BIOLOGY, ECOLOGY, BEHAVIOR, PARASITOIDS AND RESPONSE TO PRESCRIBED FIRE OF CAVITY NESTING HYMENOPTERA IN NORTH CENTRAL FLORIDA

By

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This study examined the biology, ecology, behavior, parasitoids and response to fire of an understudied group of insects, the cavity nesting Hymenoptera. Five state parks in north central Florida were surveyed for two years with trap nests yielding over 3,000 captured nests. Trap-nesting Hymenoptera represent important guilds, such as predators and pollinators, within these surveyed habitats and are an integral part of maintaining desired biodiversity of both flora and fauna. Over the two year period, biology, ecology, and prey of a potter wasp, *Monobia quadridens*, a mud-dauber wasp, *Trypoxylon lactitarse,* and two grass carrying wasps, *Isodontia auripes* and *Isodontia mexicana*, were examined in depth. In addition, more than 100 species of trap-nesting Hymenoptera and associated arthropods were examined yielding data on distribution, host ranges, biology and ecology. Also, a detailed inventory of identified trap-nesting hymenoptera and associated arthropods is provided to expand park faunal records.

In addition to examining biology and ecology of this group, this study examines the effect prescribed fire has on these insects. Prescribed fire is a commonly used practice in managed parks and natural areas to restore and maintain native and protected habitat and these insects, as pollinators and predators of plant feeders, may play an important role in the succession of desirable, native habitat after the fire event. Prescribed fire was used by the park managers in such a manner that allowed for comparison of equally sized areas of identical habitat. Overall, the community of trap-nesting Hymenoptera was affected by the scale of prescribed fire used by the park service in terms of overall diversity and abundance of key species. The diversity and richness of cavity nesting Hymenoptera may be used as an indicator of when to use prescribed fire to maintain native ecosystems and foster a healthy biodiversity.

CHAPTER 1
INTRODUCTION AND LITERATURE REVIEW

Introduction

During the late 1960s and 1970s, the United States began to confront the costs of unrestricted patterns of settlement and land use on the environment (Porter and Marsh 2005). Wetlands, water and air quality, and threatened species were all protected by new laws, with many states passing laws and regulations to further address these concerns. Conservation and restoration of natural areas are now common requirements of land and community development mandated by local, state, and federal agencies.

As human population and development increase and the relative amount of these natural areas decreases, the quality and health of these natural areas are becoming of more importance. Agricultural practices, resource gathering, waterway diversions, fragmentation of natural habitat and alteration of patterns of natural vegetation are increasing with human population expansion and affecting even previously protected and isolated natural areas (Collinge 1996, Dale *et al.* 1998, Kramer 2005). Degrading habitat health, measured by biodiversity, is a major concern for natural resource managers and governmental agencies. Currently, the primary driver for the loss in biodiversity is habitat modification and destruction due to changes in land-use practices (Kramer 2005). As human populations expand and the wildland-urban interface increases, more natural and protected areas are increasingly affected by these changes in land use. In addition, resource managers use many land management techniques, such as prescribed fire and mechanical removal of vegetation, directly in natural and protected areas in order to protect human interests. These direct impacts to the natural and protected areas should be monitored to assure minimal negative impact to biodiversity.

As more natural and protected areas are subjected to these changing forces, land managers must be able to quantify changes in order to identify areas at risk. There are many tools in the environmental and ecological sciences for quantifying changes and differences in biodiversity, yet an initial inventory or measurement is needed for future assessments.

Species Richness And Diversity: Estimating Their Values

Diversity has been a persistent theme in ecology and is frequently seen as an indicator of ecological health (Magurran 1988). Although often incorrectly used interchangeably, species richness and diversity are distinct entities that relay sometimes quite different information.

Species richness, the number of species in an area, is a simple yet informative measurement of a community. Intuitively, this simple measurement is ideal for comparing communities in conservation and management of biodiversity, assessing anthropogenic effects on protected lands and influencing public policy. Yet, this measure is not simple to accurately attain. Complete species inventories usually require huge amounts of resources and expertise and are impractical and quite often impossible to compile. Almost every taxonomic survey will undoubtedly have undiscovered species. This trend is especially true with hyper-diverse taxonomic groups such as arthropods, nematodes, bacteria, and fungi. These groups are impossible to completely survey. Many groups of interest that are especially sensitive to anthropogenic disturbance are these hyper-diverse taxonomic groups. In these cases, the best option for measuring richness is through sampling of target environments or particular regions of interest, such as a habitat slated for conservation or development.

Three broad categories of estimators exist to estimate the number of species in a community: estimators that fit a lognormal abundance distribution and estimate the hidden or unsampled portion of the curve, estimators that fit asymptotic equations to species accumulation curves, and non-parametric estimators that use relative abundance of rare species to estimate the number of unseen species. In recent years, there has been a heightened interest in biodiversity that has resulted in new measurement techniques including niche apportionment models, new techniques for measuring taxonomic diversity, and improved methods of species richness estimation (Heltshe and Forrester 1983, Chao 1984, Hughes 1986, Chao 1987, Magurran 1988, Chao and Lee 1992, Colwell and Coddington 1994, Longino *et al.* 2002, Colwell *et al* 2004, Magurran 2004, Chao *et al.* 2005). Fortunately, long difficult mathematical calculations are usually no longer needed to estimate species richness through the many computer software packages readily available such as EstimateS (Colwell, 2005), Distance (Thomas *et al.* 2005), WS2m (Turner *et al.* 2003) and COMDYN (Hines *et al.* 1999), among others. Magurran (2004) provides more examples of such programs and discusses their use, theory and sources of acquisition.

These estimators of species richness are useful for letting researchers know when they have sampled sufficiently to have confidently surveyed the majority of species present. Such information is crucial since funds, time, and the taxonomic experts needed for reliable identification are usually in short supply (Hopkins and Freckleton 2002).

Species richness is an informative measure but can, on its own, be misleading. Species richness is simply the number of species within a geographic area, but how desirable these species are is another matter. Quite often such information is used in conservation, preservation, restoration efforts and public policy. However, degraded areas not desirable for conservation may have a relatively high value of species richness (when compared to its desirable counterpart) due to exotic, feral and transient species. Disturbed habitats may serve as sinks drawing in species from surrounding habitats. During my undergraduate research (unpublished data) in Everglades National Park we saw more species of flower-visiting insects on the mowed roadsides (a disturbed habitat) than in the neighboring marl prairie. Utilizing solely species richness, we could suggest that building more roads in the marl prairie would increase pollinator species richness of the park. Of course such a conclusion and suggestion is ludicrous. Consequently, a detailed understanding of ecological relationships of the species sampled is essential when applying such studies to land-use practices and policies (McCraken and Bignal 1998).

Much more ecological insight can be attained though measurement of diversity than solely through species richness estimation. Diversity is a measure of species richness and the abundance distribution of these species, and therefore can detect effects unseen by species richness alone. Disturbance effects may cause changes in diversity through shifts in the abundance of species or increases in the dominance of some species. Magurran (1988) details the theory and calculation of various diversity measures including the Shannon (1949) and Simpson (1949) indices of diversity. Such indices are easily calculated by traditional means, but many software packages can quickly calculate these values, including updated versions of the indices that take abundance data into account. Computer software such as EstimateS (Colwell 2005) is available and can easily calculate richness and diversity values with a variety of estimators.

Overview of Trap-nesting Hymenoptera

Aculeate Hymenoptera are an integral part of most terrestrial ecosystems (Jenkins and Matthews 2004), including natural and disturbed habitats of north central Florida. These Hymenopterans fill many important roles, most commonly as pollinators, predators, and parasitoids. Changes in their populations would have a cascading effect, altering the habitat's flora and fauna (Raw 1988, LaSalle and Gauld 1993, Neff and Simpson 1993, Jenkins and Matthews 2004). The majority of these Hymenopteran species are solitary in behavior.

The nests of solitary bees and wasps are usually difficult to find and examine (Krombein 1967, Jayasingh and Freeman 1980, Alves-dos-Santos 2003). Many nest in pre-existing cavities in various substrates such as wood, clay, rock and man-made structures (Bequaert 1940, Krombein and Evans 1954, Krombein 1967, 1970, Bohart and Menke 1976, Coville and Coville 1980, Coville 1982). This practice makes their nests not only difficult to find, but also extremely difficult to successfully extract and examine. The majority of these insects readily accept trap-nests (drilled wooden blocks) since they normally nest in preexisting cavities created by other creatures. In addition, many of these insects frequently reuse cavities for nesting, allowing for long term observations on biology and ecology. Many successful studies of solitary bees and wasps have used trap-nests to examine various aspects of their biology and ecology. Trap-nests have been used to examine species composition and diversity at particular sites (Parker and Bohart 1966, 1968, Krombein 1967, 1970 and Camillo *et al.* 1995), population dynamics of occupants

(Jayasingh and Freeman 1980), evaluation of habitat health and effects of habitat fragmentation (Frankie *et al.* 1998 and Tscharntke *et al.* 1998), genetic study (Packer *et al.* 1995) and survey of exotic species (Mangum and Sumner 2003). Trap-nests are extremely useful when the study focuses on gathering biological data of occupant species. Various studies have examined nesting behavior and architecture (Medler 1967, Krombein 1967, 1970, Camillo *et al.* 1993, Pereira *et al.* 1999 and Alves-dos-Santos 2003), prey captured (Krombein 1967, 1970, and Camillo and Brescovit 1999, 2000), and associated parasitoids (Krombein 1967, 1970, Wcislo *et al.* 1996 and Scott *et al.* 2000). Trap-nests are a powerful survey tool that allows collection of data on abundance, prey, habitat, phenology, and nest architecture that are not detectable through other survey methods that target Hymenoptera (Gathmann *et al.* 1994, Steffan-Dewenter 2002, Miyano and Yamaguchi 2001, Jenkins and Matthews 2004).

Effect Of Fire on Trap-Nesting Hymenoptera

Fire is an integral part of forest and grassland ecosystems throughout the United States. Native Americans used fire for many purposes, such as a tool to clear areas for agriculture. Fire in natural areas, however, poses many hazards especially when in close proximity to urban areas. In response to this threatening hazard policies of complete fire suppression became popular in the 1920s and 1930s (Long *et al.* 2005). One result of the absence of periodic fires was a buildup of woody understory and excessive fuels. This caused subsequent fires to become more intense, damaging and unmanageable. Forest management with prescribed burning is the current popular tool. Prescribed fire has been shown to be effective in reducing hazardous fuels, disposing of logging debris, preparing sites for seeding or planting, improving wildlife habitat, managing competing vegetation, managing invasive weeds, controlling insects and diseases, improving forage for grazing, enhancing appearance, improving access and in perpetuating fire-dependent species (Cumming 1964, Helms 1979, Wade *et al.* 1988, Biswell 1999, DellaSala and Frost 2001, Fuller 1991, Mutch 1994, Paynter and Flanagan 2004 and Long *et al.* 2005). Many studies have been conducted to examine the effect of fire on plant (Main 2002, Vazquez *et al.* 2002, Laterra 2003, Lloret 2003, Reinhart 2004, Schoennagel 2004, Barton 2005, Overbeck e*t al* 2005, Ansley *et al.* 2006) and animal communities (Chew *et al.* 1959, Kahn 1960, Lawrence 1966, Simons 1989, Mushinsky 1992, Saab and Vierling 2001, Cunningham *et al.* 2002, Meehan and George 2003) with some examining arthropods. Fire not only causes direct mortality in arthropods (Fay and Samenson 1993, Bolton and Peck 1946, Miller 1978, Evans 1984) but also indirectly affects arthropod communities via changes in plant community composition and habitat alteration (Lawton 1983, Evans 1984). Unfortunately, most invertebrate studies have focused on terrestrial arthropods monitored via sweeping or pitfall traps (Bess 2002, Brand 2002, Niwa 2002, Clayton 2002, Fay 2003, and Koponen 2005) and have overlooked trap-nesting Hymenoptera and other aerial insects.

