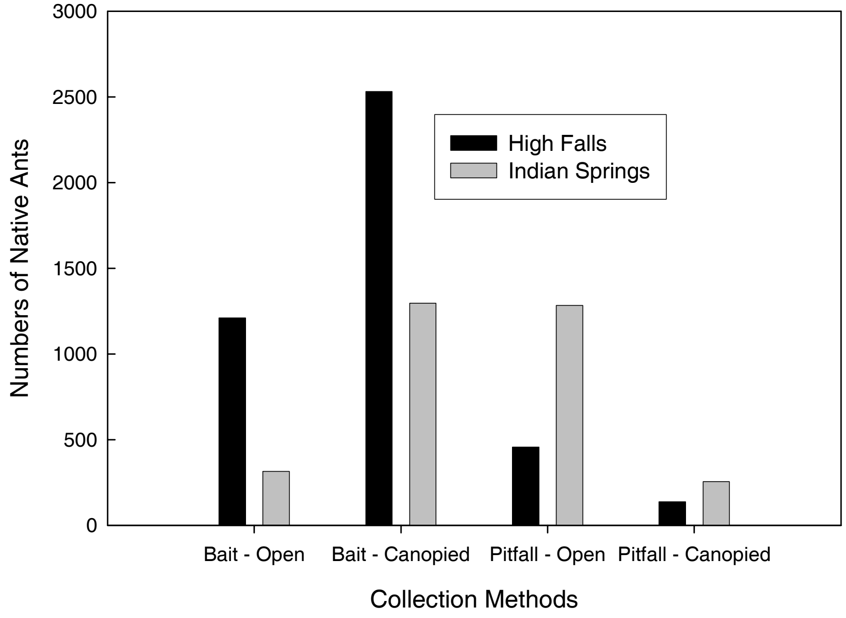
4000
3000
2000
1000
0
Numbers of Native Ants
7171
5341
▨ High Falls - Open
▨ High Falls - Canopied
▩ Indian Springs - Open
☒ Indian Springs - Canopied
25 Sep 2001
25 Oct 2001
8 Nov 2001
12 Dec 2001
12 Jan 2002
7 Feb 2002
7 Mar 2002
10 Apr 2002
29 May 2002
27 Jun 2002
17 July 2002
17 Aug 2002
Sampling Dates

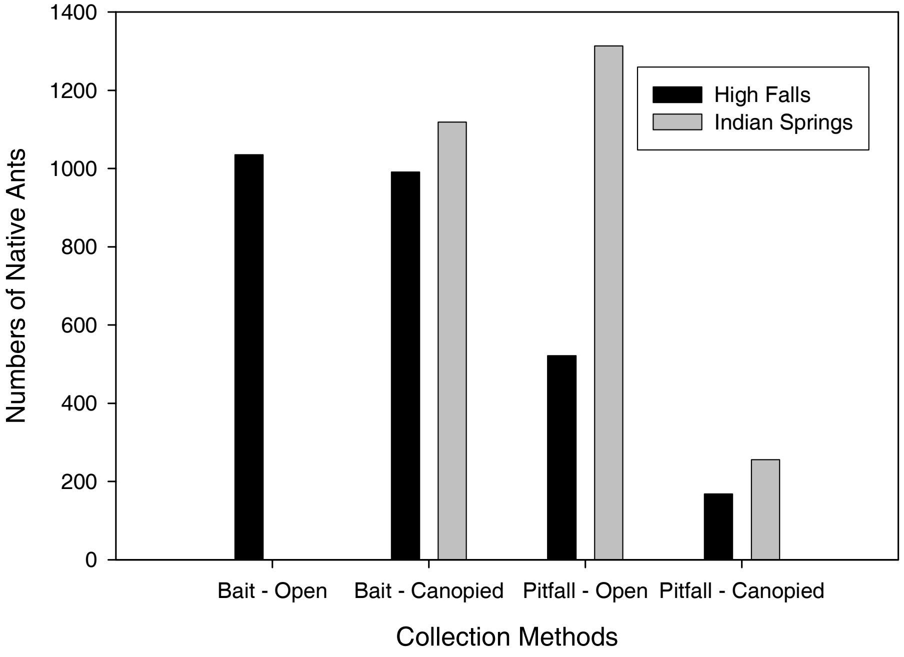
Figure 2.4

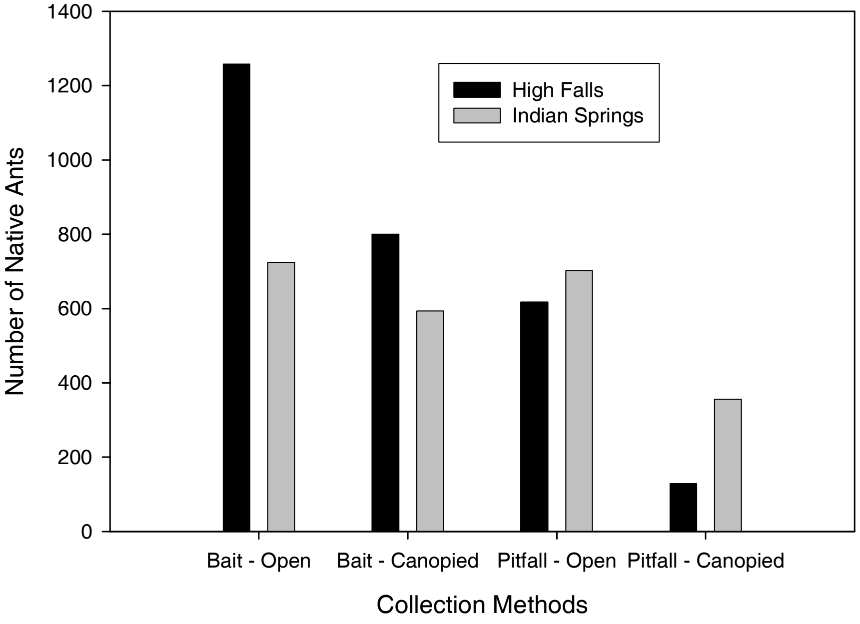
25 Sept 2001

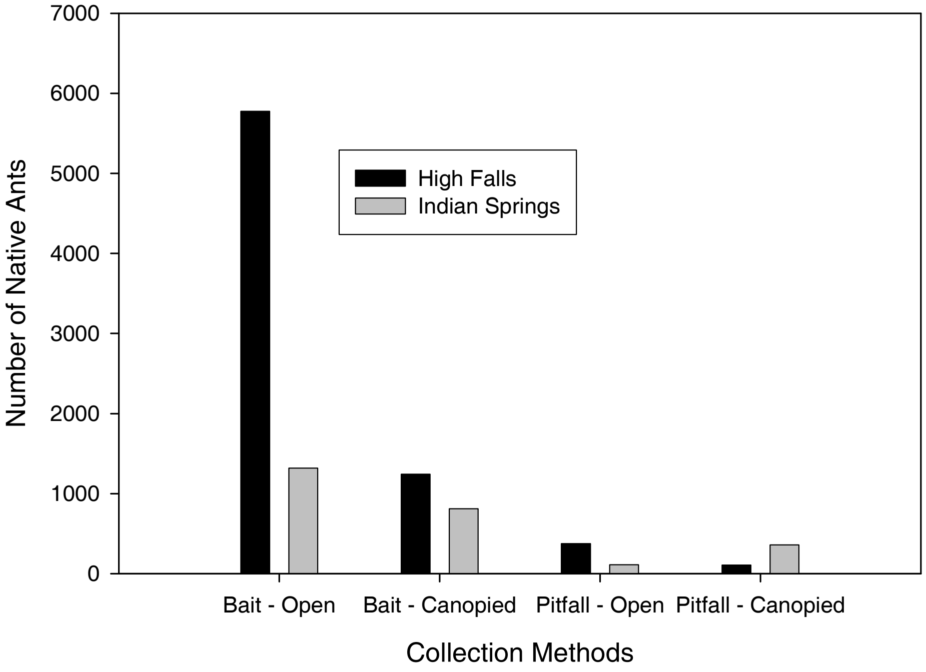


25 Oct 2001

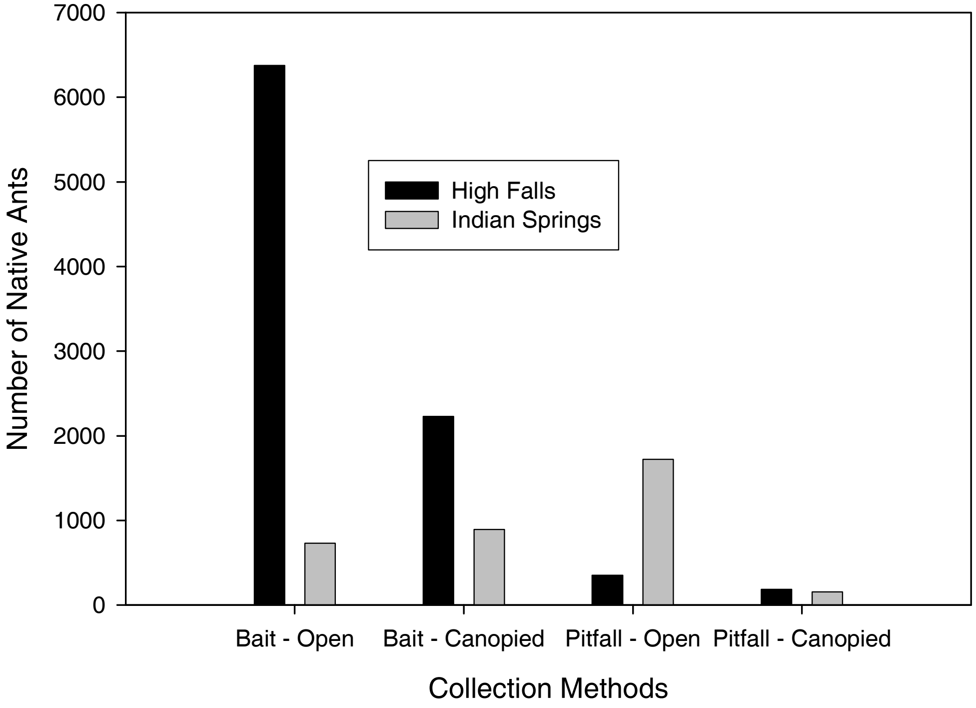



10 Apr 2002


29 May 2002



27 June 2002



17 July 2002

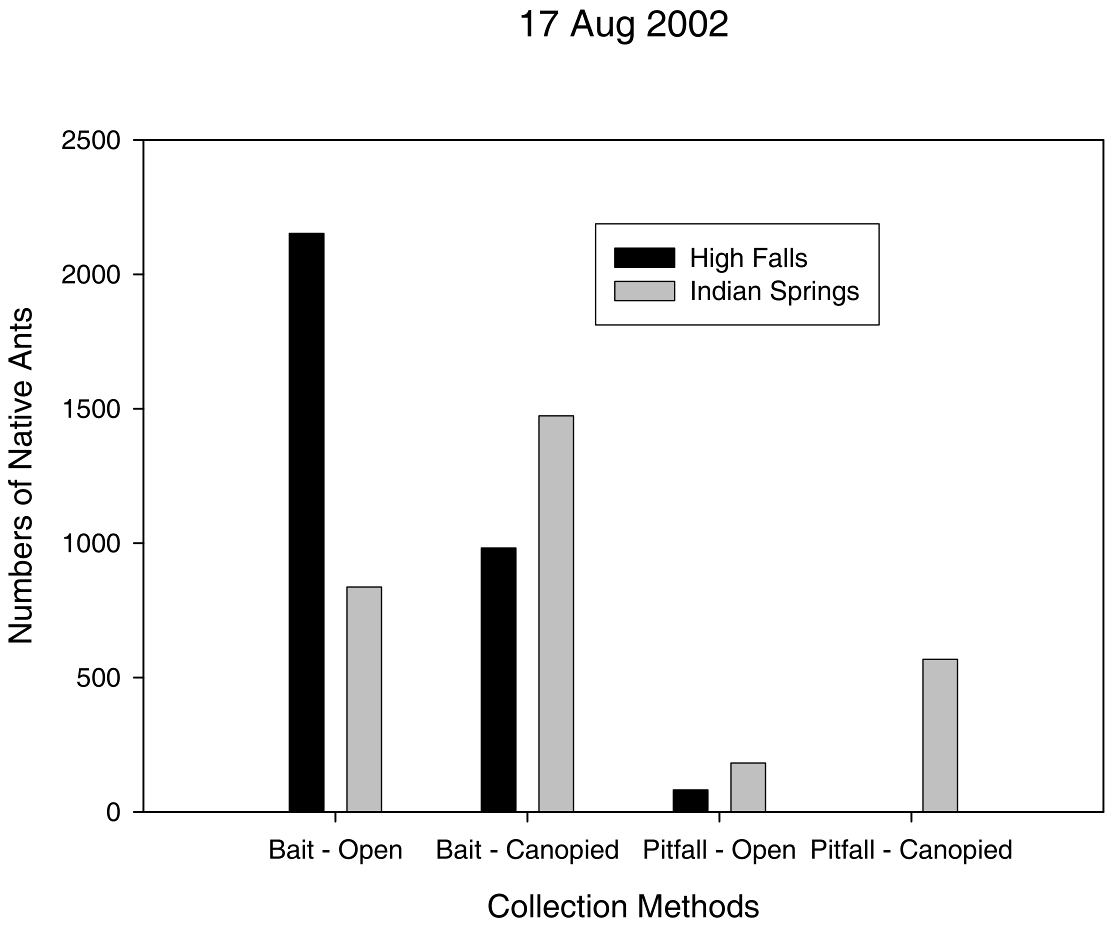

17 Aug 2002
High Falls
Indian Springs
Numbers of Native Ants
0
500
1000
1500
2000
2500
Bait - Open
Bait - Canopied
Pitfall - Open
Pitfall - Canopied
Collection Methods