Hymenopterans Sampled and Summary

This study provides a record and survey of trap-nesting Hymenoptera in five Florida state parks to further enhance the understanding of these habitats. It also provides a bench mark for future assessments of the insect fauna in these habitats.

The following chapters provide a detailed inventory and biological notes on many trap-nesting Hymenopterans and associated arthropods. These findings may be used in assessing habitat quality and perhaps aid in identifying any changes in biodiversity over time for the five state parks studied.

Observations of biology and natural history are important to document, especially at the extremes of geographical range and in unique areas for a species that is cosmopolitan in range, such as *Isodontia*. In particular *I. mexicana* has become established in Hawaii and France (Bohart and Menke 1976) providing unique habitats in comparison to its native North America. This case provides observations of *I. mexicana* in the southeast extreme of the geographical range. O'Neil and O'Neil (2003) recently studied a population of *I. mexicana* in Montana and should provide a nice comparison to this Florida population. Debates of species and subspecies versus clines and ecotypes commonly arise and it is important that we identify possible subjects to further examine the mechanisms of speciation and hybrid zones. For example, the splitting of *Anisota senatoria* into *A. senatoria* and *A. peigleri* by Riotte (1975) has been questioned by Tuskes *et al.* (1996) and throughout many taxa, taxonomists that are "lumpers" or "splitters" are constantly at odds.

In addition, such information is valuable to help identify possible projects for evolutionary biologists and studies in biogeography. For example, Mark Deyrup and Thomas Eisner (2003) examined the differences of coloration between Florida Hymenoptera and their northern relatives (subspecies, clinal types, etc.) utilizing museum specimens and natural history data from past studies. Their preliminary observations called for further exploration of Florida biogeography to help recognize distinctive species and examine mimetic complexes. *Isodontia mexicana* is a cosmopolitan species that is easily captured, studied and occurs sympatrically with *I. auripes* at this site. Therefore chapter 2 examines ecology and natural history of a cosmopolitan species of a trap-nesting Hymenopteran, *Isodontia mexicana* (Hymenoptera: Sphecidae), and a sister species, *I. auripes,* in these Florida study sites. These observations give a basis for geographical comparison for this wide-ranging species. Observations and findings for *I. mexicana* populations have been recently published by O'Neill (2001), O'Neill and O'Neill (2003), and historically by Bohart and Menke (1963), Lin (1966), Krombein (1967), Bohart and Menke (1976). These studies took place in distant parts of the geographical range, as compared to the Florida population observed, and may offer insight and inspiration for additional study. Such studies, for example, Sears *et al.* (2001), may examine behavioral, biological and natural history differences of a species in two extremes of its range. Such information may also be useful for examining aspects of biogeography and evolutionary history (Deyrup and Eisner 2003). For chapter 2 there are two main objectives: 1) Examine similar features and aspects of natural history of Florida population that was examined in Montana populations and infer whether these features warrant further biogeographical examination, 2) and since the two sister species (*I. mexicana* and *I. auripes*) occur sympatrically in these Florida sites, determine if they differ substantially in the examined features to inspire a closer look at possible speciation/separating mechanisms.

In Chapter 5 a second species, *Monobia quadridens* (Hymenoptera: Vespidae), is examined in the same manner. *Monobia quadridens* is also a cosmopolitan species in terms of geographical range and has been previously studied in different areas by Bequaert (1940), Krombein (1967), and Krombein *et al*. (1979). *Monobia quadridens* has not been studied in the recent literature in terms of biology and natural history. The objectives for chapter 5 are to 1) determine if this wasp has preference in cavity size for nesting, 2) determine the nest architecture, 3) determine the range of prey provisioned by this wasp in this portion of its geographic range, compareing findings to other published records, 4) and determine the emerging sex ratio of trap-nested individuals.

In Chapter 3 the spider prey captured by the most abundant trap-nesting Hymenopteran in this study, *Trypoxylon lactitarse* (Hymenoptera: Sphecidae) is examined. Previous studies (Rau 1928, Krombein and Evans 1954, Krombein 1956, 1967, Medler 1965, Lin 1969, Coville 1979, 1981, 1982, Coville and Coville 1980, Genaro *et. al.* 1989, Camillo *et. al.* 1993, Genaro and Alayon 1994, Jimenez and Tejas 1994, Camillo and Brescovit 1999, 2000) have highlighted differing prey preferences in various species of *Trypoxylon* and Rehnberg (1987) and Camillo and Breviscovit (1998) examined prey preferences for *Trypoxylon lactitarse*. This chapter, therefore, has five main objectives: 1) Determine what prey *T. lactitarse* is provisioning at these Florida sites, 2) Determine if *T. lactitarse* is a generalist or specialist in terms of prey provisioned, 3) Determine what, if any, is *T. lactitarse*'s prey preference, 4) Does *T. lactitarse*'s prey preference seem to differ between sites? 5) Determine the benefits and potential problems with using this wasp (and potentially other spider-provisioning trap-nesters) as a sampling tool for estimating spider abundance and species richness.

In Chapter 4 the impact prescribed fire has on trap-nesting Hymenoptera and associated arthropods is examined and poses the following questions: 1) Does overall diversity and species richness of trap-nesting Hymenoptera differ between burned and unburned sites? 2) In terms of species sampled, how similar are the burned and unburned sites? 3) Is the diversity of sampled functional groups (predator, parasitoid and pollen specialists) affected by fire? 4) What species, if any, seem to be negatively or positively affected by fire in terms of abundance?

There was a large amount of data collected in the process of addressing the objectives of chapters 2-5. This final chapter summarizes and reports this mass data, which are highly desirable, and required by the Florida State Department of Environmental Protection. The objectives of chapter six are 1) report the abundances and species richness of all trap-nesting Hymenoptera and associated arthropods sampled at each of the five surveyed Florida State Parks and 2) determine, by using estimators, if the inventory offered can be considered adequate and, if adequate, estimate total species richness and diversity of trap-nesting hymenopterans and associated arthropods for each state park surveyed.

CHAPTER 2

NEST ARCHITECTURE, PREY, AND SEXUAL DIMORPHISM IN THE GRASS-CARRYING WASPS *ISODONTIA* (*MURRAYELLA*) *MEXICANA* (SAUSSURE) AND *ISODONTIA AURIPES* (FERNALD) (HYMENOPTERA: SPHECIDAE: SPHECINAE)

Abstract

Isodontia (*Murrayella*) *mexicana* (Saussure) and *Isodontia* (*Murrayella*) *auripes* (Fernald) nested in trap nests at four different state parks in north central Florida. Nests consisted of fragments of native nutrush grasses (Cyperaceae: *Scleria* sp.). Females provisioned either a communal cell, or separated cells with 1 to 15 tree crickets (Gryllidae: Oecanthinae: *Oecanthus*), bush crickets (Gryllidae: Eneopterinae, *Orocharis*), meadow katydids (Tettigoniidae: Conocephalinae, *Odontoxiphidium*), coneheaded katydids (Tettigoniidae: Copiphorinae, *Belocephalus, Conocephalus* and *Neoconocephalis*), and false katydids (Tettigoniidae: Phaneroperinae, *Scudderia*). Both *Isodontia* species displayed the sexual size difference typically found in the Sphecidae with females significantly larger than males. Female-biased provisioning has been shown to occur in other populations of *I. mexicana* and seems to occur in the Florida populations as well. Although *I. auripes* exhibits this sexual size trend, the communal brood chamber of the nest architecture rules out any provisioning difference as the cause for the size difference.

Introduction

Isodontia (Hymenoptera) is one of the cavity-nesting genera of the Sphecid subfamily Sphecinae and this genus is unique in its nesting biology. While other solitary aculeate wasps that nest in pre-existing cavities use mud, agglutinated sand, plant resin or masticated plant materials as nest partitions and plugs (O'Neill and O'Neill 2003, O'Neill 2001), *Isodontia* use dry grass leaves that they cut, pack, and twist into position within the nest (Lin 1966, Krombein 1967, Bohart and Menke 1976, O'Neill and O'Neill 2003). They are commonly known as the grass-carrier wasps since they can be observed flying with bits of grass as long as 80 mm in their mandibles (Bohart and Menke 1963). Several species of *Isodontia* construct nests with a common brood chamber that contains as many as 12 larvae feeding on a common prey mass (Bohart and Menke 1976, O'Neill and O'Neill 2003). Here I report on a two-year study where female *Isodontia mexicana* and *Isodontia auripes* nested in trap-nests set up in four state parks in north central Florida. I examined 90 nests of *I. mexicana* and 89 nests of *I. auripes* out of 235 total *Isodontia* nests and recorded information on nest structure, prey, sex ratio, sexual size dimorphism, emergence schedules and parasitoids. I then determined if they exhibited sexual dimorphism typically seen in other Sphecid wasps, identified nest architecture highlighting the difference between the two species, identified prey used to provision nests and examined survival of brood including parasitoids and predators of these wasps. There are two main objectives for this study: 1) Examine similar features and aspects of natural history of Florida population that were examined in Montana populations and infer whether these features warrant further biogeographical examination, and 2) since *I. mexicana* and *I. auripes* occur sympatrically in these Florida sites, determine if they differ substantially in the examined features to inspire a closer look at possible speciation/separating mechanisms.

Methods and Materials

Tools and Trap Preparation

The traps used in this study were fabricated from seasoned 37-mm x 86-mm x 2.4m pine/spruce timbers obtained from a local home improvement store. The pine/spruce timbers were cut into 10-cm-long blocks. Two cavities of one of five diameters (3.2, 4.8, 6.4, 7.9 or 12.7-mm) were drilled into each block. Cavities were drilled to a depth of 80 mm on each short side (the 37-mm side), offset approximately 10-mm from the center point. Traps were assembled using one block of each diameter with the smallest cavity on top and the largest on the bottom. Blocks were stacked so that no cavity was situated directly above or below a cavity in the adjacent block. The five blocks were bound together with strapping tape (3M® St Paul, MN), and 16-gauge wire was used to further bind the stack and suspend the trap from trees and shrubs at the field sites. Each bundle of five blocks was considered to be a single trap.

Field Sites

I set traps at five locations: 1) Suwannee River State Park in Suwannee County (30° 23.149′ N, 083° 10.108′ W), 2) Mike Roess Gold Head Branch State Park in Clay County (29° 50.845′N, 081° 57.688′ W), 3) Devil’s Millhopper Geological State Park in Alachua County (29° 42.314′N, 082°23.6924′ W), 4) San Felasco Hammock Preserve State Park (29° 42.860′ N, 082°27.656′ W) in Alachua County and 5) Silver River State Park in Marion County (29° 12.317′N, 082° 01.128′ W). The habitats surveyed at Suwannee River State Park were burned and unburned sand hill habitat, while the habitat at Mike Roess Gold Head Branch State Park was burned sand hill pineland and ravine. Sites at San Felasco Hammock Preserve State Park consisted of upland and mesic hardwood hammock. Surveyed areas of Devil’s Millhopper Geological State Park consisted of pine flatwood habitat and sites at Silver River State Park consisted of river habitat and upland mesic forest. Descriptions of these habitats can be found in Franz and Hall (1991).

Field Placement

Transects were set up with ten traps placed approximately 10 m apart and hung approximately 1.5 m off the ground on trees or limbs with placement on dead standing wood preferred. Transects were initially established (direction and distance from center of plot) randomly. Four transects were established in Suwannee River State Park while three transects were established Mike Roess Gold Head Branch State Park. Three transects were established in San Felasco State Park but size constraints only allowed a single transect in Devil's Millhopper State Park. Finally, two transects were set up in Silver River State Park. Transects were in the field from April 2003 until January 2005.

Field Collection and Laboratory Rearing

Traps remained in the field two years and were checked monthly. Preliminary field tests revealed that one-month intervals were sufficient to avoid trap saturation (no available cavities). Traps were considered occupied when insects were observed actively nesting, harboring or had sealed a cavity with mud or plant material. Occupied traps were removed and replaced with a new trap. These occupied traps were brought into the forest entomology lab at the University of Florida in Gainesville, FL, for processing. Occupied blocks were removed for observation while unoccupied blocks were reincorporated into replacement traps. Each occupied cavity was given a unique reference number.

Location, date of collection, diameter of cavity, and various notes describing the nature of the occupants and/or plug were recorded for each reference number. Occupied cavities were then covered with a 2, 4, 6, or 8-dram glass shell vial. The shell vials were attached to the wood section with masking tape (Duck®, Henkel Consumer Adhesive Inc., Akron Ohio) appropriate for wood application. These sections were then placed in a rearing room and observed daily for emergence. The rearing room was maintained as nearly as possible at outside mean temperatures for Gainesville, Florida.

When emergence occurred, the specimens were removed, preserved and given the same reference number as the cavity from which they had emerged. Dates of emergence, identification of occupants, measurements and notes were taken for each cavity at emergence. When an insect was harboring or actively tending a nest, it was captured, identified, and given a reference number corresponding to the cavity. The contents of the nest/cavity were then extracted and recorded. After the contents were extracted, the wood block was reused in replacement traps. These processed blocks were re-drilled to the next larger diameter cavity to eliminate any alterations or markings (either physical or chemical) by the previous occupant prior to reuse.

Specimen Diagnostics and Identification

Isodontia auripes and *I. mexicana* occur sympatrically and it is important to distinguish between the two species. Appendix B (adapted from Bohart and Menke (1963)) provides characters to distinguish between the species and sexes of each species.

All cavity nesters and their prey were identified by the author with some specimens identified and/or verified by entomologists Jim Wiley[1], Lionel Stange[1], Thomas Walker[2], and John M. Leavengood Jr.[1,2] (Florida State Collection of Arthropods[1] Gainesville, FL and University of Florida[2], Gainesville, FL). Voucher specimens have been deposited at the Florida State Collection of Arthropods in Gainesville, Florida.

Statistical Analysis

Descriptive statistics (means, ranges, SD, etc.) were calculated the Microsoft Excel statistical package (Microsoft, Inc, CA). Since all sites where both *Isodontia* species occurred were similar (sand hill habitat) data were pooled for analysis. One main concern may be the difference of burned and unburned sandhill habitats. Collections for both species in unburned habitat was quite low with only 11% of total abundance for *I. mexicana* and 10% of total abundance for *I. auripes.* Chi-squared goodness of fit test was used to examine nest diameter preference for pooled habitats and burned and unburned habitats separately. The assumption was that wasps would nest equally in all diameters. Since neither species nested in 3.2-mm diameter cavities, that cavity size was omitted from analysis. Head width of adults was measured to the nearest 0.01mm using an ocular micrometer. Head capsule comparison was analyzed using, the Mann-Whitney test.

Results

Habitat

Both *Isodontia* species were captured at Suwannee River, Gold Head, and Devil's Millhopper State Parks. Only *Isodontia mexicana* was captured at San Felasco S. P., and neither *Isodontia* species was captured at Silver River S. P.

Nest Architecture

I examined 90 nests of *Isodontia mexicana* and 89 nests of *I. auripes*. An additional 56 cavities that had *Isodontia* nests were trapped but species identification of these nests was not possible due to predation or disturbance. Females of *I. mexicana* preferred to nest in 7.9-mm cavities (20 of 90 nests) and 12.7-mm cavities (68 of 90 nests; Table 2) and none nested in 3.2-mm and 4.8-mm cavities. Only 2 of 90 females nested in a 6.4-

mm cavity. Females did not equally nest in all diameters (chi-squared contingency table, $X^2 = 133.5$, df = 3, P< .001). Results were similar when the population was separated into burned and unburned habitats (P< 0.001, df=3, $X^2_{\text{burned}}= 108.4$, $N_{\text{burned}} = 10$, $X^2_{\text{unburned}}= 30$, $N_{\text{unburned}}=80$).

Likewise, females of *I. auripes* nested in mostly 12.7-mm cavities (85 of 89 nests). Only one nest of *I. auripes* was placed in a 4.8-mm cavity and 3 nests were placed in 7.9-mm cavities (figure 2-4)(chi-squared contingency table, $X^2 = 236.1$, df = 3, P<0.001). Results were similar when the population was separated into burned and unburned habitats (P <0.001, df=3, $X^2_{\text{burned}}=215.2$, $N_{\text{burned}} = 8$, $X^2_{\text{unburned}}= 17.2$, $N_{\text{unburned}}= 81$)

Both species used grass as back wall and opening plugs, and *I. mexicana* also made brood cell partitions out of the grass material. The grass did not have any binding agents (such as resin or secretions), but was twisted and compacted into position. Many nests had a slight amount of grass within the brood cell(s) when extracted and the pupae had a fair amount of grass pieces adhering to them (Figure 2-3). The occurrence of grass within the brood cell suggests that females may line the cell, but female and larval activity cannot be distinguished without further observation. All *I. mexicana* observed utilized separated brood cells (figure 2-1), with individual cells each 20-30mm. Each egg was laid on an orthopteran prey item and then separated from the next egg and provisioned prey mass by a tightly packed partition of grass. These nests had a mean of 2.50 brood cells (SD = 0.88, range = 1-4, N= 90). The majority of *I. mexicana* nests had 3 cells, however the “over-wintering” type of nest with only one brood cell may have resulted in a lower mean. In fact, when these outliers are removed the mean becomes 2.86 (SD= 0.50, range

2-4 N= 72). O'Neill and O'Neill (2003) observed *I. mexicana* in Montana had a range of 1-6 separated cells in cavities 15 cm deep. In contrast, *Isodontia auripes* consistently used a common brood cell in its nest architecture. Cells tended to be 50-60 mm in length. All provisions and eggs were laid in a single cell without any internal partitions. Both species used neatly coiled, tightly packed plugs of grass for the back end of the nest and to close the opening. These tightly packed plugs ranged from 6-10 mm thick for all nests in 12.7-mm and 7.9-mm diameter cavities. The tightly packed plugs in the few nests in smaller diameter (4.8-mm and 6.4-mm) cavities tended to be slightly thicker at 10-15 mm. Both species also used a loose plug between the opening and the outermost tightly packed plug. These loose plugs tended to include longer lengths of the grass and occasionally contained seed heads. Loose plugs occupied the outermost 5-20 mm of the cavity and always extended beyond the cavity opening. These plugs of grass resemble broom-like tufts and regularly extended 30-60 mm beyond the cavity opening and occasionally reached up to 100 mm beyond the cavity opening. The few seed heads included in the loose plug material allowed for identification of the grasses used by these wasps. Mark Garland (Botanist at the Florida Department Agriculture, Division of Plant Industry, Gainesville, Florida) identified the materials as the native nutrushes *Scleria* sp (*ciliate/ pauciflora*) (Cyperaceae).

Sex Ratio and Sexual Dimorphism

Isodontia mexicana that emerged from trap nests had a sex ratio of 1.2 males per female (N= 119). *Isodontia auripes* that emerged from trap nests had a sex ratio of 5.3 males per female (N= 144).

Isodontia mexicana display sexual size dimorphism typical for the Sphecidae (O'Neill 2001). Females that emerged from nests (mean head width = 3.10 mm, SD =

0.20 mm, range 2.7-3.6 mm, N= 53) were larger than males (mean head width = 2.84 mm, SD = 0.18 mm, range 2.4-3.2 mm, N= 65; Mann-Whitney U= 2930, P < 0.0001). Twenty-three percent of the females were larger than the largest male and 15% of the males were smaller than the smallest female. These differences are far less than in the Montana populations of *I. mexicana* examined by O'Neill and O'Neil (2003).

Isodontia auripes females that emerged from nests (mean head width = 3.30 mm, SD = 0.397 mm, range 2.4-3.9 mm, N= 23) were larger than males (mean head width = 3.01, SD = 0.259 mm, range 2.2-3.5, N = 121; Mann-Whitney U= 2276.5, P < 0.0001), with 30% of females larger than the largest male and 3% of the males being smaller than the smallest female.

Overall, *I. auripes* tended to be larger than *I. mexicana* (females: Mann-Whitney U= 867.5, P < 0.01, males: Mann-Whitney U= 6270, P< 0.001).

Prey

Extracting the contents of 20 *Isodontia* nests yielded samples with provisions in an identifiable condition. Thomas J. Walker (Professor Emeritus, University of Florida, Gainesville, Fl.) positively identified prey provisions from these nests. Nests of *I. mexicana* contained *Odontoxiphidium apterum* Morse 1891 (Tettigoniidae: Conocephalinae), *Oecanthus quadripunctatus* Beutenmuller 1894 (Gryllidae: Oecanthinae), *Belocephalus* sp. (Tettigoniidae: Copiphorinae), *Orocharis luteolira* T Walker1969 (Gryllidae: Eneopterinae) and *Scudderia* sp. (juv) (Tettigoniidae: Phaneroperinae) (Table 2.4).

Nests of *I. auripes* contained *Odontoxiphidium apterum*, *Oecanthus celerinictus* T Walker 1963 (Gryllidae: Oecanthinae), *Oecanthus niveus* (De Geer 1773) (Gryllidae: Oecanthinae), *Orocharis luteolira*, *Neoconocephalis* spp. (juv) (Tettigoniidae:

Copiphorinae), *Conocephalus brevipennis* (Tettigoniidae: Conocephalinae), *Scudderia furcata* sp. (juv) (Tettigoniidae: Phaneroperinae), and other *Oecanthus* spp. (juv) (Table 2.5).

Amount of prey provisioned varied greatly. Provisioned prey ranged from 1-19 prey items per nest. Nests and/or brood cells that had one or few prey items tended to contain large adult tettigoniids and those nests and/or brood cells with many prey tended to contain juveniles and/or small species of gryllids.