Figure 2.5

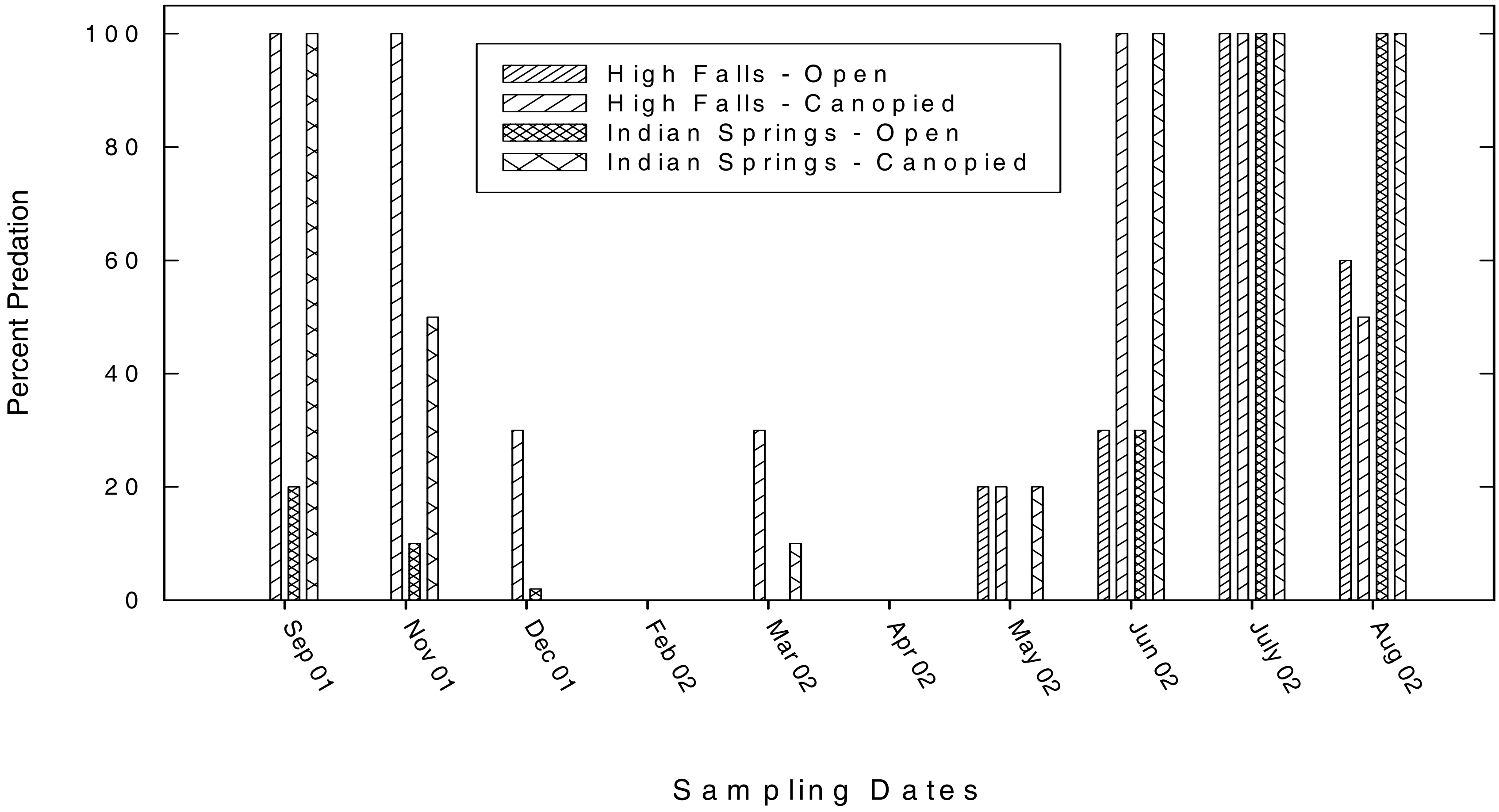
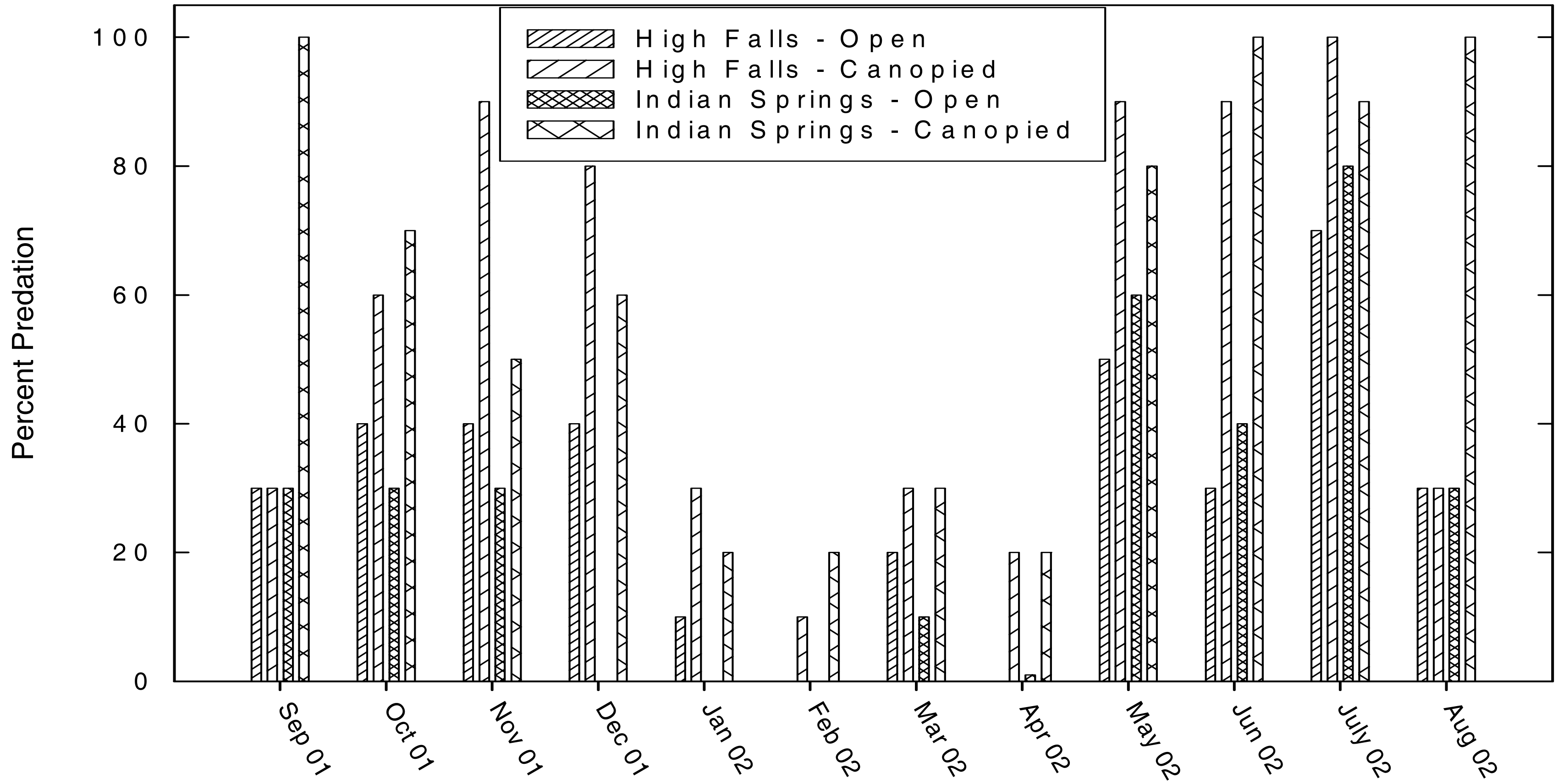

Percent Predation
0
20
40
60
80
100
High Falls - Open
High Falls - Canopied
Indian Springs - Open
Indian Springs - Canopied
Sep 01
Nov 01
Dec 01
Feb 02
Mar 02
Apr 02
May 02
Jun 02
July 02
Aug 02
Sampling Dates

Figure 2.6


High Falls - Open
High Falls - Canopied
Indian Springs - Open
Indian Springs - Canopied
Percent Predation
0
20
40
60
80
100
Sep 01
Oct 01
Nov 01
Dec 01
Jan 02
Feb 02
Mar 02
Apr 02
May 02
Jun 02
July 02
Aug 02

CHAPTER 3

A SURVEY OF GROUND-DWELLING ANTS (HYMENOPTERA: FORMICIDAE) IN GEORGIA[1]

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[1] Ipser, R. M., W. A. Gardner, M. A. Brinkman, and H. B. Peeler. Accepted for publication. Florida Entomologist

ABSTRACT

Ground-dwelling ants (Hymenoptera: Formicidae) were sampled at 29 sites in 26 counties in Georgia using pitfall traps, leaf litter extraction, visual searching, and bait stations. We found 96 ant taxa including nine species not previously reported from Georgia: *Myrmica americana* Weber, *M. pinetorum* Wheeler, *M. punctiventris* Roger, *M. spatulata* Smith, *Pyramica wrayi* (Brown), *Stenamma brevicorne* (Mayr), *S. diecki* Emery, *S. impar* Forel, and *S. schmitti* Wheeler, as well as three apparently undescribed species (*Myrmica* sp. and two *Stenamma* spp). Combined with previous published records and museum records, we increased the total number of ground-dwelling ants known from Georgia to 144 taxa.

Key Words: ground-dwelling ants, Formicidae, survey, Georgia, species

INTRODUCTION

The state of Georgia in the southeastern United States is characterized by a relatively wide range of soil, topographic and climatic conditions. The eight Major Land Resource Areas (MLRAs) identified in the state are (1) Atlantic Coast Flatwoods, (2) Southern Coastal Plains, (3) Carolina and Georgia Sand Hills, (4) Black Lands, (5) Southern Piedmont, (6) Southern Appalachian Ridges and Valleys, (7) Sand Mountains, and (8) Blue Ridge (USDA – SCS 1981). Each MLRA is characterized by a unique combination or pattern of soils, climate, water resources, and land use. These factors, in turn, affect the biotic communities and habitats as well as the floral and faunal characteristics of each.

The diversity and abundance of ants (Hymenoptera: Formicidae) in Georgia are relatively unknown. Wheeler (1913) published a list of 72 ant species collected in Georgia by J. C. Bradley and W. T. Davis; taxonomic revisions have since decreased this list to 62 species. Since that publication, museum records and collections have been the primary sources of occurrence and distribution of ant species in the state; these data are limited in scope. With the exception of Florida (Johnson 1986, Deyrup 2003) and South Carolina (Smith 1934), surveys for ant species are also limited from areas bordering Georgia.

The objective of the study reported herein was to collect, identify, and catalog ground-dwelling ant species from representative MLRA's in Georgia. Undisturbed habitats were purposely sampled to avoid high population levels of two invasive ant species – *Solenopsis invicta* Buren and *Linepithema humile* (Mayr) – that occur throughout the state and reportedly compete with and displace other ant species (Porter & Savignano 1990, Holway 1999).

MATERIALS AND METHODS

Sample Methods and Sites

Twenty-nine sites were sampled 1 to 4 times between June 2000 and September 2002 for ground-dwelling ants (Fig. 3.1). Most sites were located in state parks; others were on state-owned properties. The sites represented six of the eight MLRA's identified in Georgia. Information and characteristics of each collection site are listed in Table 3.1.

Each site was 600 m^2 and was located in wooded areas and at least 60 m from any paths, roads, or right-of-ways. Sampling methods employed were pitfall trapping, extraction from leaf litter collections, visual searching, and baiting as described by Agosti & Alonso (2000) and Bestlemeyer et al. (2000). For each sampling event, 20 pitfall traps were placed individually at 1-m intervals along a transect. Traps were 40-ml plastic vials filled to 60% of container volume with propylene glycol. The vials were placed in the ground with the upper opening level with the soil surface. The traps remained in the ground for 7 d when they were removed, capped, and transported to the laboratory for processing. Leaf litter was gathered by hand from several locations within the 60 m^2 site. These were combined and placed in a 50-L plastic bag, stored on ice, and transported to the laboratory. In the laboratory, litter samples were divided and placed in Berlese funnels (Agosti & Alonso 2000) for 24 h to separate ants. Bait stations used were those described by Brinkman et al. (2001). Tuna packaged in oil was placed in a thin layer over the surface of a 2.5-cm diam filter paper disk (Whatman no. 1) in a plastic Petri dish (10 x 35 mm). Ten stations were placed individually at 2-m intervals along a transect. The stations remained uncovered on the ground for 2 h. They were then covered, placed on ice, and transported to the laboratory for processing. The ground, tree trunks, fallen trees, and other surfaces were visually searched for ants at each sampling time. The total amount of time spent on visual searching was 1.5 h, but varied based on the number of individuals involved in the search. Ants discovered in the visual searches were collected, placed in 70% ethyl alcohol, and transported to the laboratory for processing.

In the laboratory, ant specimens were separated and placed in 95% ethyl alcohol. Identifications were made with keys by Bolton (1994, 2000), Buren (1968), Creighton (1950), Cuezzo (2000), Deyrup et al. (1985), DuBois (1986), Gregg (1958), Holldobler & Wilson (1990), Johnson (1988), MacKay (2000), Smith (1957), Snelling (1973, 1988), Snelling & Longino (1992), Taylor (1967), Trager (1984, 1988), Ward (1985, 1988), Wilson (1955), and Wing (1968), and by comparison with specimens housed in the University of Georgia Natural History Museum (Athens, GA). Stefan Cover (The Museum of Comparative Zoology, Harvard Univ., Cambridge, MA) and Mark Deyrup (Archbold Biological Station, Lake Placid, FL) confirmed species identifications. Voucher specimens have been deposited in the University of Georgia Natural History Museum and the Museum of Comparative Zoology at Harvard University.

RESULTS AND DISCUSSION

Ninety-six species of ground-dwelling ants representing 33 genera were collected and identified in this 2-year survey (Table 3.2). Of those collected, 9 species have not been previously reported from Georgia. These are *Myrmica americana* Weber, *M. pinetorum* Wheeler, *M. punctiventris* Roger, *M. spatulata* Smith, *Pyramica wrayi* (Brown), *Stenamma brevicorne* (Mayr), *S. diecki* Emery, *S. impar* Forel, and *S. schmitti* Wheeler.

Of those previously unreported species, *M. americana* was collected from 3 sites, *M. pinetorum* was collected from 1 site, *M. punctiventris* was collected from 7 sites, and *M. spatulata* was collected from 2 sites. Ants of this genus nest in soil and in rotting wood and are primarily carnivorous, but they will feed on plant exudates such as nectar (Creighton 1950). In addition, *P. wrayi* and *S. brevicorne* were each collected from 1 site, *S. diecki* was collected from 8 sites, *S. schmitti* was collected from 5 sites, and *S. impar* was collected from 2 sites. All *Stenamma* species are carnivorous, and *Pyramica* are specialized predators of collembolans (Holldobler & Wilson 1990).

Eleven individuals of *Myrmica* and 3 individuals of *Stenamma*, possibly representing two species, were collected from Amicalola State Park in Dawson Co. (site 6) and represent as yet undescribed species (S. Cover, personal comm.). Those specimens were collected on 2-V-2000 primarily by pitfall trapping and leaf litter collection.

A review of ant specimens deposited in the Archbold Biological Station (ABS), the University of Georgia Natural History Museum (UGANHM), the lists of ants published by Wheeler (1913), and a survey conducted by Jouvenaz et al. (1977) reveal that 48 species of ground-dwelling ants representing 21 genera have been reported from Georgia but were not collected in the survey reported herein (Table 3.3). To date, these two lists (Tables 3.2, 3.3) comprise the ground-dwelling ant species reported from Georgia. Species collected within the *Aphaenogaster picea/rudis/texana* complex and the *Solenopsis molesta* complex are footnoted in Table 3.2.

In terms of occurrence and distribution, *Prenolepis imparis* (Say) was collected from 17 of the 29 sites sampled; the *Aphaenogaster picea/rudis/texana* complex was collected from 21 sites; the *Solenopsis molesta* complex from 17 sites, and; *Crematogaster ashmeadi* Mayr from 16 sites in this survey. All other species were collected from less than one-half of the sites. Members of the genus *Pheidole* were most numerous with 2,765 individuals representing 10 species collected at 14 sites. *Dorymyrmex burnei* (Trager), *D. insanus* (Buckley), and *Cyphomyrmex rimosus* (Spinola) were collected only at southern sites, while *Amblyopone pallipes* (Haldeman), *Ponera pennsylvanica* Buckley, and *Tapinoma sessile* (Say) were collected from sites in northern Georgia. *Pseudomyrmex ejectus* (Smith) was collected from pitfall traps at one site. *Pseudomyrmex* spp. are characteristically arboreal in their habits. These specimens most likely dropped to the forest floor, and thus were collected as ground-dwellers. Three species - the seed harvester *Pogonomyrmex badius* (Latreille), the obligate slave raider *Polyergus lucidus* Mayr, and the generalist *Aphaenogaster miamiana* Wheeler - were recovered only on Sapelo Island, a barrier island on Georgia's coast.

The survey reported herein provides a basis for various ecological studies and assessments. Ant assemblages, species composition, and community structure are important in terms of community ecology. For example, in Australia, ants are one of the most functionally important faunal groups (Matthews & Kitching 1984, Anderson 1992) and are model organisms for studies in community ecology (Anderson 1983, 1988, 1991, Greenslade & Halliday 1983). Ants also have been used as bio-indicators in mine site rehabilitation (Majer 1983, 1985).

Schultz & McGlynn (2000) noted the many interactions that occur between ants and other organisms within habitats. They further postulated that if these interactions are understood, one could predict ecological conditions within a given habitat based upon the presence or absence specific ants. Furthermore, one could correlate the presence of a specific ant species with specific ecological conditions, and these correlations could be used as predictors of ant biodiversity and interactions among ant species (Alonso 2000).

This survey is the first published listing of ground-dwelling ants in Georgia since Wheeler (1913). This compilation will serve to support biodiversity, systematics, and ecological studies for Georgia and surrounding environs.

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Table 3.1. Locations and characteristics of sites sampled for ground-dwelling ants in Georgia, 2000-2002.