Survival

Ants (C*rematogaster* spp.) pillaged many *Isodontia* nests and it was impossible to identify the species of *Isodontia*. Therefore, overall *Isodontia* survival was calculated. A total of 235 nests were examined yielding 320 individuals of 529 resulting in a survival/emergence percentage of 60.49%. Mean brood per nest was 2.27 (SD= 1.311), yet this number is not useful since the two species differ in nesting strategies. Fifteen nests were lost to *Crematogaster* ant raids which accounted for 8.7% mortality of brood. Seven nests were lost to bombyliid fly parasitoids in the genera *Anthrax* and *Lepidophora* accounting for 3.4% of brood mortality. In addition, 2 nests were lost to a phorid fly parasitoid and 1 nest was lost to a male mutillid in the genus *Spheropthalma* (*Sphaeropthalma*), most likely the species *pensylvanica*. One nest was lost to supersedure (the act of taking over by a second individual of the same or different species of a cavity partially stored by the first individual) when a vespid, *Stenodynerus* sp. placed her mud nest in front of the *I. auripes* nest in progress.

Discussion

Documented observations of biology and natural history are important especially at the extremes of geographical range and in unique areas, for a species that is cosmopolitan in range, such as the genus *Isodontia.* In particular *I. mexicana* has become established in Hawaii and France (Bohart and Menke 1976) providing unique habitats in comparison to its native North America. Florida populations, as in this case, provide observations in the southeast extreme of the geographical range. O'Neil and O'Neil (2003) examined a population in Montana. With the ever-ongoing debate of species and subspecies versus clines and ecotypes it is important that we identify possible subjects to further examine the mechanisms of speciation and hazy hybrid zones. For example, the splitting of *Anisota senatoria* into *A. senatoria* and *A. peigleri* by Riotte (1975) has been called into question by Tuskes *et al.* (1996) and through out many groups taxonomists that are "lumpers" or "splitters" are constantly at odds.

In addition, such information is valuable to help identify possible projects for evolutionary biologists and studies in biogeography. For example, Mark Deyrup and Thomas Eisner (2003) examined the differences of coloration between Florida Hymenoptera and their northern relatives (subspecies, clinal types, etc.) utilizing museum specimens and natural history data from past studies. Their preliminary observations called for further exploration of Florida biogeography to help recognize distinctive species and examine mimetic complexes. Mimetic complexes are adaptive syndromes that reflect the evolutionary history of species, and historical events that cannot be repeated by an investigator and leave no fossil record (Deyrup and Eisner 2003), yet data such as these can help examine such events. *Isodontia mexicana* is a cosmopolitan species that is easily captured, studied and occurs sympatrically with *I. auripes* at these Florida sites. Such data can be extremely useful when examining speciation by highlighting divergence of these two sympatric sister species and by highlighting the divergence of *I. mexicana* in its geographical extremes.

My study is by no means comprehensive, but does offer substantial data in a unique part of *I. mexicana* range that may offer insight into divergence and speciation processes.

Habitat

Isodontia auripes was not captured in San Felasco Hammock Preserve State Park, but was captured a few kilometers away at Devil's Millhopper Geological State Park. *Isodontia mexicana* was not particularly abundant at San Felasco and *I. auripes* was probably present at San Felasco just not captured. All transects with *Isodontia* were in or adjacent to sand hill habitat that tended to be xeric. Silver River State Park does not have sandhill habitat that was particularly of substantial size or xeric in nature and lacks both *I. auripes* and *I. mexicana.* Both species were present in Suwannee River S.P. in both recently burned and unburned sandhill habitat, although the majority of nests (82% for *I. mexicana* and 87% for *I. auripes*) were captured in burned habitats (see chapter 4).

Nest Architecture

Several species of *Isodontia* have nests that contain a common brood cell where up to 12 larvae will feed on a single prey mass. *Isodontia auripes* exhibited this behavior and all nests (apart from single "over-wintering" emergence) of this species had common brood cells. Although *I. mexicana* has been reported to have a common brood cell in some populations(Krombein 1967), the populations I studied had separated brood cells within each nest (Figure 2-1). Bohart and Menke (1963) reported that some *Isodontia* use grass to line the nest. O'Neill and O'Neill (2003) reported that the population of *I. mexicana* they observed in Montana did not line nest cells. Pupae of both species had some amount of grass incorporated into the cocoon suggesting there was some manner of grass lining each cell (Figure 2-3). Krombein (1970) observed larvae of *Isodontia auripes* pulling grass fragments from the plugs and incorporating into the spinning of the cocoon. This behavior may be the explanation for the grass fragments incorporated into cocoons. The small amount of grass incorporated into the cocoons in addition to the lack of remaining grass in the chambers suggests that these species in fact do not actively line the brood cells with grass. The nature of my traps did not allow for direct observation of pupating activity.

Isodontia females of both species plug the opening of nest cavities with clumps of loosely packed grass. These plugs of grass resemble broom-like tufts and regularly extended 30-60 mm beyond the cavity opening and occasionally reached up to 100 mm. Bohart and Menke (1976) reported these plugs extending only up to 50 mm beyond the cavity opening. In Montana populations of *I. mexicana*, many plugs were flush with the opening, that tufts apparently being clipped short by the female (O'Neil and O'Neil 2003). I did not observe any of this clipping in Florida. The only nests that did not have the tufts of the closure plug extending beyond the opening were those that completely lacked the closure plug. These nests had only the final tightly packed partition suggesting that the plug had fallen out, the females had not completed her nest at time of collection or she had died before nest completion.

I observed an interesting deviation of *I. mexicana* nest architecture. About 18 nests were found to have one separated brood cell was provisioned with prey and a single egg, then the remaining nest was packed with both tightly packed partitions and loose plugs. Only 18 such nests were extracted and recorded, yet in the spring many other nests yielded only one adult without evidence of other pupae. It was impossible to determine if these nests were a fall-winter behavior (rather than the other chambers eggs not successfully hatching or being pillaged by ants) since the emerging adults are quite destructive of the nest commonly pushing the entire contents of the nest out of the cavity. These types of nest may be the result of an end of life span behavior of the nesting females. These fall-winter types were usually found in the fall with the earliest collected in August. However, normal nests with multiple brood cells were found throughout the year including in December.

Sex Ratio and Sexual Dimorphism

The two species of *Isodontia* had dramatically different sex ratios. *Isodontia mexicana* displayed a sex ratio of 2.1: 1 (M: F). However, *I. auripes* displayed a sex ratio drastically different at 5:1 (M: F). O'Neill and O'Neill (2003) found that males of *I. mexicana* tended to emerge from smaller diameter nesting cavities. Yet, the majority of *I. auripes* occupied the largest diameter nest (12.7 mm) and one of the few nests in smaller diameters yielded a female (7.9 mm). Therefore, this conclusion does not seem applicable. An alternative explanation is the Trivers-Willard hypothesis which states that sex allocation is condition dependant (Trivers and Willard 1973). This assumes that females can control the sex of the offspring, and it has been shown that nest-provisioning hymenopterans precisely determine the sex of each offspring (Green *et al.,* 1982, O'Neill 2001 O'Neill and O'Neill 2003). In fact, the majority of *Isodontia* nests were located in recently burned (within 1 and 2 years) sandhill habitat. Females can be expected to produce more of the sex for which quality makes the greatest difference in reproductive success (Clutten-Block et al 1984, Miller and Aviles 2000). Therefore, in poor conditions, males should be produced and in good conditions females should be produced, assuming the burned condition is a detrimental condition. Unfortunately, the relatively low amount of *Isodontia* nests captured in unburned areas did not allow a meaningful comparison. It can be speculated that the fire event eliminated nesting materials and reduced prey populations. The sites were surveyed for two years beyond the fire event. Grasses tend to respond positively and quickly after a fire event. The reduction of plant biomass may have provided less harborage for prey items and therefore easier hunting for the wasps. Yet, the sex ratios were equal in both years following the fire event. The relative amount of prey and nesting material needs to be known as well as further study beyond the fire event to detect any response lag. However, *I. mexicana* did not exhibit such a skewed sex ratio that *I. auripes* displayed. Since both species have similar biology (same prey, nesting habitat, nesting materials) and occur sympatrically, could interspecific competition be the driving force? Unfortunately the current data set cannot suggest any answers with any kind of confidence. Additional research focusing on interspecific competition is needed.

Prey

The prey provisioned by both *Isodontia* species has substantial overlap between my records and those reported in the literature (Table 2.4 & 2.5). *Orocharis luteolira* (Gryllidae: Eneopterinae) and *Belocephalus* sp (Tettigoniidae: Copiphorinae) were the only prey for *I. mexicana* that were not reported in the literature. *Oecanthus celerinictus* (Gryllidae: Oecanthinae), *Odontoxiphidium apterum* (Tettigoniidae: Conocephalinae) and *Neoconocephalus* sp (Tettigoniidae: Copiphorinae) were the only prey for *I. auripes* not reported in the literature. Both *Isodontia* species examined provisioned 3 species in common, but *I. mexicana* provisioned 6 unique species while *I. auripes* provisioned 2 unique species (Table 2.1). Under closer observation with more nests dissected, the range of prey items for both *Isodontia* may become more similar. Amount of prey provisioned varied greatly. Provisioned prey ranged from 1-19 prey items per nest. However, since these wasps prey on both adult and juvenile prey, biomass of the provisions is probably more important than quantity. Nests and/or brood cells that had one or few prey items tended to contain large adult tettigoniids and those nests and/or brood cells with many prey tended to contain juveniles and/or small species of gryllids. Therefore, prey per nest and prey items per brood cell are statistics of questionable value. Nesting females seem to be filling brood cells rather than provisioning a particular number of prey items per egg.

These *Isodontia* species displayed the typical sexual size difference found in the Sphecidae, suggesting a possible provisioning strategy by nesting females. Female-biased provisioning has been shown to occur in Montana populations (O'Neill and O'Neill 2003) of *I. mexicana*, and it also seems to occur in Florida populations of *I. mexicana.* However, *I. auripes* exhibited this sexual size trend, yet the communal brood chamber nest architecture rules out any provisioning difference as the cause for the size difference since both sexes regularly emerged from the same nest. A possible explanation could be that females deposit female eggs on prey earlier than male eggs. Since eggs that are deposited earlier tend to hatch earlier, female larvae would have more time with the prey mass and would most likely consume more of the prey mass. Krombein (1970) reported that the last egg to hatch in a nest of *I. auripes* where 6 eggs were laid actually died from lack of food.

One nest experienced supersedure. A vespid, *Stenodynerus* sp., usurped a nesting *I. auripes* female and placed her mud nest in front of the *I. auripes* nest in progress of provisioning. Two *I. auripes* successfully developed behind the *Stenodynerus* nest, but were unable to break through the mud partitions of the vespid nest and subsequently died. These *I. auripes* adults were of normal size suggesting that the female oviposits on prey after there are a number of sufficient prey items in the communal chamber to support that egg. This was an isolated observation, however and more data are needed to substantiate this hypothesis.

Conclusion

Nest structure and prey in the observed Florida populations were similar to those reported by Medler (1965), Krombein (1967), Bohart and Menke (1976) and O'Neil and O'Neil (2003). Both *Isodontia mexicana* and *I. auripes* displayed sexual dimorphism typically found in the Sphecidae. More importantly, these two sister species occur sympatrically and have a broad range of overlap in biology and prey species, yet they had extremely different sex ratios. Sex allocation is typical in the Sphecidae and a skewed ratio suggests a harsh environment. There is substantial overlap in prey items, but there are unique prey items to each species. Whether those prey items remain unique as sampling for provisioned prey is increased is unknown. In addition, prey populations were not sampled or estimated leaving possible disparity of unique prey unknown. Whether the skewed sex ratio is a result of direct interspecific competition or differences in mutually exclusive prey populations, the relationship of these two sympatric sister species may offer evaluation of competitive exclusion, divergence and possible speciation events.

Acknowledgements

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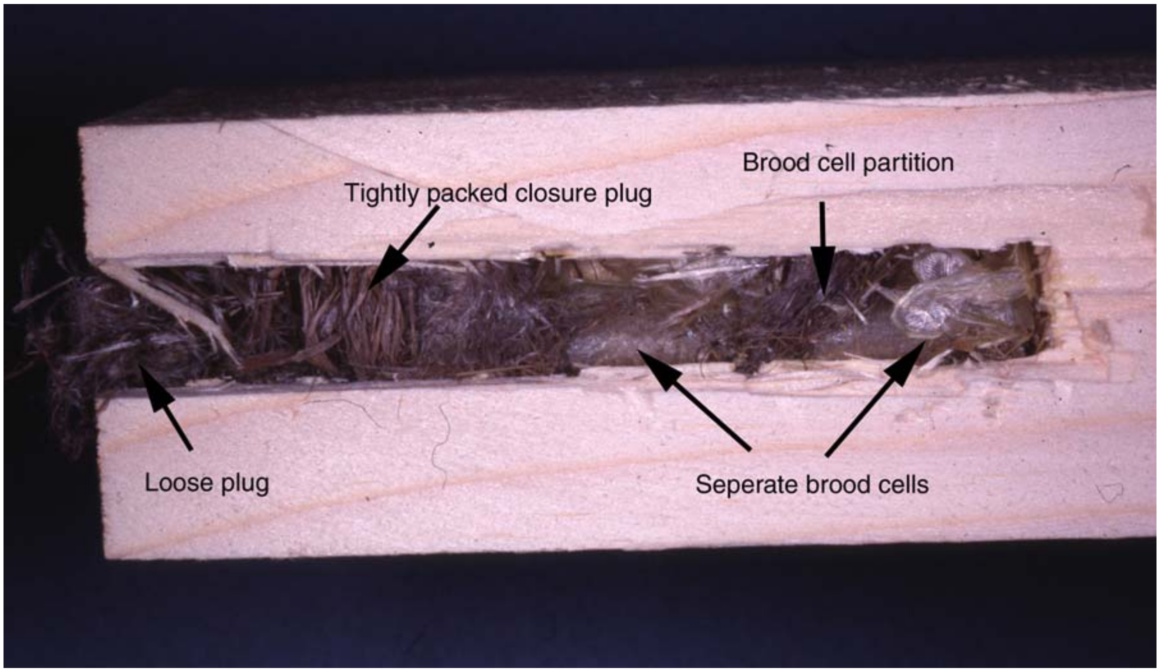

Figure 2-1. Cross section of *Isodontia mexicana* nest in a 12.7mm cavity

Figure 2-2. *Isodontia auripes* larvae on provisioned *Scudderia furcata*

Figure 2-3. *Isodontia* cocoon

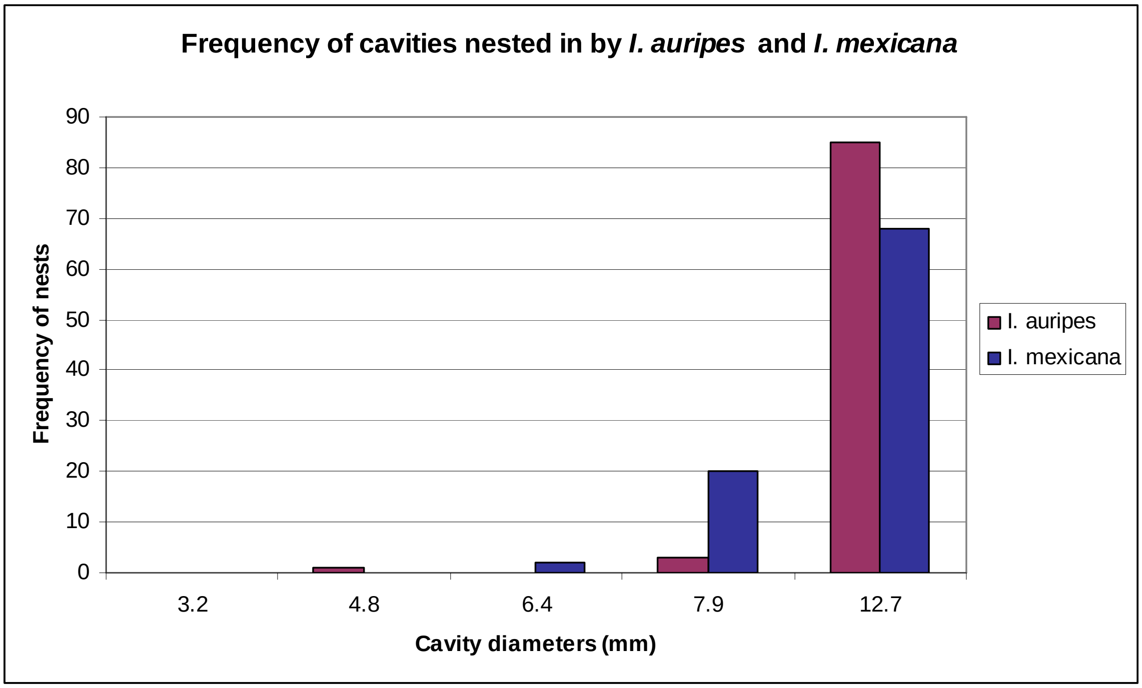

Figure 2-4. Frequency of cavities nested in by *I. auripes* and *I. mexicana*

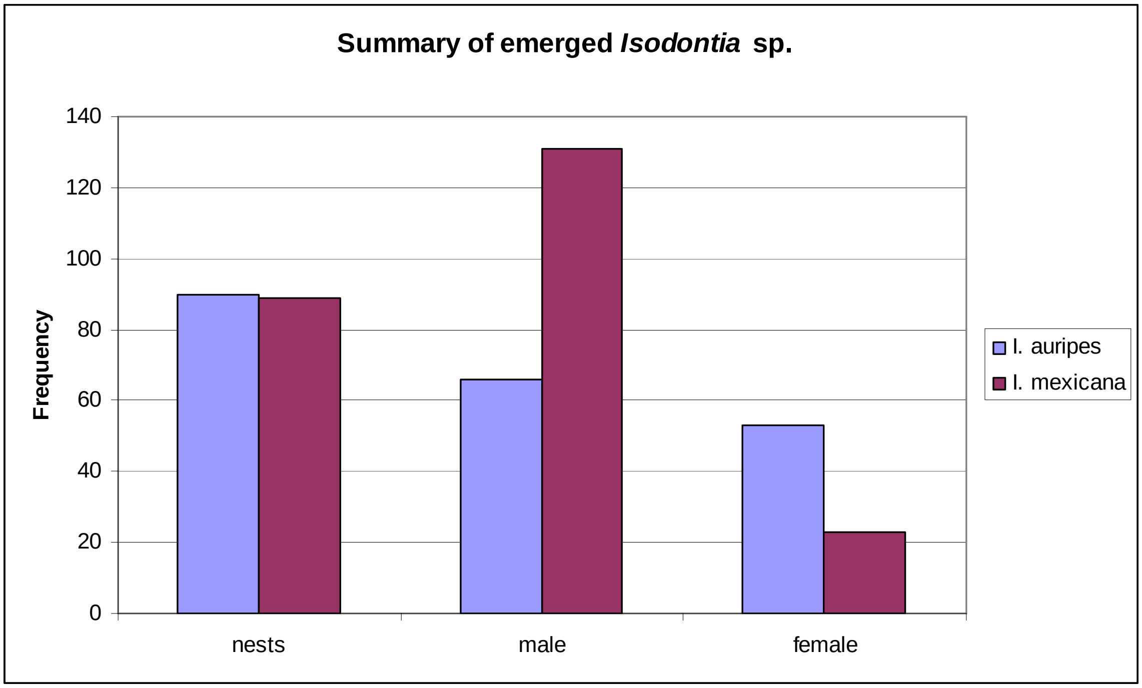

Figure 2-5. Summary of emerged *Isodontia mexicana* and *Isodontia auripes* from captured nests

Table 2-1. Comparison of *Isodontia auripes* and *I. mexicana*

	Isodontia auripes	*Isodontia mexicana*
Identification	Violaceous wings Red-brown legs Male: 18 mm, Female: 19 mm	Clear wings, with black veins and smoky brown along anterior margin Black legs Male: 16 mm, Female: 17 mm
Architecture	Single chamber 50-60mm	3 (1-4) chambers 20-30mm each
Prey (Bold = Prey provisioned by both species)	(Gryllidae: Oecanthinae); Oecanthus celerinictus T Walker 1963 Oecanthus niveus (De Geer 1773) Oecanthus spp. (juv). (Gryllidae: Eneopterinae); Orocharis luteolira, T Walker1969 (Tettigoniidae: Conocephalinae); Odontoxiphidium apterum, Morse 1891 Conocephalus brevipennis Scudder 1862 (Tettigoniidae: Copiphorinae); Neoconocephalis spp. (juv) (Tettigoniidae: Phaneroperinae); Scudderia furcata Bruner 1878 Scudderia sp. (juv)	(Gryllidae: Oecanthinae); Oecanthus quadripunctatus Beutenmuller 1894 (Gryllidae: Eneopterinae); Orocharis luteolira, T Walker1969 (Tettigoniidae: Conocephalinae); Odontoxiphidium apterum Morse 1891 (Tettigoniidae: Copiphorinae); Belocephalus sp. (Tettigoniidae: Phaneroperinae); Scudderia sp. (juv)
Dimorphism (Mean head width (mm))	Females: 3.30 + 0.397 Males: 3.01 + 0.259	Females: 3.10 + 0.20 Males: 2.84 + 0.18
Sex ratio (M:F)	5:1	1.2:1
Cavity diameters (mm) nested	6.4, 7.9, 12.7	4.8, 7.9, 12.7
Habitat	Sandhill, Ravine (adjacent to sandhill), Pine Flatwoods	Sandhill, Ravine (adjacent to sandhill), Pine Flatwoods, Mesic hardwood hammock
State Parks	Suwannee River State Park, Mike Roess Gold Head Branch State Devil’s Millhopper Geological State Park	Suwannee River State Park, Mike Roess Gold Head Branch State Devil’s Millhopper Geological State ParkSan Felasco Hammock Preserve State Park

Table 2-2. Frequency of cavities nested in by *I. auripes* and *I. mexicana*

Cavity diameter (mm)	*I. auripes*	*I. mexicana*
3.2	0	0
4.8	1	0
6.4	0	2
7.9	3	20
12.7	85	68
Total nests	89	90

Table 2-3 Summary of emerged *I. auripes* and *I. mexicana*

	Number of nests	Male	Female	Total adults (Emerged)
Isodontia auripes	90	66	53	119
Isodontia mexicana	89	131	23	154
Isodontia (unknown sp)	56	–	–	
Total	235			273