Survey Site	Sites	County	N;W	Major Land Resource Areas	Elevation
1	Cloudland Canyon	Dade	34°50.4; 085°28.9	Sand Mountain	602 m
2	Sloppy Floyd	Chattooga	34°26.4; 085°20.2	Sand Mountain/Southern Appalachian	303 m
3	Fort Mountain	Murray	34°46.6; 084°42.5	Southern Appalachian/Blue Ridge	906 m
4	Red Top Mountain	Bartow	34°08.6; 084°42.2	Southern Appalachian/Blue Ridge	325 m
5	Vogel	Union	34°46.1; 083°54.9	Blue Ridge	236 m
6	Amicalola Falls	Dawson	34°34.2; 084°14.7	Blue Ridge	900 m
7	Unicoi	White	34°43.9; 083°43.6	Blue Ridge	887 m
8	Black Rock Mountain	Rabun	34°54.4; 083°24.3	Blue Ridge	1055 m
9	Tallulah Gorge	Rabun	34°44.4; 083°23.3	Blue Ridge	539 m
10	John Tanner	Carroll	33°36.1; 085°09.9	Southern Piedmont	332 m
11	Fort Yargo	Barrow	33°57.9; 083°43.4	Southern Piedmont	303 m
12	UGA Whitehall Forest	Clarke	33°53.7; 083°21.9	Southern Piedmont	887m
13	Victoria Bryant	Franklin	34°17.7; 083°09.7	Southern Piedmont	236 m
14	Tugaloo	Franklin	24°29.5; 083°04.4	Southern Piedmont	374 m
15	Richard B. Russell	Elbert	34°10.8; 082°45.9	Southern Piedmont	214m
16	Bobby Brown	Elbert	33°58.1; 082°34.6	Southern Piedmont	89 m
17	UGA Griffin Campus	Spalding	33°16.0; 084°17.2	Southern Piedmont	307 m
18	Indian Springs	Butts	33^{o}14.9; 083°55.5	Southern Piedmont	193 m
19	High Falls	Monroe	33^{o}10.3; 084°00.7	Southern Piedmont	178 m
20	Elijah Clark	Lincoln	33°51.3; 082°24.0	Southern Piedmont	154 m
21	Mistletoe	Columbia	33°39.9; 082°22.9	Southern Piedmont	163 m
22	Providence Canyon	Stewart	32°04.0; 084°54.3	Southern Coastal Plain	222 m
23	George L. Smith	Emanuel	32°32.7; 082°07.5	Southern Coastal Plain	123 m
24	Seminole	Seminole	30°48.2; 084°52.7	Southern Coastal Plain	35 m
25	Reed Bingham	Colquitt	31°09.6; 083°32.3	Southern Coastal Plain	78 m
26	Laura S. Walker	Ware	31°08.5; 083°12.9	Atlantic Coast Flatwoods	47 m
27	Sapelo Island Dunes	McIntosh	31°23.4; 081°15.9	Atlantic Coast Flatwoods	0 m
28	North Sapelo Island	McIntosh	31°23.4; 081°15.9	Atlantic Coast Flatwoods	19 m
29	UGA Bamboo Farm	Chatham	31°59.9; 081°16.2	Atlantic Coast Flatwoods	19 m

Table 3.2. List of ground-dwelling ants collected in Georgia 2000-2002 survey with collection site (s) noted.

Species	Survey Sites[1]
Acanthomyops interjectus (Mayr)	5
Amblyopone pallipes (Haldeman)	6,8,21,9
Aphaenogaster ashmeadi (Emery)	10,28
Aphaenogaster fulva Roger	6,10,11,18,19
Aphaenogaster lamellidens Mayr	11,16,18,19
Aphaenogaster miamiana Wheeler	27
Aphaenogaster picea/rudis/texana complex[2]	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,18,19,20,21,23,29
Aphaenogaster tennesseensis (Mayr)	23
Brachymyrmex depilis Emery	18,19,22,23,24,25,26,29
Brachymyrmex musculus Forel	23,29
Camponotus americanus Mayr	1,2,4,10,11,14,18,19
Camponotus castaneus (Latreille)	10,14,29
Camponotus floridanus (Buckley)	19,24,29
Camponotus nearcticus Emery	10,21,26
Camponotus pennsylvanicus (De Geer)	1,2,4,8,9,10,11,18,19,23
Camponotus subbarbatus Emery	1,19
Crematogaster ashmeadi Mayr	2,4,9,10,11,12,14,16,18,19,20,21,23,26,28,29
Crematogaster cerasi (Fitch)	29
Crematogaster lineolata (Say)	1,2,7,9,11,12,14,18,19,20
Crematogaster minutissima Mayr	10,18,19
Cyphomyrmex rimosus (Spinola)	22,24,25,26
Dorymyrmex bureni Trager	22,25,26,27,29,26
Dorymyrmex insanus (Buckley)	25,29
Forelius analis (Andre)	10,14,18,19,29
Forelius pruinosus (Roger)	25
Formica archboldi Smith	10
Formica exsectoides Forel	1
Formica pallidefulva Latreille	6,10,14,17,19,20,21,23,29
Formica rubicunda Emery	1

Formica schaufussi Mayr	10,19
Formica subintegra Wheeler	10
Formica subsericea Say	1,5,6,7,9,10,11,18,20
Hypoponera opaciceps (Mayr)	5,7,18,20,23,29
Hypoponera opacior (Forel)	10,17,18,19,20,21,23,29
Lasius alienus (Foerster)	5,6,8,18,19,25,29
Lasius neoniger Emery	10
Leptothorax curvispinosus Mayr	2,3,4,9,10,11,29
Leptothorax pergandei Emery	9,16,24,28,29
Leptothorax schaumii Roger	14,19
Leptothorax smithi Baroni Urbani	16
Linepithema humile (Mayr)	10,17,21,25
Monomorium minimum (Buckley)	1,10,18,19,21
Monomorium viride Brown	27
Myrmecina americana Emery	1,3,4,5,8,9,10,11,13,14,16,20,21
Myrmica americana Weber	6,18,23
Myrmica pinetorum Wheeler	19
Myrmica punctiventris Roger	5,7,8,9,10,18,19
Myrmica spatulata Smith	5,9
Myrmica sp. (undescribed)[3]	6
Odontomachus brunneus (Patton)	29
Pachycondyla chinensis (Emery)	11,14,15,16,18
Paratrechina arenivaga (Wheeler)	6,10,12,19,22
Paratrechina faisonensis (Forel)	1,7,10,11,14,17,19,21,28,29
Paratrechina parvula (Mayr)	19
Paratrechina vividula (Nylander)	2,4,7,9,10,11,19,20,28,29
Pheidole adrianoi Naves	29
Pheidole bicarinata Mayr	10,21,26,29
Pheidole bicarinata vinelandica Forel	10,14
Pheidole crassicornis Emery	18,19,22,23,25,26
Pheidole dentata Mayr	1,10,14,16,19,21,23,24,29
Pheidole dentigula Smith	10,18,19,23,24,28,29
Pheidole littoralis Cole	23

Pheidole metallescens Emery	23
Pheidole morrisii Forel	29
Pheidole tysoni Forel	10,18,19,21,23
Pogonomyrmex badius (Latreille)	27,29
Polyergus lucidus Mayr	29
Ponera pennsylvanica Buckley	1,2,5,6,7,8,9,10,11,14,18,19
Prenolepis imparis (Say)	1,2,3,5,6,7,8,9,10,11,12,14,16,18,19,20,23
Proceratium croceum (Roger)	7
Proceratium pergandei (Emery)	19
Pseudomyrmex ejectus (Smith)	21
Pyramica bunki (Brown)	11
Pyramica carolinensis (Brown)	3
Pyramica ornata (Mayr)	10,18,19,21
Pyramica rostrata (Emery)	18,19
Pyramica wrayi (Brown)	29
Solenopsis geminata (Fabricius)	27
Solenopsis invicta Buren	10,18,19,21,22,24,25,26,28,29
Solenopsis molesta complex[4]	2,4,7,9,10,11,12,14,17,18,19,21,22,23,24,26,29
Stenamma brevicorne (Mayr)	18
Stenamma diecki Emery	1,4,5,6,7,8,9,23
Stenamma impar Forel	18,19
Stenamma schmitti Wheeler	5,6,8,18,19
Stenamma spp. (2 undescribed species)[5]	6
Strumigenys louisianae Roger	18,19,21,23,29
Tapinoma sessile (Say)	3,6,8,9,18,19,21
Trachymyrmex septentrionalis (McCook)	13,14,19,22,23,25

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[1] Sites and site information are provided in Table 1.

[2] *Aphaenogaster picea/rudis/texana* complex includes *A. picea* (Wheeler), *A. picea rudis* Enzmann, *A. texana* Wheeler, and *A. texana carolinensis* Wheeler species (S. Cover, personal communication).

[3] Previously undescribed species (S. Cover, personal communication).

[4] *Solenopsis molesta* complex includes *S. carolinensis* Forel, *S. molesta* (Say), *S. pergandei* Forel, *S. texana* Emery, *S. truncorum* Forel species (S. Cover, personal communication).

[5] Two previously undescribed species and first records from Georgia (S. Cover, personal communication).

Table 3.3. Species of ground-dwelling ants previously reported to occur in Georgia but not collected in the 2000-2002 state survey.

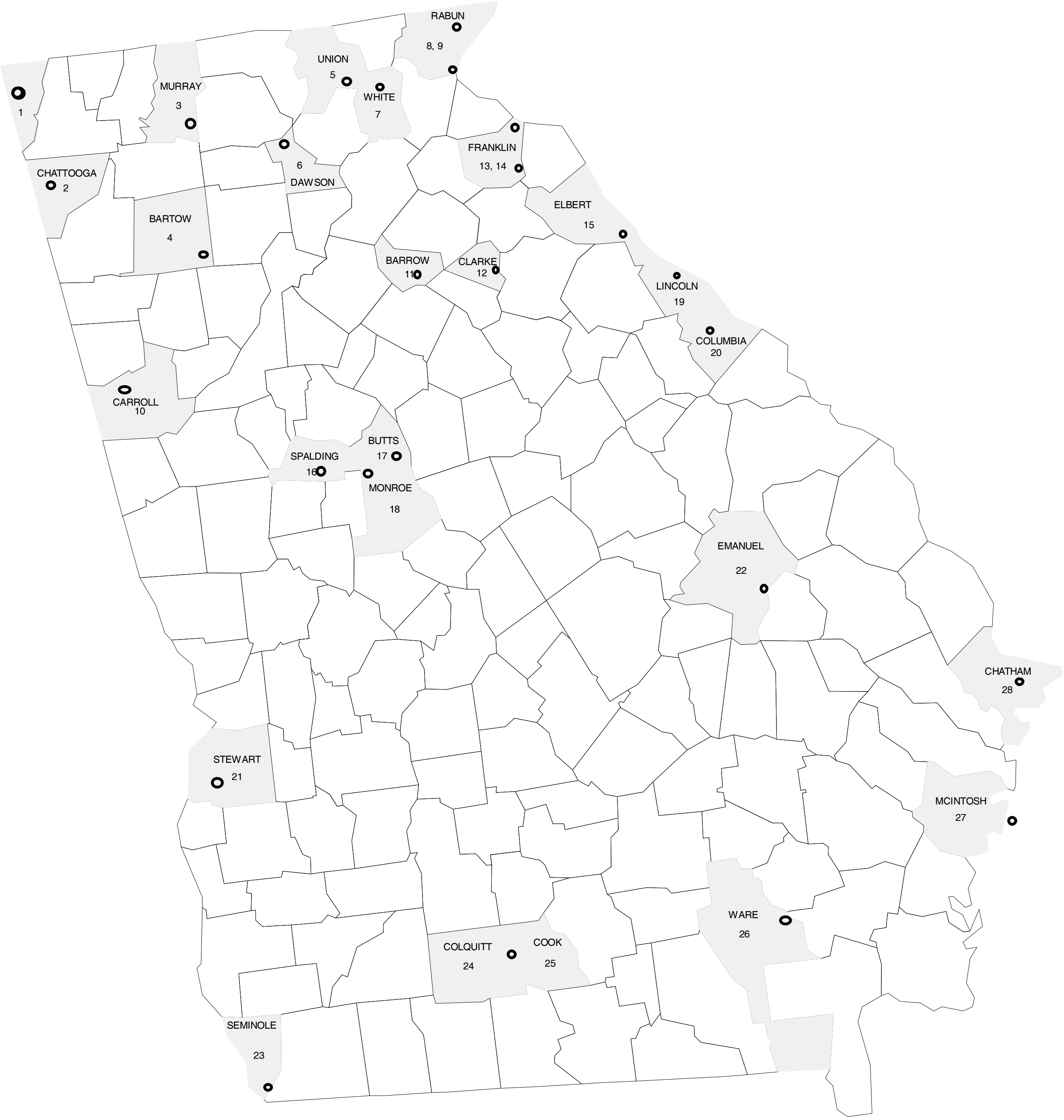
Species	Record
Acanthomyops claviger (Roger)	UGANHM[1]
Acanthomyops murphyi (Forel)	UGANHM[1]
Aphaenogaster ashmeadi (Emery)	Wheeler 1913
Aphaenogaster treatae Forel	Wheeler 1913
Camponotus caryae (Fitch)	UGANHM[1]
Camponotus decipiens Emery	Wheeler 1913
Camponotus discolor (Buckley)	Wheeler 1913
Camponotus impressus (Roger)	ABS[2]
Camponotus socius Roger	Wheeler 1913
Crematogaster missuriensis Emery	ABS[2]
Crematogaster pilosa Emery	Wheeler 1913
Crematogaster sp. (undescribed)	ABS[2]
Cryptopone gilva (Roger)	UGANHM[1]
Discothyrea testacea Roger	ABS[2]
Dolichoderus mariae Forel	Wheeler 1913
Dolichoderus pustulatus Mayr	Wheeler 1913
Dorymyrmex grandulus (Forel)	UGA NHM[1]
Formica difficilis Emery	Wheeler 1913
Formica integra Nylander	Wheeler 1913
Formica nitidiventris Emery	Wheeler 1913
Formica obscuriventris Mayr	Wheeler 1913
Leptothorax bradleyi Wheeler	Wheeler 1913
Leptothorax texanus Wheeler	ABS[2]
Monomorium pharaonis (L.)	Wheeler 1913
Myrmica latifrons Starcke	Wheeler 1913
Nievamyrmex carolinensis (Emery)	UGANHM[1]
Nievamyrmex nigrescens (Cresson)	UGANHM[1]
Nievamyrmex opacithorax (Emery)	Wheeler 1913
Paratrechina longicornis (Latreille)	Wheeler 1913
Pheidole pilifera (Roger)	UGANHM[1]
Ponera exotica Smith	ABS[2]
Proceratium creek De Andrade	ABS[2]
Proceratium crassicorne Emery	ABS[2]
Pseudomyrmex pallidus (Smith)	Wheeler 1913
Pyramica abdita (Wesson)	ABS[2]
Pyramica angulata (Smith)	ABS[2]
Pyramica clypeata (Roger)	UGANHM[1]
Pyramica dietrichi (Smith)	UGANHM[1]
Pyramica laevinasis (Smith)	ABS[2]
Pyramica ohioensis (Kennedy & Schramm)	ABS[2]
Pyramica pergandei (Emery)	ABS[2]

Pyramica pilinasis (Forel)	ABS[2]
Pyramica pulchella (Emery)	ABS[2]
Pyramica reflexa (Wesson)	ABS[2]
Solenopsis picta Emery	UGANHM[1]
Solenopsis tennesseensis Smith	ABS[2]
Solenopsis xyloni McCook	Jouvenaz et al. 1977
Tetramorium bicarinatum (Nylander)	UGA NHM[1]

[1] University of Georgia Natural History Museum.

[2] Archbold Biological Station.

Figure 3.1. Georgia sites sampled for ground-dwelling ants, 2000-2002.



RABUN
8, 9
UNION
5
WHITE
7
MURRAY
3
1
6
DAWSON
FRANKLIN
13, 14
CHATTOOGA
2
ELBERT
15
BARTOW
4
BARROW
11
CLARKE
12
LINCOLN
19
COLUMBIA
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CARROLL
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BUTTS
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SPALDING
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MONROE
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EMANUEL
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CHATHAM
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STEWART
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MCINTOSH
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WARE
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COLQUITT
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COOK
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SEMINOLE
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CHAPTER 4

PARTICLE SIZE PREFERENCE OF SIX ANT SPECIES (HYMENOPTERA: FORMICIDAE)[1]

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[1] Ipser, R. M. and W. A. Gardner. To be submitted to Journal of Economic Entomology

ABSTRACT

Laboratory studies were conducted to determine the bait particle size preference of six ant species. Preferences from a selection of four particle sizes (2.36mm, 2.00mm, 1.44mm, 0.85mm) were determined for each species. The red imported fire ant, *Solenopsis invicta* Buren, and two native species, *Aphaenogaster fulva* Roger and *Aphaenogaster lamellidens* Mayr, preferred particle size 8 (2.36 mm), with a particle size preference profile of 8>10=14=20 for *S. invicta* and 8>10>14>20 for *A. fulva* and *A. lamellidens*. The native species *Formica pallidefulva* Latreille preferred particle size 8 and 10 equally, with a particle size preference profile of 8=10>14>20. The Argentine ant, *Linepithema humile* (Mayr), preferred size 10 (2.00 mm) and size 14 (1.44 mm) equally, with the size preference profile of 10=14>8>20. The native ant, *Pheidole dentata* Mayr, preferred size 20 (0.850 mm), with a preference profile of 20>14>10=8. Particle size preference was positively correlated with worker head capsule width. Competitive interactions between *S. invicta* and the four native species for bait particles resulted in dominance of the laboratory foraging arena and subsequent raiding of the nests by *S. invicta*. *Linepithema humile* workers recruited faster to a food source than *S. invicta, A. fulva*, and *A. lamellidens*, but *S. invicta* recruited more workers than all other species. Competitive interactions between *S. invicta* and *L. humile* at 30°C resulted in dominance of the laboratory foraging arena by *S. invicta* and subsequent raiding of *L. humile* nests by *S. invicta*. At 17°C, *S. invicta* ceased foraging, and *L. humile* dominated the foraging arena. At temperatures higher than 35°C, both species ceased foraging.