Table 2-4 Prey records for *I. mexicana*

Prey	Present study	O'Neill & O'Neill 2003	Bohart & Menke 1976	Krombein 1967	Lin 1966	Medler 1965
Gryllidae: Gryllinae Gryllus sp.			X		X	
Gryllidae: Eneopterinae	X		X			
Orocharis sp	X		X			
Orocharis luteolira T Walker	X					
Gyllidae: Oecanthinae	X	X	X	X	X	X
Oecanthus sp.	X	X	X	X	X	X
O. exclamationis Davis*						
O. nigricornis F Walker		X				X
O. quadripunctatus Beutenmuller	X	X				X
O. fultoni T Walker		X				X
O. niveus (DeGeer)				X	X	X
O. saltator Uhler				X		
O. celerinictus T Walker*						
Neoxabea sp.			X			X
N. bipunctata (DeGeer)						X
Tettigoniidae: *Conocephalinae*		X	X	X		
Conocephalus sp		X	X	X		
C. brevipennis (Scudder)*						
C. fasciatus (DeGeer)		X				
C. saltans (Scudder)		X				
Odontoxiphidium sp	X		X	X		
O. apterum Morse	X			X		
Orchelimum sp.			X		X	
Tettigoniidae: Copiphorinae						

Table 2-4 Continued

Prey	Present study	O'Neill & O'Neill 2003	Bohart & Menke 1976	Krombein 1967	Lin 1966	Medler 1965
Belocephalus sp.	X					
Neoconocephalus sp.			X			
Tettigoniidae: *Phaneropterinae*						
Scudderia sp.	X		X			
Scudderia furcata Brunner*						
Tettigoniidae: Tettigoniinae*						
Atlanticus sp.*						
A. gibbosus Scudder*						
Neobarretta sp.			X			

* Not found but present in *Isodontia auripes* nests

Table 2-5 Prey records for *Isodontia auripes*

Prey	Present study	Bohart & Menke 1976	Krombein 1970	Krombein 1967
Gryllidae: Gryllinae *Gryllus* sp.				
Gryllidae: Eneopterinae	X	X	X	
Orocharis sp	X	X	X	
Orocharis luteolira T Walker	X		X	
Gryllidae: Oecanthinae	X	X		X
Oecanthus sp.	X	X		X
O. exclamationis Davis				X
O. nigricornis F Walker*				
O. quadripunctatus Beutenmuller*				
O. fultoni T Walker*				
O. niveus (DeGeer)	X			X
O. saltator Uhler				X
O. celerinictus T Walker	X			
Neoxabea sp.		X		X
N. bipunctata (DeGeer)				X
Tettigoniidae: Conocephalinae		X		X
Conocephalus sp		X		X
C. brevipennis (Scudder)*				

Table 2-5. Continued

Prey	Present study	Bohart & Menke 1976	Krombein 1970	Krombein 1967
C. fasciatus (DeGeer)*				
C. saltans (Scudder)*				
Odontoxiphidium sp*				
O. apterum Morse	X			
Orchelimum sp.		X		X
Tettigoniidae: Copiphorinae	X			
Belocephalus sp.*				
Neoconocephalus sp.	X			
Tettigoniidae: Phaneropterinae		X		X
Scudderia sp.		X		X
Scudderia furcata Brunner*				
Tettigoniidae: Tettigoniinae		X	X	
Atlanticus sp.		X	X	
A. gibbosus Scudder			X	
Neobarrettia sp.*				

* Not found but present in *Isodontia mexicana* nests

CHAPTER 3
SPIDER PREY IN NESTS OF THE MUD DAUBER WASP *Trypoxylon lactitarse* (HYMENOPTERA: SPHECIDAE)

Abstract

Prey from 88 nests of *Trypoxylon lactitarse* in five state parks in north central Florida were examined, yielding 1173 individual spiders from 15 families, 40 genera and 64 species. Overall, *Neoscona* sp. was the most commonly collected prey species (23.78%), followed by *Mimetus* sp. (12.27%) and *Pisaurida mira* (8.86%). Araneidae (56.26%) was the most commonly collected family, followed by Mimetidae (12.27%) and Pisauridae (10.57%). *Trypoxylon lactitarse* tended to be a generalist in its prey preference with a fairly even diversity of prey captured. Although the majority of prey items were common web-spinners, many rarely surveyed spiders, such as Aniphedids and some Salticids, were collected. Since *T. lactitarse* hunts for spiders in wide-ranging microhabitats and with more intensity than human collectors, surveying nest contents is an extremely useful tool to expand spider species richness estimates, species inventories, and natural history data.

Introduction

Trypoxylon lactitarse is a solitary wasp found in the western hemisphere from Canada to Argentina. Females of *T. lactitarse* nest in cavities constructing linear cells subdivided by partitions of mud and provision these cells with numerous paralyzed spiders. Data concerning prey are normally difficult to obtain, but this wasp deposits prey in nests that are easily collected (Camillo and Breviscovit 1998, Rehnberg 1987).

The wasp nests in preexisting cavities and readily accepts trap-nests, allowing for prey data to be easily collected. Previous studies (Rau 1928, Krombein and Evans 1954, Krombein 1956, 1967, Medler 1965, Lin 1969, Coville 1979, 1981, 1982, Coville and Coville 1980, Genaro *et. al.* 1989, Camillo *et. al.* 1993, Genaro and Alayon 1994, Jimenez and Tejas 1994, Camillo and Brescovit 1999, 2000) have shown that different species of *Trypoxylon* have different prey preferences. These differences in prey preference can be in proportion of each family, genus, or species taken; amount of families taken; and relative proportion of spider groups (orb-weaving, hunting or wandering) in the prey. Coville (1987) suggested that preferences for different species or species groups may arise because of different hunting behaviors of the wasps, different microhabitats hunted, or the wasps are conditioned to a certain type of spider. Some species capture spiders predominately from one family and occasionally spiders from other families (Camillo and Brescovit 2000), while some species, including *T. lactitarse*, prey on spiders of many different families (Camillo and Brescovit 1999).

Nests of *Trypoxylon lactitarse* provide large amounts of spiders from various families, including spiders rarely caught by humans. Because these wasps hunt extensively in different microhabitats and areas rarely sampled by humans, sampling their nests and prey may provide additional information on spiders in the area.

I set out to investigate the following questions about *Trypoxylon lactitarse* and its nest contents to determine: 1) What prey is *T. lactitarse* provisioning at these Florida sites? 2) Is *T. lactitarse* a generalist or specialist in terms of prey provisioned in Florida? 3) What, if any, is *T. lactitarse*'s prey preference? 4) Does *T. lactitarse*'s prey preference seem to differ between sites? 5) What are the benefits and problems with using this wasp (and potentially other spider-provisioning trap-nesters) as a sampling tool for estimating spider abundance and species richness?

Methods and Materials

Tools and Trap Preparation

The traps used in this study were fabricated from seasoned 37-mm x 86-mm x 2.4-m pine/spruce timbers obtained from a local home improvement store. The pine/spruce timbers were cut into 100, 10-cm-long blocks. Two cavities of one of five diameters (3.2, 4.8, 6.4, 7.9 or 12.7-mm) were drilled into each block. Cavities were drilled to a depth of 80 mm on each short side (the 37-mm side), offset approximately 10-mm from the center point. Traps were assembled using one block of each diameter with the smallest cavity on top and the largest on the bottom. Blocks were stacked so that no cavity was situated directly above or below a cavity in the adjacent block. The five blocks were bound together with strapping tape (3M® St Paul, Minnesota), and 16-gauge wire was used to further bind the stack and suspend the trap from trees and shrubs at the field sites. Each bundle of five blocks was considered to be a single trap.

Field Sites

I set trap nests at five locations: 1) Suwannee River State Park in Suwannee County (30° 23.149′ N, 083° 10.108′ W), 2) Mike Roess Gold Head Branch State Park in Clay County (29° 50.845′N, 081° 57.688′ W), 3) Devil’s Millhopper Geological State Park in Alachua County (29° 42.314′N, 082°23.692′ W), 4) San Felasco Hammock Preserve State Park (29° 42.860′ N, 082°27.656′ W) in Alachua County and 5) Silver River State Park in Marion County (29° 12.317′N, 082° 01.128′ W). The habitats surveyed at Suwannee River State Park were burned and unburned sand hill habitat, while the habitat at Mike Roess Gold Head Branch State Park was burned sand hill pineland and ravine. Sites at

San Felasco Hammock Preserve State Park consisted of upland and mesic hardwood hammock. Surveyed areas of Devil's Millhopper Geological State Park consisted of pine flatwood habitat and sites at Silver River State Park consisted of river habitat and upland mesic forest. Descriptions of these habitats can be found in Franz and Hall (1991).

Field Placement

Transects were set up with 10 traps placed approximately 10 m apart and hung approximately 1.5 m off the ground on trees or limbs with placement on dead standing wood preferred. Transects were initially established (direction and distance from center of plot) randomly. Four transects were established in Suwannee River State Park while three transects were established in Mike Roess Gold Head Branch State Park. Three transects were established in San Felasco State Park but size constraints only allowed a single transect in Devil's Millhopper State Park. Finally, two transects were set up in Silver River State Park. Transects were in the field from April 2003 until January 2005.

Field Collection and Laboratory Rearing

Traps remained in the field two years and were checked monthly. Preliminary field tests revealed that one-month intervals were sufficient to avoid trap saturation (no available cavities). Traps were considered occupied when insects were observed actively nesting, harboring or had sealed a cavity with mud or plant material. Occupied traps were removed and replaced with a new trap. These occupied traps were brought into the forest entomology lab at the University of Florida in Gainesville, FL, for processing. Occupied blocks were removed for observation while unoccupied blocks were reincorporated into replacement traps. Each occupied cavity was given a unique reference number.

In order to examine prey items of *Trypoxylon lactitarse,* traps were dissected for nest contents when a wasp was encountered provisioning, guarding, or sealing a nest during collection runs. Prey items were removed, preserved, and given the same reference number as the cavity from which they had been removed. After the contents were extracted, the wood block was reused in replacement traps. These processed blocks were re-drilled to the next cavity diameter to eliminate any alterations or markings (either physical or chemical) by the previous occupant prior to reuse.

Specimen Identifications

All specimens were identified by the author with most of the spider prey specimens identified and verified by G. B. Edwards at the Florida State Collection of Arthropods in Gainesville, Fl. Voucher specimens have been deposited at the Florida State Collection of Arthropods.

Statistical Analysis

Similarity was calculated with Jaccard's similarity index (IS_j) (Southwood 1978). This index is the proportion of the combined set of species present at either site that are present in both sites. This value ranges from 0 to 1, with 0 meaning no similarity (no species in common) in both sites and 1 meaning all species are present at both sites. The value is calculated using the following equation:

$IS_J = c / (a + b + c)$

Where c is the number of species common to both sites and a and b respectively are the species exclusive to those sites

Similarity was also calculated with Sorensen's similarity index (IS_s) (Sorensen 1948). This index is the proportion of the combined set of species present at both sites that are present in both sites. This value ranges from 0 to 1, with 0 meaning no similarity (no species in common) in both sites and 1 meaning all species are present at both sites. The value is calculated using the following equation:

$$IS_s = 2c / (a + b)$$

Where c is the number of species common to both sites and a and b are respectively the total number of species at each site `

Chao-Jaccard raw (uncorrected for unseen species) abundance-based similarity index, Chao-Jaccard estimate (corrected for unseen species) abundance-based similarity index, Chao-Sorensen raw (uncorrected for unseen species) abundance-based similarity, and Chao-Sorensen estimate (corrected for unseen species) abundance-based similarity (Chao *et al*. 2005) was calculated with EstimateS 7.5 (Colwell 2005).

Diversity was calculated using Simpson's index of diversity and Simpson's index of dominance (Simpson 1949). Simpson's index of diversity values range from 1 to S, where S is the total number of species. Simpson's index of dominance ranges from 0-1.

Simpson's index of dominance, λ is given by:

$$\lambda = \sum_{i=1}^{s} (n / N)^2$$

where n is the total number of organisms of the i^{th} species and N is the total number of organisms of all species.

Simpson's Index of Diversity is given by: $1/\lambda$

Diversity was also calculated using the Shannon-index (Shannon and Weaver 1949) H′, given by:

$$H' = - \sum_{i=1}^{s} p_i \ln p_i$$

where $p_i = n/N$ and n is the total number of organisms of a particular species and N is the total number of organisms of all species

Diversity is a combination of species richness (number of species) and evenness of species abundance. Therefore, Shannon's index of evenness, J (Pielou 1966), is given by:

$J = H' / \ln s$ where s is the total number of species

Species richness was estimated using rarefaction curves (Colwell *et al.* 2004). This estimate of species richness is based on a sub-sample of pooled species actually discovered. In addition, three non-parametric species richness estimators, ACE (Abundance-based Coverage Estimator: Chao *et al.* 2000, Chazdon *et al.* 1998), first order jackknife (Burnham and Overton 1978, 1979, Smith and van Belle 1984, Heltshe and Forrester 1983) and Chao 1(Chao 1984) were used. These estimators produce estimates of total species richness including species not present in any sample. Most of the indices and all of the richness estimators were computed using EstimateS 7.5 (Colwell, 2005).

Results

I examined 88 nests of *Trypoxylon lactitarse* and found 1173 individual spiders from 15 families, 40 genera, and 64 species from all five state parks (Table 3-1). Overall, *Neoscona* sp. was the most commonly collected species (23.78%), followed by *Mimetus* sp. (12.27%) and *Pisaurida mira* (8.86%). See Table 3-1 for a summary of captured species tabulated by site of capture. When subdivided by site, (Figures 3-2 through 3-6) the top five species of spider prey for each site was similar to overall pooled results. The most abundant species, *Neoscona* sp., was the most abundant species for three of the sites and second and third most abundant for the remaining two sites. For all sites, the five most abundant species were included in the ten most abundant species for pooled data, except for 2 species at Gold Head Branch. At the Gold Head Branch site, the most abundant species, *Trachelas* sp., is third most abundant species for pooled data, *Theridion* sp., and fifth most abundant species, *Neoscona crucifera*, were not included in the pooled top ten most abundant species captured.

The most abundant families of spiders collected were Araneidae (56.26%), Mimetidae (12.27 %), Pisauridae (10.57%), Salticidae (6.82%) and Tetragnathidae (6.82%) (Figure 3-7).

Prey diversity as reported by Shannon's and Simpson's indices is similar among sites except for the Simpson's index value for Devil's Millhopper which is remarkably different at 6.81 (Table 3-3). The Shannon evenness index for all but one site is above 0.7, (Table 3-3) suggesting a fair degree of evenness. The evenness of the prey diversity is illustrated on the rank proportional abundance graphs (Figures 3-8, 3-9).

Similarity of prey between sites, reported by Jaccard's similarity, Sorensen's similarity, Chao-Jaccard raw (uncorrected for unseen species) abundance-based similarity, Chao-Sorensen raw (uncorrected for unseen species) abundance-based similarity, Chao-Jaccard estimate (corrected for unseen species) abundance-based similarity, Chao-Sorensen estimate (corrected for unseen species) abundance-based similarity (Chao *et al*. 2005) indexes are summarized in Table 3-3. Overall, the classic formulas for Jaccard's and Sorensen's indices gave the lowest values with Jaccard's index being the lower of the pair. This is intuitive since these indices are calculated with actual observed species. All the Jaccard's indices, including the Chao versions, were more conservative by yielding lower values than their Sorensen counterparts. The only exception to this trend was a single site comparison, Silver River vs. San Felasco were both estimate versions of Chao-Jaccard's and Chao-Sorensen's gave a value of 1.0 for complete similarity.

Species richness estimates given by rarefaction, first order jackknife, ACE (abundance-based coverage estimator) and Chao 1 estimator are given in Figures 3-10. The only site at which all these estimators stabilized, however, was at San Felasco State Park and the Chao 1 and ACE estimators stabilized for Gold Head Branch. The other sites and estimators did not completely reach an asymptote and can be viewed with skepticism (figure 3-11).

Discussion

Prey diversity varied among sites due to a large difference in species composition; however, the Shannon evenness index for all but one site is above 0.7, suggesting a fair amount of evenness. This trend can also be seen on the rank proportional abundance graphs (figures 3-1, 3-2). This level of evenness suggests that *Trypoxylon lactitarse* is not specializing on a few prey species with occasional secondary species, but rather behaving as a generalist and hunting a wide variety of available spider prey including both web spinning and hunting spiders.

The somewhat low levels of similarity for Jaccard's and Sorenson's (Table 3-6) indices between all sites suggest a distinct variation in spider prey composition. The Chao-Jaccard estimate abundance-based and the Chao-Sorensen estimate abundance-based similarity indexes show a higher degree of similarity between sites than their raw estimate counterparts. These estimate-based indexes are corrected for under-sampling bias and suggest that sites are more similar that the current observations reveal. Since under-sampling or limited sampling effort is the generally the case, the Chao-Jaccard and

Chao-Sorensen estimates would be the best choice. Of these two, the Chao-Jaccard estimate is generally the more conservative yielding (slightly) lower estimates of similarity. The highest estimated similarity values were between Silver River state park and San Felasco state park and the lowest similarity was between Devil's Millhopper state park and Gold Head Branch state park, yet the estimators for these sites did not stabilize suggesting these sites were under-sampled. These findings are expected since the similarity of the respective habitats coincides with prey item similarity. This further suggests that *Trypoxylon lactitarse* is a generalist predator capturing prey that is abundant in the habitat and not searching for a particular species within any habitat. Yet, since the sample sizes for each of the sites were different, due to opportunistic nature of the sampling, an additional study with a more systematic, even sampling focusing on obtaining nest contents is needed to provide more confident results. Furthermore, estimators for Devil's Millhopper and Mike Roess Gold Head Branch did not stabilize due to small sample sizes, so these results should be viewed with skepticism. The estimators for the remaining sites did stabilize (except for the Chao 1 estimator in Silver River) and we can be confident in these species richness estimations.

Finally, do *Trypoxylon lactitarse* nest provisions provide useful data on spider populations? The characteristics of the nest provisions confirm that *T. lactitarse* is a generalist predator of spiders, which is ideal for surveying a population. Intuitively, these wasps collect spiders much more intensively and efficiently than human collectors. These nests also yielded a fair amount of rare species (uniques, singletons, and doubletons) further suggesting a complete survey of the target group. These three factors suggest that nests of *T. lactitarse* are an ideal survey tool for spiders. In addition, species richness estimators (such as in the freeware EstimateS (Colwell, 2005)) extrapolate total species richness for a site and, therefore, suggest a sufficient level of species inventory for a particular site. Sufficient sampling, however, is crucial for successful estimation. In most sites, the estimators did not stabilize due to undersampling (figure 3-11). The estimators for San Felasco site did stabilize and two estimators stabilized at Gold Head Branch suggesting that sufficient samples were taken to estimate species richness for *Trypoxylon lactitarse* provisioned prey with confidence at those sites (figure 3-11). The fact that estimators did not stabilize for Silver River and half of the estimators for Gold Head Branch did not stabilize is not surprising because of the smaller sample sizes. What is surprising, however, is that none of the estimators stabilized for Suwannee River. Although similar numbers of samples (contents of a single nest) were taken in the two parks, all estimators for San Felasco stabilized between 10-20 samples while no estimators stabilized for Suwannee River after 28 samples. I suggest that each survey effort monitor estimators for stabilization for each site individually in order to determine sufficient sampling.

These findings in no way suggest that this sampling represents the total spider fauna of the particular sites, but simply that we have sufficiently examined the prey of *Trypoxylon lactitarse*. These estimators are indeed practical to determine the richness of spiders preyed upon by the wasps and when this sampling has been sufficient. As discussed earlier, *T. lactitarse* is a generalist in Florida and in tropical regions, and provides a wide range of spider prey. Trap-nests also have the advantages of other spider provisioning wasps being trapped. *Trypoxylon johnsonii, T. carinatum, T. collinum collinum, T. clavatum johanis,* and *T. clavatum clavatum* are other spider provisioning wasps that were also captured at these Florida field sites, but their nest contents were not extracted. Even though some wasps may be specialists (Camillo and Brescovit 2000) in addition to generalists such as *T. lactitarse* (Camillo and Brescovit 1999), these wasps intuitively search longer and in different microhabitats and, therefore, provide more abundance and possibly variety of spiders than hand collecting alone. Yet, some wasps do have preferences for one family or another. Even the generalist hunters may periodically favor one group of spiders that are locally abundant or more easily captured at that time over groups they would normally prey upon. It may be prudent, therefore, to take samples at various times of the year to avoid temporal population cycles of spiders.

This technique for sampling spider fauna would be ineffective alone, however, as a part of a structured inventory protocol including other techniques, such as hand collecting and pitfall traps, may provide more complete and accurate cataloguing of spider faunas. This is especially true since underestimates have been shown to most commonly be derived from shortcomings of sampling techniques rather than sampling effort (Longino and Colwell 1997, King and Porter 2005). When various techniques are integrated together to create a structured inventory procedure, such as the Ants of the Leaf Litter (ALL) protocol for sampling ant communities (Agosti *et al.* 2000) and the methodology proposed by Coddington *et al* (1991) for spiders, they can be extremely powerful and reliable tools (Toti *et al.* 2000). Various techniques such as Malaise traps (Jennings and Hilburn 1988) and trap nests can be used in addition to the standard hand collecting, sweeping, and pitfall trapping, to provide an efficient and complete method of determining spider fauna of an area when long term sampling is an option.