Key words: *Aphaenogaster fulva*, *Aphaenogaster lamellidens*, bait particle size, competition, foraging, *Linepithema humile*, *Pheidole dentata*, *Solenopsis invicta*.

INTRODUCTION

The red imported fire ant, *Solenopsis invicta* Buren, and the Argentine ant, *Linepithema humile* (Mayr), are native to South America. Both have expanded their ranges into North America following their accidental introductions into the southeastern U.S. (Korzukhin et al. 2001, Suarez et al. 2001). Both are nuisance pests, causing substantial losses and reduction in net profit of agricultural systems (Taber 2000, Vega and Rust 2001). Furthermore, the sting and aggressive behavior of *S. invicta* pose health problems for humans, domestic animals, and wildlife (Vinson 1994, 1997, Taber 2000).

Invading *S. invicta* and *L. humile* populations reportedly displace native ant and other arthropod species (Bond and Slingsby 1984, Porter and Savignano 1990). Yet, some native ant species co-exist and even compete with these exotic ant species in North America (Whitcomb et al. 1973, Nickerson et al. 1975). Drees and Gold (2003) suggest that conservation of native species, especially those that directly or indirectly compete with *S. invicta* or *L. humile*, could help in managing these two pests.

Insecticides used for controlling pest ant species are increasingly formulated as baits because baits pose minimal environmental and safety problems (Drees and Gold 2003). Particle baits are more attractive than liquid baits and possess a higher potential for control due to their ability for large-scale broadcast dispersal (Krushelnycky and Reimer 1998). However, current baiting tactics are not species specific, and baits targeted at pest ant species may also be attractive to and foraged upon by nontarget ant species. Hooper-Bui and Rust (2001) and Hooper-Bui et al. (2002) suggest that specificity and efficacy of insecticides formulated as baits could be improved by matching bait particle size profile to the preferred profile of the target pest ant, thereby maximizing recruitment rate and toxicant transported to the colony by foragers.

Other tactics could include timing of application during optimal ant foraging conditions. For example, recruitment rates and foraging of ant species also varies in response to temperature (Holldobler and Wilson 1990). Thus, applying baits during peak foraging temperatures of the target pest ant species could increase efficacy of the bait and help prevent uptake by nontarget native ant species via increased competition by dominant pest ant species. For example, at 36^{o}C and higher, foraging by *S. invicta* and *L. humile* begins to decline (Porter and Tschinkel 1987, Markin 1970). However, the native species *Forelius analis* (Andre), a competitor of *S. invicta* and *L. humile*, is a heat-tolerant species and will forage at these temperatures (unpubl. data). Thus, applications of baits during non-peak foraging temperatures should be avoided.

Ant species that compete well against *S. invicta* are usually woodland species that also occupy open uncanopied habitats (Holldobler and Wilson 1990, Taber 2000). *Pheidole dentata* Mayr, a species that nests in and under logs in canopied habitats, forages in open habitats as well and has evolved a complex strategy of defense against *S. invicta* (Wilson 1976). *Pheidole dentata* will modulate recruitment in response to competition, thereby depositing more pheromone to elicit greater numbers of major workers for resource and colony defense (Wilson 1976). Other species such as *Aphaenogaster fulva* Roger, *A. lamellidens* Mayr, and *Formica pallidefulva* Latreille are forest dwellers that exhibit nesting habitats similar to that of *P. dentata*. These species should also be good candidates as competitors against *S. invicta* via their venom, chemical sprays, and recruitment rate (Holldobler and Wilson 1990).

The objectives of this study reported herein were to: (1) determine the particle size preference of *S. invicta*, *L. humile* and 4 native ant species; (2) correlate particle size preference with head capsule width of foraging workers of each species; (3) determine effects of ambient temperature on the foraging activities of *S. invicta* and *L. humile*; (4) examine the competitive interactions between species for the bait particles, and; (5) measure recruitment rate and intensity to a food resource for several ant species.

MATERIALS AND METHODS

Ant Colonies

Red imported fire ants used in these studies were from colonies removed from field populations in Spalding Co., GA, from April through October 2002. Individual colonies and associated soil were shoveled into 15 to 20-liter plastic buckets with the upper 10 cm of the inner surface coated with a thin film of Fluon® (Northern Products, Woonsocket, RI) to prevent ant escape. Once in the laboratory, colonies collected in buckets were allowed to acclimate for 5 d, after which ants and brood were extracted from soil using procedures described by Jouvenaz et al. (1977). Extracted colonies were placed individually into plastic housing arenas (55 x 44 x 13 cm), with the top inner edges coated with Fluon to prevent ant escape. Each housing arena contained at least one artificial nest constructed from 150-mm plastic Petri dishes (12 x 12 x 3.5 mm) with the bottom one-third filled with dental plaster to retain moisture. Colonies were fed three times each week on an alternating diet of tuna and crickets.

Argentine ants and the four native ant species – *A. fulva*, *A. lamellidens*, *F. pallidefulva*, and *P. dentata* - also were collected from field populations in Spalding Co., GA, from April through October 2002. Colonies and some associated soil were placed directly in plastic housing arenas (55 x 44 x 13 cm) with the top inner edges of arenas coated with Fluon to prevent ant escape. Colonies were maintained as previously described.

Sugar water and tap water were continuously supplied in test tubes stoppered with cotton plugs. Colonies were maintained in a room with a mean temperature of 26.6°C, 70% relative humidity, and a 12:12 h light/dark photo cycle. All colonies contained queens and brood. Each colony was starved for 5 days prior to use in testing.

Bait Particles

Bait particles of four sizes were created by grinding freeze-dried crickets in a coffee grinder (Braun™; household type # 4041) and sieved to corresponding sizes of 8 (2.36 mm), 10 (2.00 mm), 14 (1.44 mm), and 20 (0.850 mm) by using sieve screens (Fisher™; model # 02202b). The crickets were obtained from Luker Farms (Port Allen, LA) and stored in a freezer until used. Crickets were removed from the freezer and allowed to thaw at 25.0^{o}C prior to grinding.

Particle Size Preference

The preferences of foragers of each of the six species were determined in assays conducted in the laboratory with a series of colony housing arenas paired with a foraging arena. Each colony housing arena contained an active colony as previously described and was connected to an adjacent foraging arena with Tygon™ tubing (1 cm diam) or a bridge constructed of wooden stakes. The tubing or the wooden bridge provided access between the housing arena and the foraging arena for the foraging workers.

Foraging arenas were 54 x 44 x 13 cm plastic trays with upper 10 cm of the inner surfaces coated with Fluon to prevent ant escape. Ants were allowed to acclimate to the foraging arena for 1 h before placement of baits in the arena. At that time, individual weigh boats (51 mm^2) containing 10 mg of the specified bait particles were placed equi-distant from the opening of the Tygon tubing or the end of the bridge in a randomized arrangement.

The tubing was used for *S. invicta* and *L. humile*, but foragers of *A. fulva*, *A. lamellidens*, *F. pallidefulva*, and *P. dentata* would not consistently use the tubing to access baits in the foraging arena. Thus, a bridge constructed of wooden stakes taped together measuring 95 cm in length was used to provide access from the housing arena to the foraging arena for foraging workers of these species.

Workers were allowed to forage until all bait particles of at least one size were removed. At that time, all containers were removed and the remaining particles in each were weighed. Differences in weight (mass) removed by the foragers were used to determine particle profile for each species. Ten replications were conducted over time for each species. With most species, colonies were used only once, but when colonies were used more than once, a minimum of 5 d was allocated between consecutive replications.

Worker Ant Head Capsule Width

For each ant species, 50 workers were randomly selected from the tests previously described to measure head capsule widths (five ants for each replication). Measurements were made with a Wild ocular eye piece (445111) and calibrated with an Olympus objective micrometer (# 0b-M 1/100). Ants were positioned with the frons facing up; measurement of width was taken above the eye (Umphrey 1996). A linear regression was conducted to correlate head capsule width with preferred particle size (Sokal and Rholf 1995).

Interspecific Competition for Bait Particles

A series of assays examined the interspecific competition between *S. invicta* and each of the four native species for bait particles. In these assays, one foraging arena was placed between a housing arena containing a colony of *S. invicta* and a housing arena containing a colony of one of the four native ant species. Foraging workers from both colonies were provided access to the foraging chamber with the previously described wooden bridges. The ends of the respective bridges were placed so that each was 15 cm from a linear arrangement of the 4 weigh boats of bait particles. All tests were conducted in an environmental chamber maintained at 25^{o}C and on a 12:12 h light dark photo-phase. Tests of interactions between *S. invicta* and each species were replicated 10 times over time. Most colonies were used only once, but when colonies were used more than once, a minimum of 5 d was allocated between consecutive replications. Colony behavior, such as ant worker response and recruitment were observed and recorded.

S. invicta and *L. humile* Competition for Bait Particles in Response to Temperature

The previously described foraging arenas were also used in evaluating competition of *S. invicta* with *L. humile* for particles of varying sizes at different temperatures. In the first experiment, individual colonies of *S. invicta* and *L. humile* were provided access to the central foraging arena via separate Tygon tubing. The openings of the respective tubes were placed so that each was 15 cm from a linear arrangement of the 4 containers of bait particles. Containers with the baits were placed in the foraging arena when one worker of either of the two species entered the foraging arena. This experiment was conducted in environmental growth chambers (Conviron; Mod # E 15) at temperatures of 5^{o}C, 10^{o}C, 30^{o}C, 36^{o}C, and 40^{o} C. The experiment conducted was a randomized two-factor design. Ten replications were conducted over time for each temperature. Colony behavior, such as ant worker response and recruitment was also observed and recorded.

A second experiment was conducted to determine if larger numbers of *L. humile* workers would alter *S. invicta* particle size selection. Two *L. humile* colonies and one *S. invicta* colony were allowed access to the same foraging arena at 30°C. Ten replications were conducted over time.

Recruitment Rate and Intensity

Fifty worker ants of *S. invicta*, *L. humile*, *A. fulva*, and *A. lamellidens* were individually timed while crossing a 16 cm portion of a wooden dowel as they were recruiting to a food source. *Formica pallidefulva* and *P. dentata* were not included in this experiment because workers did not readily cross the 16 cm wooden dowel. A 25-cm wooden dowel (25 mm diam) was used in this experiment to keep worker ants in a single line when recruiting additional workers to the resource. To support the dowel rod, each end of the dowel was connected to a plastic tube cemented in a 35-mm plastic cup. One plastic cup was placed in the colony housing arena and the other cup was placed in a separate arena. Workers of each species were allowed access to a food resource placed in the plastic cup that was in the separate arena. Once recruitment began, 50 individual ants were timed while crossing the 60 cm length. In addition, number of worker ants on the food source was counted every 10 min for 100 min. All experiments were conducted at 25°C.

Statistical Analysis

All data were analyzed using a general linear model in the Statistical Package for the Social Sciences (SPSS). A one-way analysis of variance was used to determine differences in weight of particles removed, differences in recruitment times among species, and differences in numbers of worker ants on the food source among species. Tukey's HSD determined significance in mean separation among the four particle sizes (Sokal and Rholf 1995).

RESULTS AND DISCUSSION

Particle Size Preference Profile

Regardless of the species tested, acceptance of a bait resulted in its complete removal within 3 h, with a positive correlation of bait particle size removed with head capsule width size ($F = 304.08$; df = 299; $P < 0.001$) ($R^2 = 0.505$). Species with workers possessing the wider head capsules preferred larger particle sizes. The mean (± SD) head capsule width of *A. fulva* was 0.91 ± 0.03 mm, *A. lamellidens* was 1.01 ± 0.06 mm, *F. pallidefulva* was 1.22 ± 0.23 mm, and *S. invicta* was 1.11 ± 0.17 mm. Each of these species significantly preferred the size 8 particle to the other three particle sizes (Table 4.1). *Formica pallidefulva* preferred size 10 equally as well as size 8. Thus, the resulting preference profiles were 8>10>14>20 for *A. fulva* and *A. lamellidens*, 8=10>14>20 for *F. pallidefulva*, and 8>10=14=20 for *S. invicta*. *Linepithema humile*, with a mean (± SD) head capsule width of 0.38 ± 0.02 mm, preferred particle size 10 over sizes 8 and 20; however, preference of particle size did not differ significantly between sizes 10 and 14 or among sizes 8, 14, and 20. *Pheidole dentata*, with a mean (± SD) head capsule width of and 0.60 ± 0.03 mm, demonstrated a preference for the smaller particles, especially particle size 20. The preference profile was 20>14>10>8.

Hooper-Bui et al. (2002) also reported a direct relationship between head capsule width and preferred particle size with six pest ant species in California (*Formica* sp., *L. humile*, *Monomorium pharaonis* (L.), *Pogonomyrmex californicus* (Buckley), *S. invicta*, and *S. xyloni* McCook). In their study, these six pest ant species also preferred specific particle sizes. Two species – *S. invicta* and *L. humile* – were included in both studies. Our results with *S. invicta* corroborate those of Hooper-Bui et al. (2002). However, Hooper-Bui et al. (2002) found that *L. humile* from California and Alabama preferred particle sizes 0.84 -1.00 mm, but we found our smallest particle (0.850 mm) to be the one least preferred by *L. humile*. We also measured a wider mean head-capsule for *L. humile* than Hooper-Bui et al. (2002), which could account, at least in part, for the preference for a larger particle. Results of both studies show that particle size preference is related to head capsule width.

Based upon the weights (Table 4.1) of each particle size removed by these species, it is apparent that the particle size preference exhibited by *P. dentata* differed substantially from the preferences of the other five species. From these results, it is possible that a formulated bait consisting of particle size ranging from 8 (2.36 mm) to 10 (2 mm) would not be as highly foraged upon by *P. dentata* as would be foraged upon by the other five species. Furthermore, a bait consisting of particle size 20 (0.85 mm) would not be preferred by *A. fulva*, *A. lamellidens*, or *F. pallidefulva*, but would be highly preferred by *P. dentata* and moderately preferred by *S. invicta* and *L. humile*.

Coupled with knowledge of the identity of nontarget native ant species occurring in a habitat, bait particles of a prescribed size could be applied to minimize impact on native species while providing efficacious control of target pest ant species. For example, if *P. dentata* occurs in the targeted area while *A. fulva*, *A. lamellidens*, and *F. pallidefulva* do not, a mixture of bait particles of 8 and 10 sizes could be used against *S. invicta* and *L. humile* to minimize impact on *P. dentata*. On the other hand, a particle size of 20 could be used against *S. invicta* and *L. humile* if *P. dentata* does not occur and *A. fulva*, *A. lamellidens*, or *F. pallidefulva* do occur.

Interspecific competition

The four native species competed poorly against *S. invicta* in the laboratory arenas at 25^{o}C, a temperature that is within the optimal foraging range for all of these species (Holldobler and Wilson 1990). In each trial, *S. invicta* dominated the foraging arena by arriving in the arena first and recruiting more workers to the bait than the competing species. In competition with all native species, *S. invicta* would subsequently raid the opposing species nests and force workers to the periphery of the housing arena. Eventually, all brood was transported back to the *S. invicta* nest, and remaining workers and queens were killed. No bait particles were foraged until the competing native ant colony was totally eliminated. Thus, particle preference in these trials was not recorded because foraging of particles corroborated our previous findings in the absence of any competing ant species.

Every ant species also functions within specific ranges of temperature, humidity, and other environmental conditions (Holldobler and Wilson 1990). Porter and Tschinkel (1987) found that maximum foraging activity of *S. invicta* occurs between from 22 and 36^{o}C. Markin (1970) reported that maximum foraging activity of *L. humile* occurs between 15 and 30^{o}C. Results of the interactions between *S. invicta* and *L. humile* reported herein indicate that, when both these species are competing for the same food resources at optimal foraging temperatures, *S. invicta* will dominate *L. humile*. In each replication within the optimal temperature ranges, both species first engaged each other in the foraging arena, and *S. invicta* eventually dominated *L. humile* workers within 3 h and raided the *L. humile* colony in the housing arena. Moreover, *S. invicta* overtook the brood boxes and forced the *L. humile* queens and workers to the periphery of their housing arenas.

When one *S. invicta* colony was in competition with one *L. humile* colony at 30°C, the resulting size preference profile for *S. invicta* differed from that observed when *S. invicta* colonies foraged in the absence of *L. humile* (F = 5.172; df = 3; P = 0.004) (Table 4.2); however, the size of the preferred particle did not. *Solenopsis invicta* only preferred particle size 8 over size 20, with no other significant differences detected among the other particle sizes. This was in contrast to the preference profile obtained when *S. invicta* foraged in the absence of *L. humile* (8>10=14=20). However, when one *S. invicta* colony was in competition with two *L. humile* colonies at 30°C, the resulting profile reverted back to the same as when foraging in the absence of *L. humile* (Table 4.3). Regardless, *S. invicta* workers continued to dominate their new territory while foraging for particles.

Temperatures outside of the optimal range adversely affected the foraging activity of *S. invicta* and *L. humile*. At temperatures of 10°C and 36°C, foraging by *S. invicta* decreased, and foraging by *L. humile* ceased. *Solenopsis invicta* dominated the foraging arena in every replication, but no longer displayed a preference for any particle size. At temperatures of 5°C and 40° C, foraging ceased for *S. invicta* as well.

Our results corroborate those of Francke et al. (1985), who stated that temperatures >42°C are lethal for *S. invicta*. We also found that foraging deceased at temperatures exceeding 33°C. Porter and Tschinkel (1987) found that *S. invicta* foraging remained significant when soil temperatures were 33°C and can continue at temperatures above 42°C in natural situations because of their extensive underground tunnel system, which apparently protects workers from exposure to extreme atmospheric and surface temperatures. Vogt et al. (2003) obtained similar results for foraging activity in Oklahoma. Unlike in Florida (Porter and Tschinkel 1987), season was observed to be the best individual predictor for foraging activity in Oklahoma (Vogt et al. 2003). Colder temperatures in Oklahoma prevent *S. invicta* from foraging from mid-December to mid-March.

Similar temperature effects have also been noted for *L. humile*. Markin (1968) demonstrated that the optimum foraging temperature for *L. humile* ranges from 15° and 30°C. However, he observed ants returning to nests at temperatures ≤ 10°C and ≥ 32°C, and found that *L. humile* remained active at temperatures up to 35°C (Markin 1970).

Linepithema humile continued to forage during colder temperatures, but not while exposed to temperatures below 17°C. Yet, Markin (1970) observed *L. humile* foraging at temperatures as low as 15°C. This, again, probably reflects an absence of soil and substrate in our trials.

Recruitment

Significant differences were detected among species in worker recruitment speed (F = 40.98; df = 3; $P < 0.01$) and mean number of individual foragers recruited to a food resource (F = 40.90 df = 3; $P < 0.001$) (Table 4.4). Foragers of *S. invicta* recruited slower than did *A. fulva*, *A. lamellidens*, and *L. humile*. However, intensity of recruitment (mean numbers of foragers recruited to a food source within 100 min) was greatest for *S. invicta* with a mean (± SD) of 124 ± 9 (F = 1010.33; df = 3; $P < 0.001$). Thus, *S. invicta* recruited slower to a food resource, but recruited more workers, than did *L. humile*.

Mass communication, the most advanced form of communication, where one group of individuals can communicate to another group entirely with pheromones, is used by *S. invicta*

(Wilson 1962, Holldobler and Wilson 1990). This form of communication is used in recruitment whereby one individual can stimulate many workers to follow a single trail pheromone at once. The other species tested in this experiment do not exhibit this level of communication. There are, however, species within the Formicinae that exhibit advanced levels of recruitment; yet these are not as advanced as the system *S. invicta* exhibits (Blum and Wilson 1964, Holldobler and Wilson 1990). Holldobler and Wilson (1990) hypothesize that the evolution of the advanced mass communication exhibited by *S. invicta* is due to colony size and a reliance on trail pheromone for recruiting and orientation of sister workers.

The observed dominance of *S. invicta* over *L. humile* and the native ant species may be largely due to the species advanced level of recruitment demonstrated by *S. invicta* and involve numbers of workers recruited to a food source. The ability to recruit nest mates to a new food source and to defend it from competitors is important in foraging success (Holldobler and Wilson 1990, Traniello 1983). For example, Banks and Williams (1989) reported that when *S. invicta* and *P. longicornis* competed for the same food resource, *P. longicornis* discovered the baits first, dominating the bait samples with many workers for approximately 30 min. Within 20 min, *P. longicornis* was able to recruit 275 individuals to three bait sources. However, while *S. invicta* was slower in recruiting individual workers to the same baits, they eventually recruited more foragers than *P. longicornis*. Within 40 min, *P. longicornis* was completely displaced from the baits by *S. invicta*.

Recruitment also permits the exploitation of a wider range of food items. Through recruitment, ants are able to handle items larger than their individual size (Traniello 1987). Genera such as *Monomorium*, *Myrmica*, *Lasius*, and *Formica* all exhibit this behavior. *Lasius* *neoniger* Emery cooperatively foraged 85% of diet given to them in a field in Massachusetts, increasing their dietary breadth (size range of prey) 33 fold (Traniello 1983).

Although we were unsuccessful in eliciting recruitment of *F. pallidefulva* in our lab studies, we would expect that the results, had we been successful, would have been similar to that found for *F. schaufussi* (Mayr). *Formica schaufussi*, a close relative of *F. pallidefulva*, has a recruitment communication that enables a single worker to organize a group of up to 15 workers to a food resource (Traniello and Beshers 1991). However, their communication system is also imprecise in directing individual workers to a food source, and as a result, this species is usually displaced from large prey by competitors (Traniello and Beshers 1991). From their field observations, similar results with *F. pallidefulva* could be expected. This species primarily occurs in canopied habitats in Georgia. Its foraging behavior is out-matched by that of *S. invicta* in open habitats (unpubl. data).

Torres (1984) discovered that arrival at a bait resource first was significantly correlated with successful bait dominance. This allows poor or equally-dominant competitors to coexist in an area because the species arriving first can recruit more workers. Subordinate species were able to dominate baits by outnumbering the scouts from other species, which discourages trail-laying behavior. We have observed this on occasion in central Georgia for the species *P. dentata* and *Monomorium viride* Brown. However, *S. invicta* remains the dominant ant species in open habitats.

The results of this study indicate that in order to improve the efficacy of commercial baits, baits should be tailored to contain particle sizes that are preferred by the pest ant species *S. invicta* and *L. humile*. Commercial baits should contain size 8 for *S. invicta* and size 10 and 14 for *L. humile*. In addition, application of baits for controlling *S. invicta* and *L. humile* should be conducted at temperatures of 20^{o}C and 30^{o}C, if possible. Maximum recruitment and foraging will occur at these temperatures. This should improve maximum bait uptake by these two pest ant species, while at the same time, reduce bait contact and uptake by nontarget native ants.

This is the first attempt to quantify competition between *S. invicta* and *L. humile*. We conclude that *S. invicta* foragers are able to withstand populations of *L. humile* that are, at the very least, double in size. This concurs with observations that a single fire ant worker overcomes eight Argentine ant workers in laboratory assays (D. Suiter, Pers. comm.). Our experiments have not attempted to determine other ecological parameters of competition, such as establishment of territorial boundaries or changes in food source site fidelity, that affect the distributions of these two pest ant species when they meet in their expanded ranges. Knowledge of these parameters could possibly yield further improvements in management strategies against the two pest ants.

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Table 4.1. Mean (±SD) weight (mg) of specified particle sizes of freeze-dried crickets removed by *S. invicta*, *L. humile*, *A. fulva*, *A. lamellidens*, *F. pallidefulva*, and *P. dentata* workers over a period of three hours in laboratory arenas.

	Mean wt. removed (mg) ± SD					
Particle size	*S. invicta*	*L. humile*	*A. fulva*	*A. lamellidens*	*F. pallidefulva*	*P. dentata*
8 (2.36 mm)	10 ± 0.0 a	6.5 ± 2.5 a	10 ± 0.0 a	10 ± 0.0 a	8.8 ± 2.5 a	0.8 ± 1.0 a
10 (2 mm)	6.8 ± 2.0 b	9.0 ± 1.9 b	7.5 ± 7.0 b	6.3 ± 1.9 b	7.3 ± 1.5 a	0.7 ± .94 a
14 (1.44 mm)	5.5 ± 1.3 b	8.1 ± 2.0 ab	5.0 ± 1.8 c	3.9 ± 1.5 c	3.2 ± 7.8 b	4.0 ± 3.2 b
20 (0.85 mm)	5.1 ± 2.2 b	5.7 ± 1.4 a	0.6 ± .69 d	0.9 ± .87 d	0.3 ± .67 c	9.0 ± 1.0 c

Means within rows followed by the same letter are not significantly different (Tukey's HSD, *P* level = 0.05).

Table 4.2. Mean (±SD) weight (mg) of specified particle sizes of freeze-dried crickets removed by *S. invicta* during competition against one *L. humile* colony.

Particle Size	Mean Amount Removed (mg)
8 (2.36 mm)	9.3 ± 2.21 a
10 (2.00 mm)	7.1 ± 2.72 ac
14 (1.44 mm)	6.5 ± 2.27 ac
20 (0.85 mm)	5.0 ± 2.66 bc

Means within rows followed by the same letter are not significantly different (Tukey's HSD, *P* level = 0.05).

Table 4.3. Mean (±SD) weight (mg) of specified particles of freeze-dried crickets removed by *S. invicta* during competition against two *L. humile* colonies.

Particle Size	Mean Amount Removed (mg)
8 (2.36 mm)	10.0 ± 0.0 a
10 (2 mm)	7.1 ± 1.10 b
14 (1.44 mm)	6.1 ± 1.79 b
20 (0.85 mm)	6.0 ± 1.70 b

Means within rows followed by the same letter are not significantly different (Tukey's HSD, *P* level = 0.05).

Table 4.4. Mean (±SD) speed of individual worker ants and average number of ants recruited to a food source at 25^{o}C.

	S. invicta	*A. fulva*	*A. lamellidens*	*L. humile*
Forager speed (cm/sec)	3.65 ± 0.78 a	3.02 ± 0.68 b	3.18 ± 0.86 b	2.13 ± 0.36 c
Mean numbers of recruited ants within 100 min	124.20 ± 8.75 a	12.9 ± 2.07 b	13.40 ± 1.42 b	78.30 ± 5.77 c

Means within rows followed by the same letter are not significantly different (Tukey's HSD, *P* level = 0.05).

CHAPTER 5

IMPACT OF BROADCAST APPLICATIONS OF HYDRAMETHYLNON AND FIPRONIL ON THE RED IMPORTED FIRE ANT (HYMENOPTERA: FORMICIDAE) AND NONTARGET GROUND-DWELLING ANTS AND OTHER ARTHROPODS[1]

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[1] Ipser, R. M. and W. A Gardner. To be submitted to Journal of Economic Entomology

ABSTRACT

A bait formulation of hydramethylnon (Amdro™) and a granular formulation of fipronil (Over'n Out™) were broadcast in a replicated field test in central Georgia. Occurrence of the red imported fire ant (*Solenopsis invicta* Buren), nontarget native species of ground-dwelling ants, and other nontarget arthropods were monitored by monthly sampling for 8 months after application. Hydramethylnon reduced *S. invicta* mound density 2 months post treatment and numbers of foraging workers 8 months post treatment. The impact of fipronil was more pronounced with significantly lower *S. invicta* mound density 7 months post treatment and numbers of foraging workers as long as 8 months post treatment. No significant differences ($P > 0.05$) were detected in numbers of native ground-dwelling ants or other ground-dwelling arthropods collected among the treatments, indicating that neither hydramethylnon nor fipronil negatively impacted nontarget arthropods in this study.

INTRODUCTION

The red imported fire ant, *Solenopsis invicta* Buren, has expanded its range in the United States since its introduction from South America through Mobile, AL, in the 1930's (Vinson 1994). This invasive insect was recently estimated to occupy over 600 counties in the U.S. (Tsutsui and Suarez 2003). While *S. invicta* is an effective predator in some agricultural cropping systems (Taber 2000), workers pose threats to humans, companion animals, and livestock (Mount 1981, Allen et al. 2001, Holtcamp et al. 1997); and their mounds and tunneling activities damage agricultural equipment, electrical and communication junction boxes, and roadways (Taber 2000, Vinson and MacKay 1990). Damages and costs of control for this pest ant have been estimated at $1.6 billion per year in the U. S. (Pimentel et al. 2000).

Bait formulations have been a primary method of delivery and application of insecticidal agents for this pest for over 40 yrs (Lofgren et al. 1964, Williams et al. 2001). Mirex (SAS# 2385-85-5) was one of the first efficacious insecticides formulated and widely applied as a bait in area-wide attempts to eradicate the pest (Williams et al. 2001). Its registration was cancelled by the U.S. Environmental Protection Agency in 1978 because of its residual persistence, bioaccumulation, and carcinogenic properties (Apperson et al. 1984).

Other insecticidal products with high biodegradability properties have since been registered for fire ant control. These include hydramethylnon (Amdro™) and acephate (Orthene™), which are highly biodegradable, but efficacious when used according to label instructions (Williams et al. 1980, Banks et al. 1981, Vander Meer et al. 1982). More recently, fipronil was introduced into the market as a 15 µg/mg [AI] granular bait applied at either 1.7 or 3.4 kg per ha, or 0.57 kg [AI]/ha as a broadcast treatment (Williams et al. 2001). The active ingredient dissipates into the soil, attaches to the exoskeleton of individual worker ants, and is transported to the colony and the queen.

There is little information on the impact of many products currently used for fire ant control on native ant species and other non-target ground-dwelling arthropods. Apperson et al. (1984) concluded that hydramethylnon had no significant effects on nontarget ant species in Brunswick Co., NC. Additional studies of potential impact on nontarget species are critical to the development of biologically-based approaches for fire ant management that include utilization of naturally-occurring interspecific competition by native ant species (Drees and Gold 2003). Additional studies are also necessary for characterizing impacts on other nontarget organisms that are critical components of affected ecosystems. The objective in this research, therefore, was to quantify the occurrence of *S. invicta*, other ground-dwelling native ant species, as well as other ground-dwelling arthropods following single broadcast applications of hydramethylnon and fipronil.

MATERIALS AND METHODS

The study was conducted in the Research and Education Garden on the University of Georgia's College of Agricultural and Environmental Sciences Griffin Campus in Griffin, GA (Spalding Co.). The experimental design was a randomized complete block with blocks in different locations within the Garden. Three treatments were randomly assigned to individual 0.06-ha rectangular square plots in each block. Treatments were hydramethylnon (Amdro™, 0.10 kg [AI]), fipronil (Over-n-Out™, 0.045 kg [AI]), and an untreated control. All treatments were replicated 4 times. Insecticides were applied at the prescribed rates using a Lesco ™ applicator (model # 705698) on 16 June 2003.

Plots were sampled for *S. invicta*, ground-dwelling ants and other ground-dwelling arthropods prior to application of insecticides, 2 wks after application and at monthly intervals thereafter. For each sampling interval, *S. invicta* mounds were counted in each plot, and pitfall traps and bait stations were used to provide estimates of population abundance and species richness of ground-dwelling arthropods in response to the treatments (Bestlemeyer et al. 2000).

Seven pitfall traps were placed at 3-m intervals along the midline of each plot. These traps were 40-ml plastic vials containing propylene glycol (filled 2/3) as a nontoxic preservative. They were inserted into the ground to a depth so that the upper rim of the vial was level with the soil surface. After 7 d, each trap was removed, capped, and returned to the laboratory where all organisms were separated, identified, and counted.

Seven bait stations also were placed at 3-m intervals along the same transect in each plot on each sampling date. Bait stations were plastic Petri dishes (35 x 10 mm) containing a 25-mm diam grade 1 Whatman filter paper disk covered with a thin layer of tuna in oil as described by Brinkman et al. (2001). These stations remained uncovered for 1 h, when they were covered, sealed with Scotch™ transparent tape, and transported to the laboratory where ants were separated, identified, and counted. If a bait station was dominated by an individual ant species prior to the 1 h interval, it was covered and sealed to collect as many numbers of individual ants as possible.

Ant identifications were made with keys by Bolton (1994, 2000), Buren (1968), Creighton (1950), Cuezzo (2000), DuBois (1986), Gregg (1958), Holldobler & Wilson (1990), Johnson (1988), Trager (1984, 1988), and by comparison with specimens housed in the University of Georgia Natural History Museum (Athens, GA). Stefan Cover (The Museum of Comparative Zoology, Harvard Univ., Cambridge, MA) and Mark Deyrup (Archbold Biological Station, Lake Placid, FL) confirmed species identifications. Voucher specimens have been deposited in the University of Georgia Natural History Museum and the Museum of Comparative Zoology at Harvard University. Other arthropods were identified to family.

All data were analyzed using a general linear model in the Statistical Package for the Social Sciences (SPSS) (Sokal and Rholf 1995). Tukey's HSD determined significance in mean separation among treatments. Individual sampling intervals were analyzed to measure monthly differences in abundance of *S. invicta*, native ground-dwelling ants, and other ground-dwelling arthropods.

RESULTS AND DISCUSSION

Solenopsis invicta mound density, *S. invicta* worker abundance, abundance of native ground-dwelling ants, and other ground-dwelling arthropods, mainly represented by beetles, did not differ significantly among treatments prior to application of insecticides. Mean (± SD) numbers of mounds (5.5 ± 0.95), *S. invicta* workers (36 ± 53), native ants (49 ± 27), and beetles (2 ± 1) collected among treatments at this time were low as compared to some post treatment dates. A possible explanation for low levels of abundance was due to lack of precipitation during the months preceding this sampling date.

Arthropod abundance fluctuated according to precipitation and temperature levels in the control plots throughout the study. In general, there was a 2 month time-lag in arthropod abundance in response to precipitation. As precipitation increased the numbers of *S. invicta* mounds, *S. invicta* workers, and arthropods also increased. The largest number of *S. invicta* workers collected was in July 2003 and September 2003. Likewise, numbers of *S. invicta* mounds, *S. invicta* workers, and arthropods decreased as precipitation and mean daily temperatures decreased, with negligible levels of each during Dec 2003, Jan 2004, and Feb 2004.

Broadcast applications of hydramethylnon and fipronil significantly ($F = 97.913$; df = 2; $P < .001$) reduced the number of active fire ant mounds in the treated areas (Fig. 5.1). Within 2 wks (7 July 2003) after application, hydramethylnon reduced the mean number of active mounds. However, by 3 months (4 Sept 2003) after application, numbers of mounds increased due presumably to founding of colonies by queens from the untreated areas (Fig 5.1). After 27 Jul 2003, the number of mounds did not differ significantly between the hyrdamethylnon and control treatments.

Two wks (7 July 2003) following application, fipronil also had significantly reduced the mean number of mounds; these numbers did not return to pretreatment levels. This was apparently due to the residual activity of the insecticide in the treated soil (Drees and Gold 2003).

Significant differences among treatments also were detected in the mean numbers of fire ant workers collected ($F = 7.37$; df = 2; $P = 0.001$) (Fig. 5.2). Significant differences were detected 4 wks (27 July 2003), 5 months (14 Nov 2003), 7 months (12 Jan 2004) and 8 months (10 Feb 2004) after application. Fire ant numbers became negligible in the treated plots as the colder temperatures occurred in 15 Dec 2003, 12 Jan 2004, and 10 Feb 2004. In the fipronil-treated plots, numbers of workers remained negligible throughout the study and never exceeded 90 individuals per plot. Again, this response was most likely the result of the residual activity of fipronil in the soil (Drees and Gold 2003). The largest numbers of *S. invicta* collected in the hydramethylnon and the fipronil plots occurred in September 2003 and June 2003, respectively (Fig. 5.2).

The results of this study concur with those of Apperson et al. (1984), who found that hydramethylnon negatively impacted *S. invicta* colonies and that multiple applications of hydramethylnon are required to achieve long-term suppression of *S. invicta* population levels. Although fipronil significantly reduced *S. invicta* population levels in this study, it did not provide 100% control. Yet, due to the residual properties of the chemical, reinfestation did not occur during this study.

Other ground-dwelling ant species in this study were combined for statistical analysis due to low collections on a per species basis. However, there were no significant differences among treatments ($F = 0.932$; df = 2; $P = 0.397$) throughout the study (Fig. 5.3). Abundance of ground-dwelling ant species among treatments was insignificant each month. The product label information for Amdro states that other ants, such as *Pheidole* spp., *Pogonomyrmex* spp., and *Linepithema humile* (Mayr) will also be eliminated from treated areas. However, our results indicate otherwise in that these species were presumably not eliminated by hydramethylnon nor fipronil. Throughout the study, a mean (± SD) of 58.5 ± 120.0 native ants were collected in the untreated control plots, 31.5 ± 71.8 in the hydramethylnon-treated plots, and 39.1 ± 55.9 in the fipronil-treated plots. The large variation in numbers collected was directly related to abiotic conditions and is supported by collection data from central Georgia in which native ant abundance also fluctuated with temperature and precipitation (unpubl. data).

There also were no significant differences detected in numbers of ground-dwelling arthropods (mainly represented by beetles) collected among treatments during this study (F = 0.016; df = 2; P = 0.984) (Fig. 5.4). Again, abundance among all treatments was insignificant at each sampling interval. Among the ground-dwelling arthropods, Coleoptera were most abundant, and the majority of coleopterans collected were from the Family Carabidae. Throughout the entire study, a mean (± SD) of 4.1 ± 4.4 beetles was collected in the control treatment, 4.2 ± 5.8 in the hydramethylnon treatment, and 4.3 ± 4.5 in the fipronil treatment. For spiders, a mean (± SD) of 1.2 ± 2.2 were collected in the control treatment, 1.4 ± 2.2 in the hydramethylnon treatment, and 1.5 ± 1.6 in the fipronil treatment.

Drees and Gold (2003) state that residual contact insecticides, such as fipronil, could decimate all ants within treated areas. Although this was our hypothesis, the results of this study indicate otherwise. IPM programs for *S. invicta* should be more biologically-intensive, and future management of all pest ant species should include a greater ecological rationale, with the premise of the conservation of native ant species (Drees and Gold 2003). Thus, insecticides that preserve native species could serve as possible tactics for such programs. Although our study indicated that neither hydramethylnon nor fipronil negatively affected nontarget native ground-dwelling ants and other arthropods, knowledge of the long-term effects as well as the effects of repeated applications (once every 3 months) of these insecticides on nontarget species has not been reported. Additional studies need to be conducted to further elucidate these responses.

Augmenting or enhancing the competitiveness of native ant species against exotic ants may help in managing pest ant species. Achieving this will involve the identification of competitive interactions and the development of strategies that will enhance the competitive ability of native ants against exotic ant species (Fowler et al. 1994, Majer 1994). With conservation of native ant species, interspecific competition through foraging and the establishment of territories will result (Anderson 1986, Fowler et al. 1990, Holldobler and Lumsden 1980), and pest ant management strategies can be developed, improved, and implemented.

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Table 5.1. Native ant species collected during study, June 2003 through February 2004.

Species
Dorymyrmex bureni Trager
Forelius analis (Andre)
Forelius pruinosus (Roger)
Formica pallidefulva Latreille
Formica schaufussi Mayr
Hypoponera opacior (Forel)
Monomorium minimum (Buckley)
Monomorium viride Brown
Paratrechina arenivaga (Wheeler)
Paratrechina parvula (Mayr)
Paratrechina vividula (Nylander)
Pheidole bicarinata Mayr
Pheidole dentata Mayr
Pheidole dentigula Smith
Pheidole tysoni Forel
Solenopsis molesta (Say)
Trachymyrmex septentrionalis (McCook)

Table 5.2. Total numbers of ground-dwelling ants and arthropods collected during study, June 2003 through February 2004.

Arthropod	Numbers Collected
S. invicta	9344
Other ground-dwelling ants	4649
Coleoptera	460
Aranea	169
Gastropoda (slugs)	33
Annelida	30
Diplopoda	16
Dermaptera	5
Chilopoda	3

Figure 5.1. Mean number of active *S. invicta* mounds in response to broadcast applications of hydramethylnon and fipronil. Bars with the same letter within the same sampling date are not significantly different (Tukey's HSD, $P = 0.05$).

Figure 5.2. Mean number of *S. invicta* workers collected in pitfall traps and bait stations in response to broadcast applications of hydramethylnon and fipronil. Bars with the same letter within the same sampling date are not significantly different (Tukey's HSD, $P = 0.05$).

Figure 5.3. Mean number of native species of ground-dwelling ants collected in pitfall traps and bait stations in response to broadcast applications of hydramethylnon and fipronil. Bars with the same letter within the same sampling date are not significantly different (Tukey's HSD, $P = 0.05$).

Figure 5.4. Mean number of ground-dwelling beetles collected in pitfall traps in response to broadcast applications of hydramethylnon and fipronil. Bars with the same letter within the same sampling date are not significantly different (Tukey's HSD, $P = 0.05$).

Figure 5.1

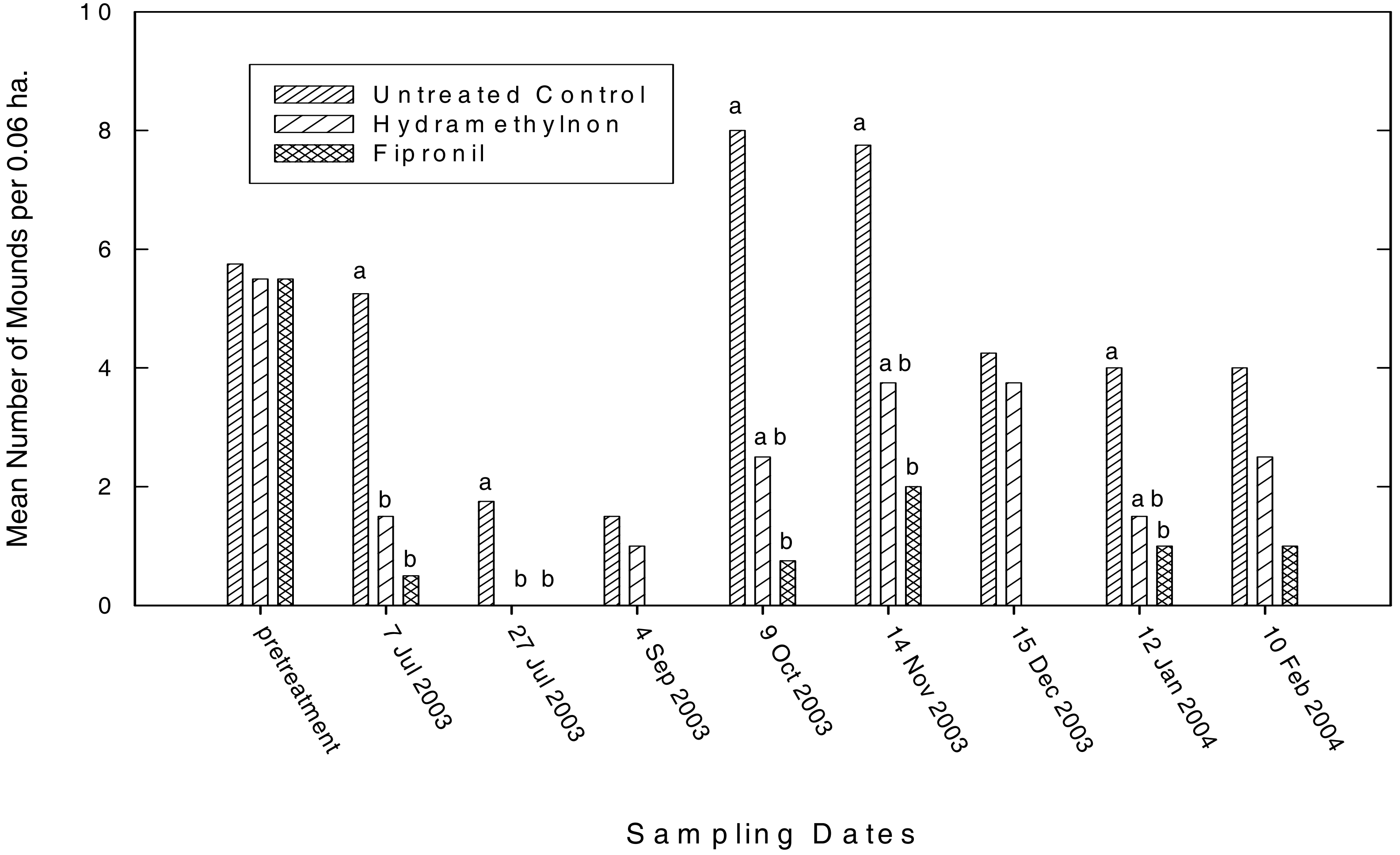

Untreated Control
Hydramethylnon
Fipronil
Mean Number of Mounds per 0.06 ha.
0
2
4
6
8
10
pretreatment
7 Jul 2003
27 Jul 2003
4 Sep 2003
9 Oct 2003
14 Nov 2003
15 Dec 2003
12 Jan 2004
10 Feb 2004
a
b
b
a
b
b
a
ab
b
a
ab
b
a
ab
b
Sampling Dates

Figure 5.2

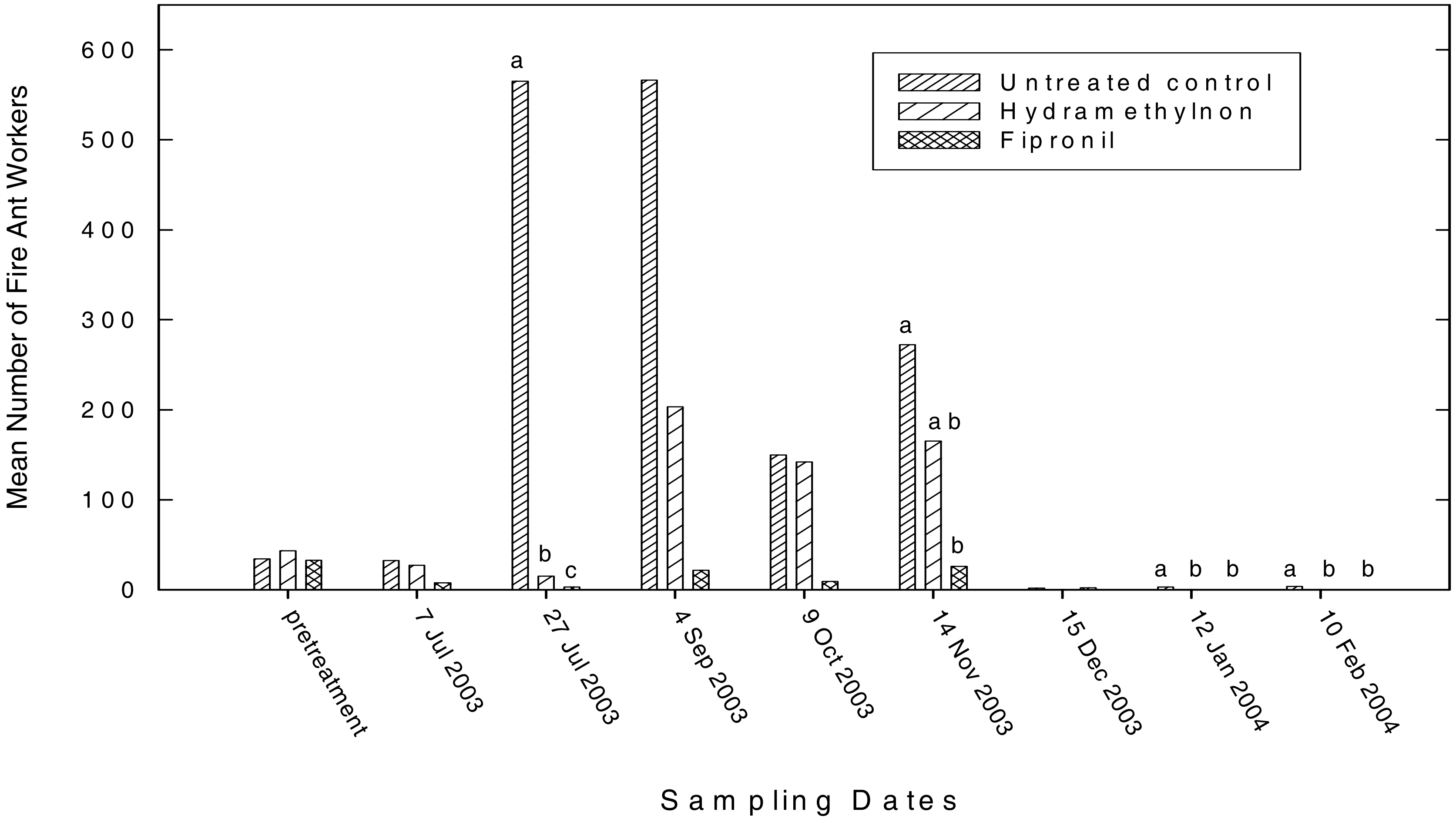

Mean Number of Fire Ant Workers
0
100
200
300
400
500
600
Untreated control
Hydramethylnon
Fipronil
a
b
c
a
ab
b
a
b
b
a
b
b
pretreatment
7 Jul 2003
27 Jul 2003
4 Sep 2003
9 Oct 2003
14 Nov 2003
15 Dec 2003
12 Jan 2004
10 Feb 2004
Sampling Dates

Figure 5.3

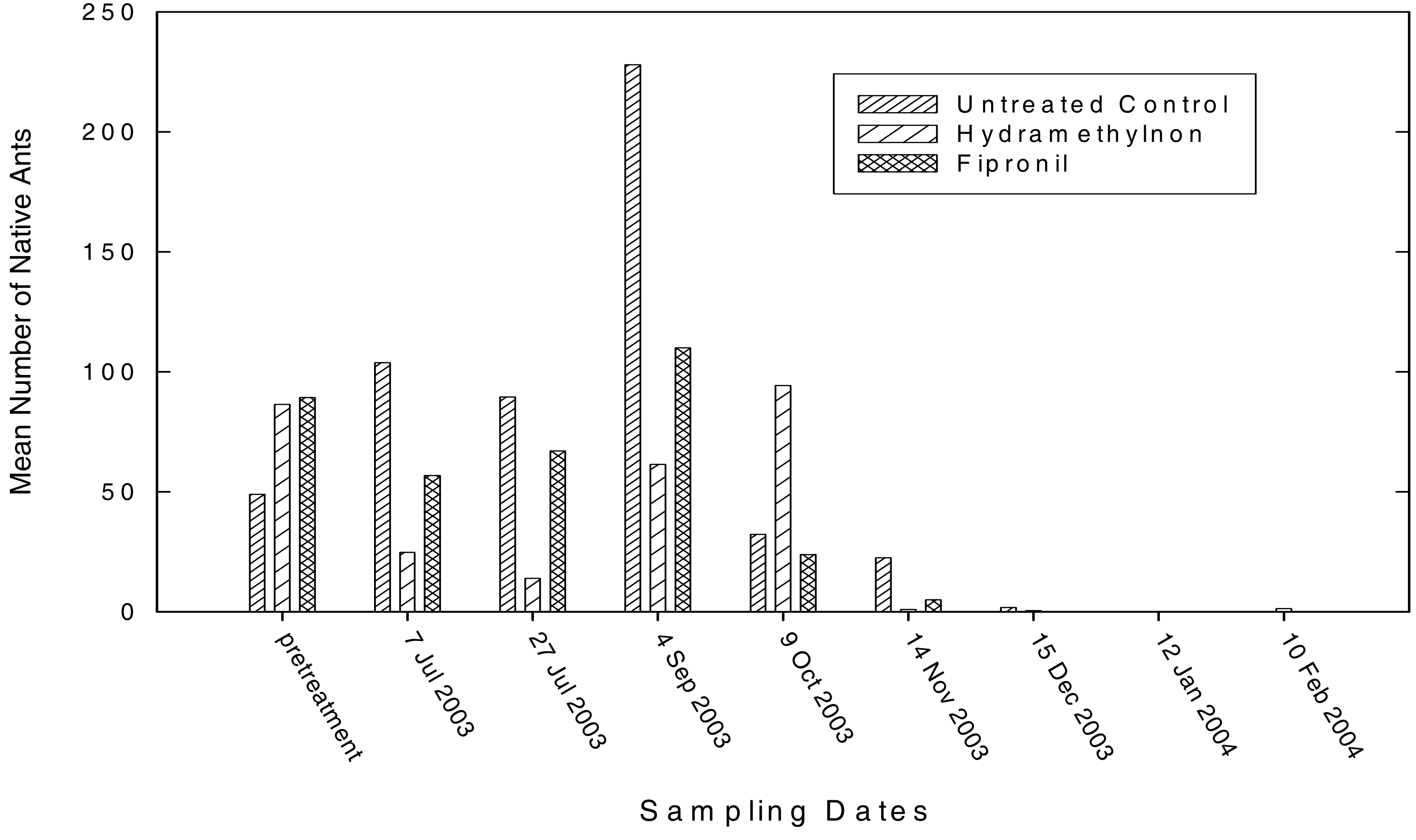
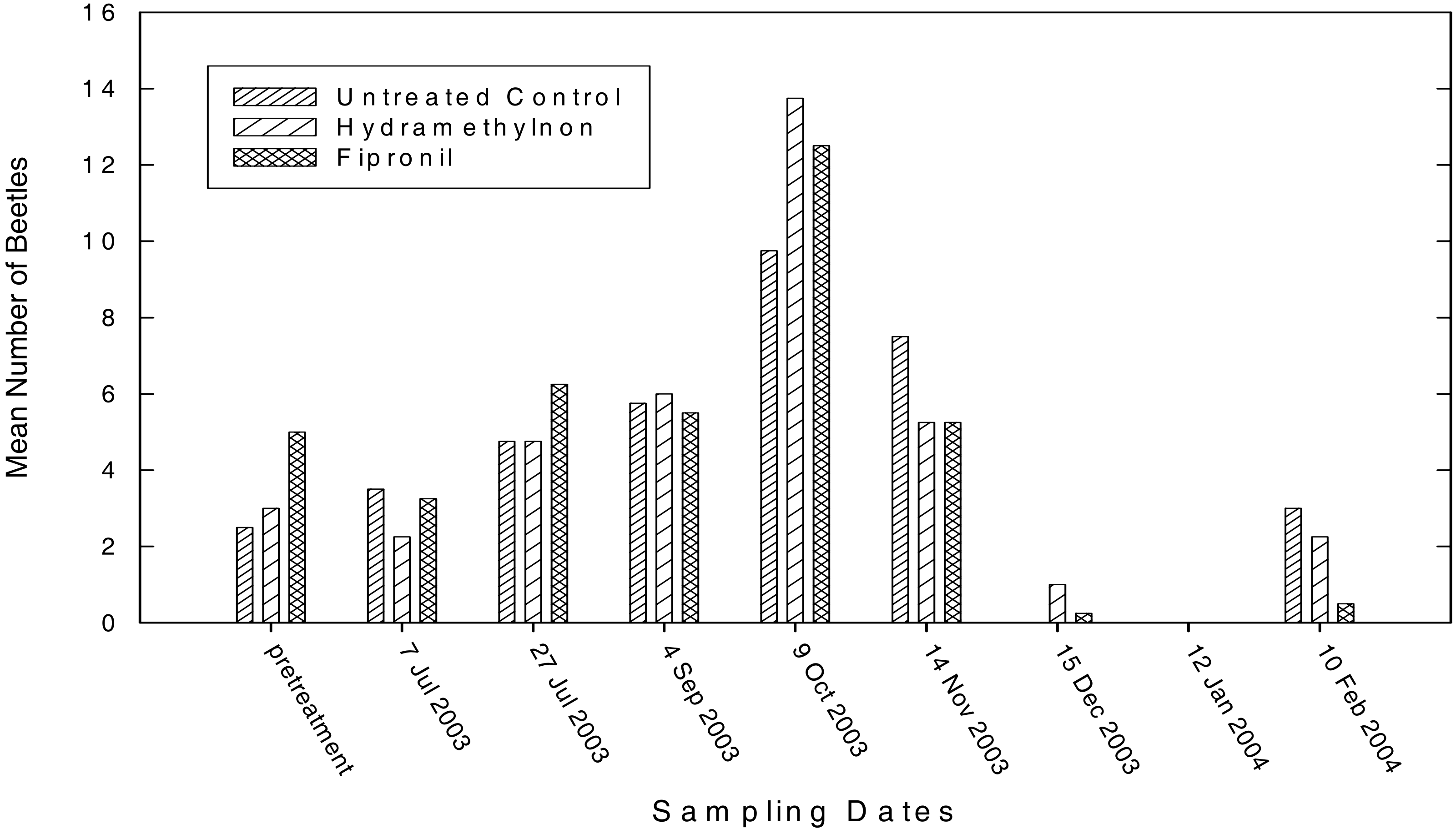

Mean Number of Native Ants
0
50
100
150
200
250
Untreated Control
Hydramethylnon
Fipronil
pretreatment
7 Jul 2003
27 Jul 2003
4 Sep 2003
9 Oct 2003
14 Nov 2003
15 Dec 2003
12 Jan 2004
10 Feb 2004
Sampling Dates

Figure 5.4


16
14
12
10
8
6
4
2
0
Mean Number of Beetles
Untreated Control
Hydramethylnon
Fipronil
pretreatment
7 Jul 2003
27 Jul 2003
4 Sep 2003
9 Oct 2003
14 Nov 2003
15 Dec 2003
12 Jan 2004
10 Feb 2004
Sampling Dates

CONCLUSIONS

The research within provides a basis for various ecological studies, assessments, and a foundation for the development of biologically-based management strategies. Canopied habitats in Georgia support a diverse amount of native ant species, and these species compete with the red imported fire ant through competition for resources and predation of reproductives. Conservation of such habitats will ensure the support of native ant species and continued suppression of *S. invicta*. Furthermore, conservation coupled with the biological knowledge and identity of native species will provide the ability for chemical methods to be tailored to minimize impact on native ant species while providing efficacious control of target pest ant species.

APPENDIX

TAXONOMIC KEY AND IDENTIFICATION GUIDE TO GROUND-DWELLING ANTS (HYMENOPTERA: FORMICIDAE) IN GEORGIA

(Adapted from various keys with additional comments)

Museum records, collection data, and scientific literature (Wheeler 1913, Ipser et al. 2004) list 144 taxa of ground-dwelling ants in Georgia. Taxonomic keys for these 144 taxa are distributed among 22 sources. The following key and identification guide is adapted from among these sources and assimilates taxonomic characteristics for these species into one key. This key and guide are offered as a resource for scientists, practitioners, agents, professionals, landowners, homeowners, and others in aiding in identification of ground-dwelling ants in Georgia.

Key to Subfamilies Based on External Morphology

1. Gastral spiracles 3-5 exposed, not overlapped nor concealed by the tergites of the preceding segments; or gaster with a distinct constriction between the first and second segments.....**Ponerinae** (P. 164)

\- Gaster without such constriction or configuration. **2**

2. Abdominal pedicel consisting of two segments. **3**

\- Abdominal pedicel consisting of one segment. **5**

3. Frontal carinae narrow and not extended laterally so that the antennal insertions are fully exposed with the head viewed from above. **4**

\- Frontal carinae expanded laterally so that they partially or wholly cover the antennal insertions when the head is viewed from above.....**Myrmicinae** (P. 154)

4. Eyes very large, suboval or reniform and consisting of several hundred fine ommatidia.....**Pseudomyrmecinae** ***Pseudomyrmex ejectus*** **(Smith)**

\- Eyes vestigial or absent; if present, consisting of a single ocellus-like structure.....**Ecitoninae***

5. Cloacal orifice distinctly circular and usually surrounded by a fringe of hairs. Stinger absent, replaced by an acid-projecting system of which the acidopore is the orifice.....**Formicinae** (p. 149)

\- Cloacal orifice slit like; the hairs, when present, not forming an encircling fringe. Stinger absent and not visible without dissection.....**Dolichoderinae** (p. 148)

* **Ecitoninae** was not collected from Georgia and is not included in this key/guide.

Subfamily DOLICHODERINAE

1. Petiole in profile usually a simple, transversely flattened strip, can be swollen anterodorsally, but never a standing scale or node. In dorsal view only 4 gastral tergites visible, with fifth tergite reflexed below the fourth. A common urban pest, producing a acrid odor when crushed.....***Tapinoma sessile*** **(Say)**

\- Petiole in profile surmounted by a conspicuous node or scale…..2

2. With propodeum in profile the angle between dorsum and declivity extended into a single raised tooth or spine. A conspicuous spiny projection on the mesosoma. Golden or medium dark brown in color. Fast moving ants.....3…***Dorymyrmex***

\- Without such configuration, mesosoma rounded or angulate, but never raised into a spine…..4

3. Color usually predominantly yellow or golden yellow. Common species in open fields and disturbed habitats. Very light pubescence. Promesonotal profile convex.....***Dorymyrmex bureni*** **Trager.**

\- Color uniform brown to black. Pubescence dense. Can be found with *D. bureni* colonies. Not necessarily associated with disturbed habitats.....***Dorymyrmex insanus*** **(Buckley)**

4. Mandibles with distinct teeth. Battleship grey or slightly reddish in color. Found mostly in open fields, but can be present in canopied habitats.....5…***Forelius***

\- Mandibles with many denticles in between teeth. Light grey in color. Exotic ant that is a major urban pest.....***Linepithema humile*** **(Mayr)**

5. Color battleship grey. No hairs on scapes and hind tibia.....***Forelius pruinosus*** **(Roger).**

\- Color varies; can have a bit of red or yellow; standing hairs on hind tibia, and usually hairs on scapes.....***Forelius analis*** **(Andre)**

Subfamily FORMICINAE

1. Antenna with 12 segments.....3

2. Antenna with 9 segments, light colored species; hairs on alitrunk..... ***Brachymyrmex depilis* Emery**

\- Black species; hairs on alitrunk..... ***Brachymyrmex musculus* Forel**

3. Antennal sockets situated close to posterior margin of clypeus, surface of metapleuron interrupted by a gap for the metaplural gland.....4

\- Antennal sockets situated well behind the posterior margin of the clypeus, metapluron uninterrupted, genus includes species which are structural pests.....***Camponotus*** (p.151)

4. With gaster in ventral view, first sternite with a conspicuous traverse sulcus behind the helcium, propodeal spiracle elliptical to broadly oval.....5

\- With gaster in ventral view the first sternite without a traverse sulcus behind the helcium, propodeal spiracle subcircular.....6

5. Mandible sickle-shape, an obligate slave raiding species.....***Polyergus lucidus* Mayr**

\- Mandible with 7 or more sharp teeth of varying size.....***Formica*** (p. 152)

6. Maxillary palps very short and consisting of 3 segments, yellowish in color and a slave raiding species .....***Acanthomyops interjectus* (Mayr)**

\- Maxillary palps longer and consisting of six segments.....7

7. Dorsal surfaces of head and body with coarse thick setae that are aligned in pairs.....***Paratrechina*** (p. 153)

\- Pilosity abundant or absent, no coarse thick setae aligned in pairs.....8

8. Mandible with six teeth, vary rarely with seven, alitrunk with an hour-glass shape, scapes long and at least half their length extends beyond the occipital margin, a cold weather species.....***Prenolepis imparis* (Say)**

\- Mandible with at least 7 teeth, usually with more than 7. Antennal scapes much shorter, alitrunk without hour-glass shape.....9…..***Lasius***

9. No standing hairs on middle and hind tibia, and few on scapes**;** pubescence dense.....***Lasius alienus*** **(Foerster)**

\- Scapes and tibia with standing hairs.....***Lasius neoniger*** **Emery**

Subfamily Formicinae

Genus CAMPONOTUS

1. Scapes with numerous fine and short hairs; reddish in color; common structural house pest..….***Camponotus floridanus*** **(Buckley)**

\- Scapes with few erect hairs or absent of hairs.....2

2. Small species, maximum body length 8-mm.....3

\- Larger sized species, body length rarely less than 8-mm in length.....4

3. Clypeus longer than broad; variable is color from purple to reddish; stripped gaster; erect hairs on cheeks.....***Camponotus subbarbatus*** **Emery**

\- Clypeus broader than long; no cheek hairs....***Camponotus nearcticus*** **Emery**

4. Head of major slightly longer than broad.....5

\- Head conspicuously longer than broad; in Georgia, body yellowish with a yellow/orange head.....***Camponotus castaneus*** **(Latreille)**

5. Black; dimorphic (two sizes of workers).....***Camponotus pennsylvanicus*** **(De Geer)**

\- In Georgia, body yellow with a black head..….***Camponotus americanus*** **Mayr**

Subfamily Formicinae

Genus FORMICA

1. Golden.....2

- Black, red, or a combination of colors.....3

2. Only 2-3 erect hairs on mesosoma.....***Formica pallidefulva*** **Latreille**

- Many erect hairs on mesosoma.....***Formica schaufussi*** **Mayr**

3. Uniformly black.....4

- Not uniformly black.....5

4. Very dark with erect hairs on mesosoma.....***Formica archboldi*** **Smith**

- Black; no erect hairs on the pronotum; large in size, alitrunk length 1.80-2.95 mm.....***Formica subsericea*** **Say**

5. Reddish bodies with black heads; slave raiding species.....***Formica rubicunda*** **Emery**

- Head and alitrunk reddish.....6

6. Gaster black; can build huge mounds (allegheny mound ants).....***Formica exsectoides*** **Forel**

- First gastral segment reddish/blackish; dense pubescence on gaster with terminal segments containing many erect hairs; slave raiding species.....***Formica subintegra*** **Wheeler**

Subfamily Formicinae

Genus PARATRECHINA

1. Dark colored species; antennal scapes without erect hairs.....***Paratrechina parvula*** **(Mayr)**

\- Light colored species; Scapes with at least a few erect hairs.....2

2. Yellowish in color; scapes with 5-17 macrochaetae; thoracic polisity darker than body color; tends to nest in sandy soils.....***Paratrechina arenivaga*** **Wheeler**

\- Uniformly dark brown; nests in more mesic microhabitats such as under logs, moss, and leaf litter; at times will inhabit grassy open fields.....3

3. No hairs on head in full face view; hairs are scattered and head shinny; found usually in open grassy habitats .....***Paratrechina vivdula*** **(Nylander)**

\- Pilosity on upper surface of head dense; found mainly in canopied habitats; usually middle and rear coxa are lighter than front coxa.....***Paratrechina faisonensis*** **(Forel)**

Subfamily MYRMICINAE

1. Postpetiole articulated on dorsal surface of the first gastral segment; gaster in dorsal view heart-shaped.....2.

\- Postpetiole articulated on anterior face of first gastral segment; gaster not heart-shaped.....5

2. Very small (2-3 mm).....***Crematogaster minutissima* Mayr**

Larger (>3 mm).....3

3. Pleurae of pronotum mostly unsculptured with a large shining surface; propodeal spines very short and distinctly incurved.....***Crematogaster ashmeadi* Mayr**

\- Pleurae of pronotum sculptured giving a roughened opaque surface.....4

4. A band of erect hairs occurs transversely across the pronotum and other erect hairs scattered randomly on mesonotum; gaster with oppressed pubescence .....***Crematogaster lineolata* (Say)**

\- Erect hairs confined to the humeral angles of the pronotum; thoracic dorsum with longitudinal, short striations or ridges; gaster with heavy pubescence and with standing hairs.....***Crematogaster cerasi* (Fitch)**

5. Apical and preapical antennal segments forming a conspicuous club of two segments.....6

\- Antenna never terminating into a 2-segmented club; club 3 segments or club more than 3 segments.....10

6. Antenna with 6 segments.....9

\- Antenna with 9-11 segments.....7….***Solenopsis***

7. Body yellow or deep castaneous brown; monomorphic and very small.....Subgenus **Diplorhoptrum** (*molesta* complex), includes ***S. molesta* (Say)**, ***S. carolinensis* Forel**, ***S. pergandei* Forel**, ***S. texana* Emery**, and ***S. truncorum* Forel**

\- Species red and polymorphic.....8

8. Teeth absent in major worker, and minor worker teeth somewhat un-defined.....***geminata* (F.)**

\- Major and minor with distinct teeth; exotic species with notorious sting.....***invicta* Buren**

9. Mandible elongate and linear, produced into a narrow projecting blade; apex of each mandible with a fork of 2 spiniform teeth arranged one above the other; mandible never triangular, subtriangular, serially dentate, or denticulate.....***Strumigenys louisianae*** **Roger**

\- Mandible triangular or sub-triangular, not produced into a narrow projecting blade, and without an apical fork of spiniform teeth.....***Pyramica*** (p. 162)

10. Antenna with 11 segments.....11

\- Antenna with 12 segments.....13

11. Promesonotal dorsum with numerous prominences, tubercles, teeth, or spines......12

\- Promesonotal dorsum smooth to coarsely sculptured, but not with prominences, tubercles, teeth, or spines.....***Leptothorax*** (in part) (p.158)

12. Promesonotum with blunt tubercles; mandible with 5-7 teeth; frontal lobes extensively expanded laterally, in full-face view overhanging and concealing the sides of the head in front of the eyes and mandibular insertions, and anteriorly reaching and overlapping the anterior margins of the lateral portions of the clypeus.....***Cyphomyrmex rimosus*** **(Spinola)**

\- Promesonotum with sharp spines; mandible usually with more than 7 teeth; frontal lobes not reaching and overlapping the anterior margins of the lateral portions of the clypeus.....***Trachymyrmex septentrionalis*** **(McCook)**

13. Palp formula 6,4; mandible with 6-10 teeth; Propodeum bidentate to bispinose.....***Myrmica*** (p. 159)

\- Palp formula less than 6,4 (up to 5,3 maximum).....14

14. In profile petiole short and subcylindrical, lacking an anterior peduncle and a large ventral process.....***Myrmecina americana*** **Emery**

\- Petiole pedunculate, but if not, then containing a large ventral process, or the propodeum unarmed, or both.....15

15. Psammophore (beard) strongly developed; metatibial spurs finely pectinate; present in xeric habitats; seed harvester; polymorphic.....***Pogonomyrmex badius*** **(Latreille)**

\- Psammophore absent; metatibial spurs simple to absent; present in canopied and un-canopied grassy habitats.....16

16. Propodeum unarmed, without spines or teeth; 3 segmented club; black species....17….***Monomorium***

- Propodeum armed with spines or teeth.....18

17. Mesoplura are smooth.....***Monomorium minimum*** **(Buckley)**

- Mesoplura contains punctations; nests in pure sandy soils; queens have bluish green reflections.....***Monomorium viride*** **(Brown)**

18. Antennal club 4 segments.....***Stenamma*** (p. 163)

- Antennal club 3 segments.....19

19. Dorsal surface of the propodeum depressed far below the level of the promesonotum; With alitrunk in profile, the pronotum or pronotum plus anterior metanotum forming a dome like arc.....20

- With alitrunk in profile, the dorsal outline simple, more or less flat or slightly convex without breaks in the outline, or at most with a metanotal groove present.....***Leptothorax*** (in part) (p. 158)

20. Species dimorphic, consisting of a minor and a major worker caste. Major worker contains an enlarged head and mandibles.....***Pheidole*** (p.160)

- Monomorphic species; antenna extremely elbowed.....***Aphaenogaster*** (p.157)

Subfamily Myrmicinae

Genus APHAENOGASTER

1. Antennal scape with a conspicuous lobe that extends rearward along the basal fourth of the scape.....***Aphaenogaster ashmeadi*** **(Emery)**

- Antennal scape without a lobe.....2

2. Outer face of the frontal lobe bearing a flange which projects rearward in a form of a tooth.....***Aphaenogaster lamellidens*** **Mayr**

- Outer face of the frontal lobe without a toothed flange.....3

3. Postpetiole broader than long and suboval in shape; propodeal spines longer than the basal face of the propodeum.....***Aphaenogaster tennesseensis*** **(Mayr)**

- Postpetiole as long as broad or longer; propodeal spines when present shorter than the basal face of the propodeum.....4

4. Anterior edge of the mesonotum rising abruptly above the adjacent portion of the pronotum forming a transverse welt which is distinctly concave; propodeal spines semi-long and directed upward; dark; head heavily sculptured and sculpture even throughout the entire head.....***Aphaenogaster fulva*** **Roger**

- Transverse welt absent; propodeal spines directed more backwards; color varies and can contain a hint of red; head not always continuously heavily sculptured.....5

5. Eyes with 13-15 facets in greatest diameter and somewhat enlarged; spines curved inward when viewed from above; conspicuous hairy pubescence; found in swamps..... ***Aphaenogaster miamiana*** **Wheeler**

- Eyes with 10-11 facets in greatest diameter; epinotal spines divergent when viewed from above; hairy pubescence not as conspicuous; head can vary in size and shape, being 1/3 longer than broad to 1/6 longer than broad; very common.....***Aphaenogaster picea/rudis/texana*** complex

Subfamily Myrmicinae

Genus LEPTOTHORAX

1. Antenna 12 segmented.....***Leptothorax pergandei*** **Emery**

\- Antenna 11 segmented.....2

2. Propodeal spines short and dentiform, their length less than ½ the distance that separates them; hard yellow to golden color.....***Leptothorax schaumii*** **Roger**

\- Propodeal spines longer than ½ the distance that separates them.....3

3. Propodeal spines curved inwardly, long and closely spaced; yellow; head completely and coarsely punctate.....***Leptothorax curvispinosus*** **Mayr**

\- Reddish; propodeal spines stout.....***Leptothorax smithi*** **Baroni Urbani**

Subfamily Myrmicinae

Genus MYRMICA

1. Frontal lobes narrow, scarcely projecting above the antennal fossae; antennae exposed when viewed from above.....***Myrmica spatulata*** **Smith**

- Frontal lobes strongly projecting out over the antennal bases; antennae not exposed when viewed from above.....2

2. Antennal scape gradually bent at the base; lamina of scape never prolonged into the upper surface of the scape.....3

- Scape with a sudden sharp bend at the base; lamina will extend into upper surface of scape.....4

3. Dark colored species; frontal lobes sub-flat; punctured on gaster.....***Myrmica punctiventris*** **Roger**

- Species light in color with a yellowish/golden tinge; frontal lobes flat and conspicuously extend further as to make the appearance that they are larger; punctures lacking on gaster.....***Myrmica pinetorum*** **Wheeler**

4. Ventral surface of the postpetiole viewed in profile flat and not forming a projection in front; light brown.....***Myrmica americana*** **Weber**

- Ventral surface of postpetiole of different configuration. Dark brown….. ***Myrmica*** sp. as yet undescribed.*

*Collected at Amicalola Falls State Park

Subfamily Myrmicinae

Genus PHEIDOLE

1. Antennal scape of the major abruptly bent at the base so that the scape turns toward the midline of the head; basal portion of scape conspicuously flattened and as broad but usually broader than the distal portion.....***Pheidole crassicornis*** **Emery**

- Antennal scape without such configuration.....2

2. Front face of major worker conspicuously sculptured which will extend to occipital lobes, sculpture can occur on lobes themselves but usually stops abruptly before the occipital margin giving the tops of the lobes a smooth appearance, and hair on front face can obscure the sculpture.....3

- Front face of major worker not so heavily sculptured or free of sculpture and usually shinny.....4

3. Humeral angles of the pronotum of the major weakly developed and not forming lateral bosses.….***Pheidole littoralis*** **Cole**

- Humeral angles distinct; minor dark red and extremely granulose in sculpture..... ***Pheidole dentigula*** **Smith**

4. Minor and sometimes majors with distinct bluish metallic reflections.....***Pheidole metallescens*** **Emery**

- Minor worker without such color configuration.....5

5. Black.....***Pheidole adrianoi*** **Naves**

- Not black.....6

6. Propodeum lacks teeth or spines.....***Pheidole morrisii*** **Forel**

- Propodeum with teeth or spines.....7

7. Mesonotum either depressed below the adjacent portion of the pronotum so that a distinct step is formed or the depression is in the form more of a suture where a hump occurs between the pronotum and the propodeum.....***Pheidole dentata*** **Mayr**

- Mesonotum of major without a depression or a hump, and a smooth outline is produced.....8

8. Yellow to golden; sides of propodeum of minor free from sculpture.....***Pheidole tysoni*** **Forel**

\- Dark; sides of propodeum of minor densely punctated.....9

9. Basal face of the propodeum in the major covered with transverse striae; pronotal rugae coarse and prominent..... ***Pheidole bicarinata*** **Mayr**

\- Basal face of the propodeum in the major mainly punctate; pronotal rugae feeble..... ***Pheidole bicarinata*** subsp. ***vinelandica*** **Forel**

Subfamily Myrmicinae

Genus PYRAMICA

1. Clypeus in anterior view with a series of 4-6 conspicuous stout standing long hairs that radiate from the apex like the ribs of a fan.....***Pyramica ornata*** **(Mayr)**

\- Clypeus without series of standing hairs.....2

2. With head in full-face view and mandibles closed, the masticatory margin with a distinct diastema basally; rare species occurring in northern parts of Georgia.....***Pyramica wrayi*** **(Brown)**

\- With head in full-face view and mandibles closed, the masticatory margin without a distinct diastema basally.....3

3. Basal lamella of mandible followed immediately by a row of 7 coarse conical teeth without trace of a diastema.....***Pyramica rostrata*** **(Emery)**

\- Basal lamella of mandible followed by a small diastema, shorter than length of basal tooth, which is followed by a row of 5 small acute teeth.....4

4. Mesonotum without a pair of long flagellate hairs; sculpture of pronotum and mesonotum evenly reticulate-punctate and not contrasting; pronotum without a median longitudinal carina.....***Pyramica bunki*** **(Brown)**

\- Mesonotum with a pair of long flagellate hairs; sculpture of mesonotum evenly reticulate-punctate and pronotum striolate with both contrasting; pronotum without a median longitudinal carina.....***Pyramica carolinensis*** **(Brown)**

Subfamily Myrmicinae

Genus STENAMMA

1. Large in size (2.75 – 4.00 mm in length).....2

\- Smaller in size (2.3 - 3.5 mm in length); eye with 3-6 ommatidia in greatest diameter.....3

2. Large (2.5 – 4 mm in length); eyes with 5-12 ommatidia in greatest diameter; node of petiole subconical; base of epinotum with a transverse welt.....***Stenamma brevicorne* (Mayr)**

\- Size of worker large, on average reaching 4 mm in length; eyes larger and heavily sculptured.....***Stenamma* sp.** as yet undescribed*

3. Thorax subopaque; enough punctures to always dull the surface of the thorax.....4

\- Promesonotum usually shining and the surface of the thorax not dulled with numerous dense and distinct punctures.....5

4. Size of worker conforming within 2.3 - 3.5 mm.....***Stenamma schmitti* Wheeler**

\- Size of worker not conforming within 2.3 – 3.5 mm .....***Stenamma* sp.** as yet undescribed*

5. Small (2.3 - 2.7 mm); thoracic sculpturing weak; postpetiole seldom smooth and shining; distribution statewide but more common in central and south Georgia.....***Stenamma impar* Forel**

\- Larger in size (2.7 - 3.5); thoracic sculpturing variable but seldom weak; the promesonotum usually distinctly shining; postpetiole usually strongly shining; distribution limited to northern Georgia.....***Stenamma diecki* Emery**

*Collected at Amicalola Falls State Park

Subfamily PONERINAE

1. Petiole broadly attached to the first gastral segment, the two separated dorsally and laterally only by a constriction.....***Amblyopone pallipes*** **(Haldeman)**

- Petiole narrowly attached to first gastral segment and the two joined by a slender junction.....2

2. Mandible long and linear.....***Odontomachus brunneus*** **(Patton)**

- Mandible linear to triangular.....3

3. With head in full frontal view frontal lobes absent; cryptic species which nests in logs.....4….***Proceratium***

- With head in full face view frontal lobes present.....5

4. Petiolar node in the form of a thick erect scale with anterior and posterior faces sub-parallel.....***Proceratium croceum*** **(Roger)**

- Petiolar node bun shaped, broad at base with anterior and posterior faces converging to a rounded summit.....***Proceratium pergandei*** **(Emery)**

5. Tibia with one spur.....6

- Tibia with two spurs; exotic species.....***Pachycondyla chinensis*** **(Emery)**

6. Subpetiolar process with a translucent window in the form of a circular hole.....***Ponera pennsylvanica*** **Buckley**

_ Subpetiolar process without such a window.....7….***Hypoponera***

7. Petiole when viewed in lateral profile slender, sub-triangular (narrower dorsally than ventrally); conspicuous punctures on head; nests in wetter habitats.....***Hypoponera opacior*** **(Forel)**

- Petiole when viewed in lateral profile, sub-rectangular (as wide dorsally as ventrally)..... ***Hypoponera opaciceps*** **(Mayr)**

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