Acknowledgements

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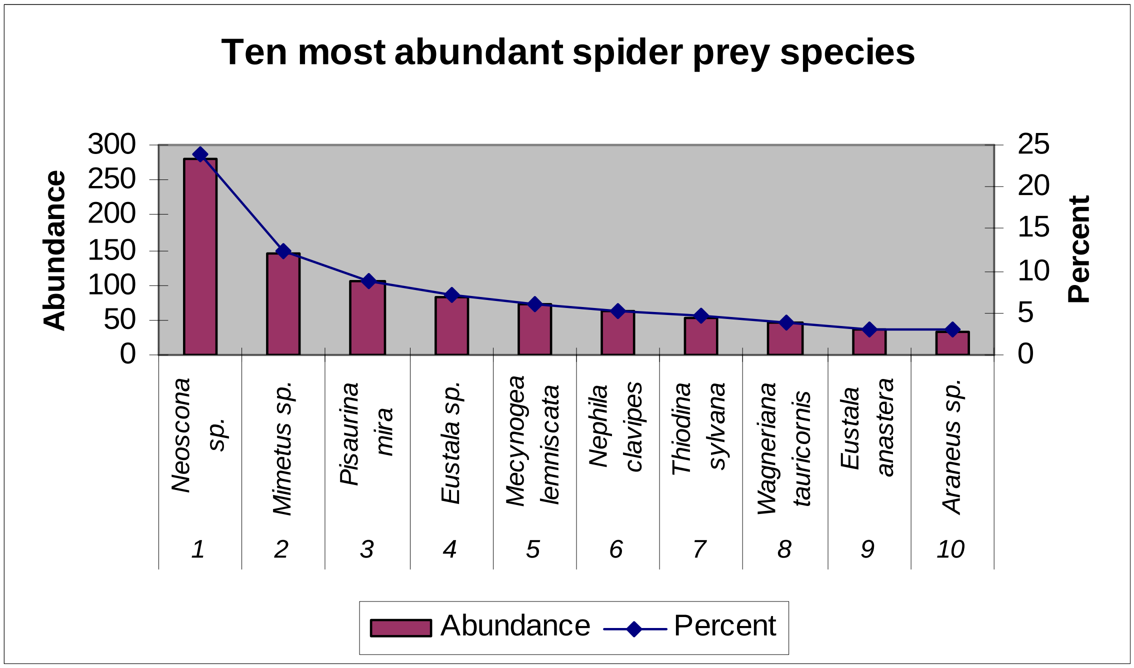

Figure 3-1. Ten most abundant spider prey species for all sites pooled

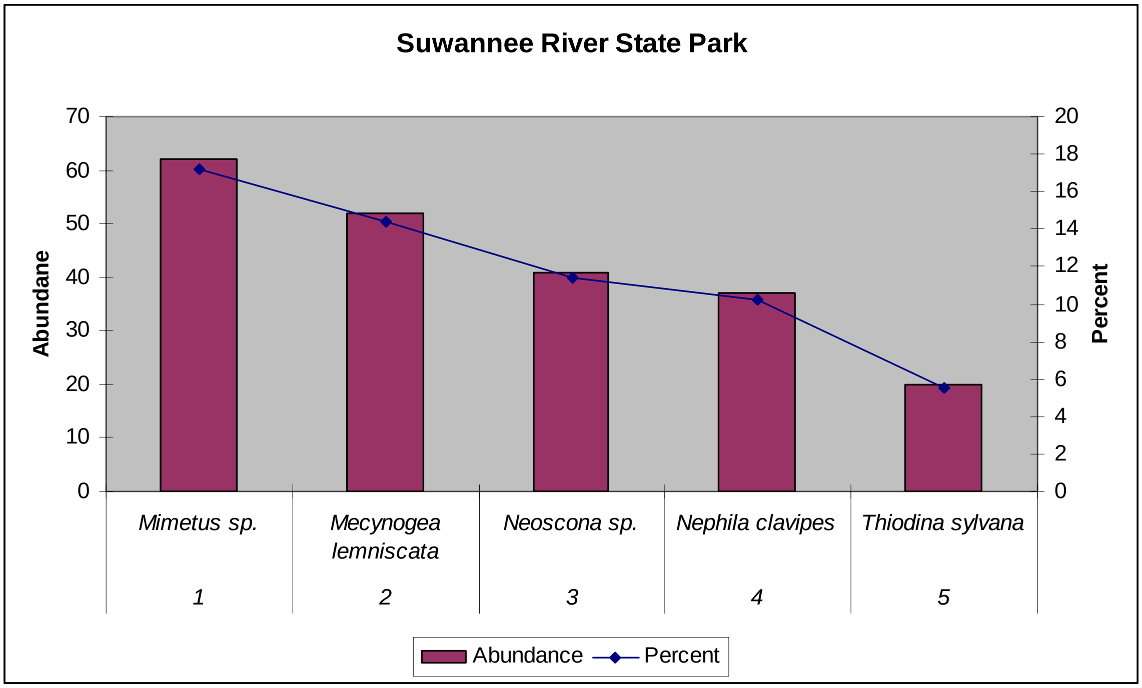

Figure 3-2. Five most abundant spider prey species at Suwannee River State Park

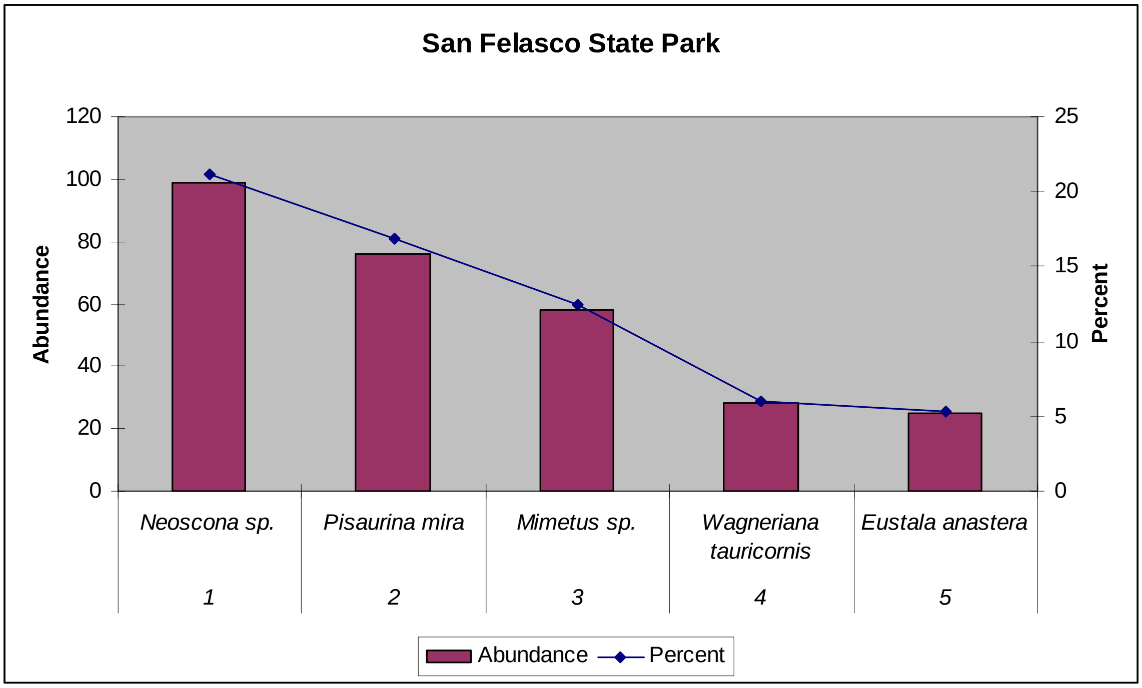

Figure 3-3. Five most abundant spider prey species at San Felasco State Park

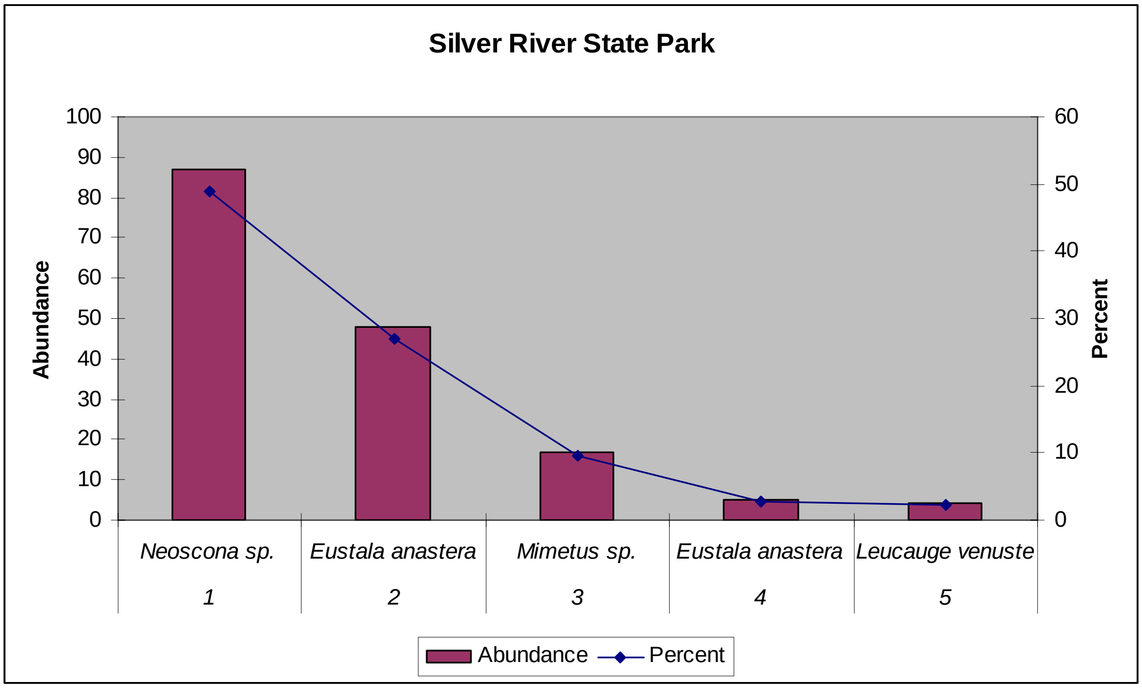

Figure 3-4. Five most abundant spider prey species at Silver River State Park

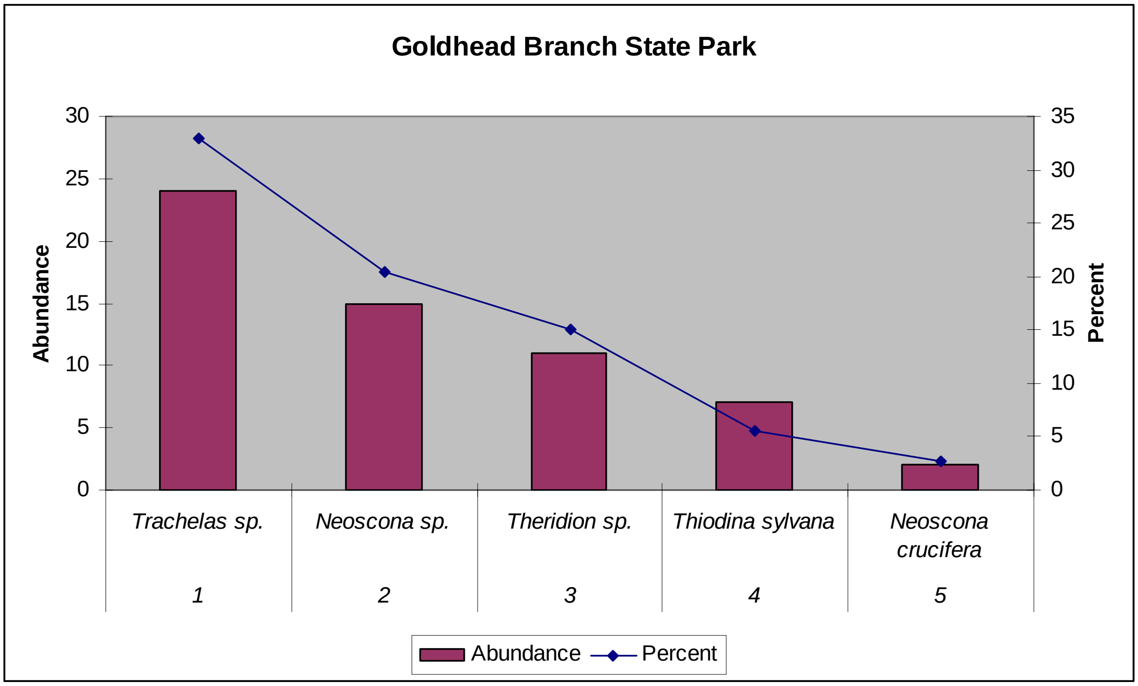

Figure 3-5. Five most abundant spider prey species at Gold Head Branch State Park

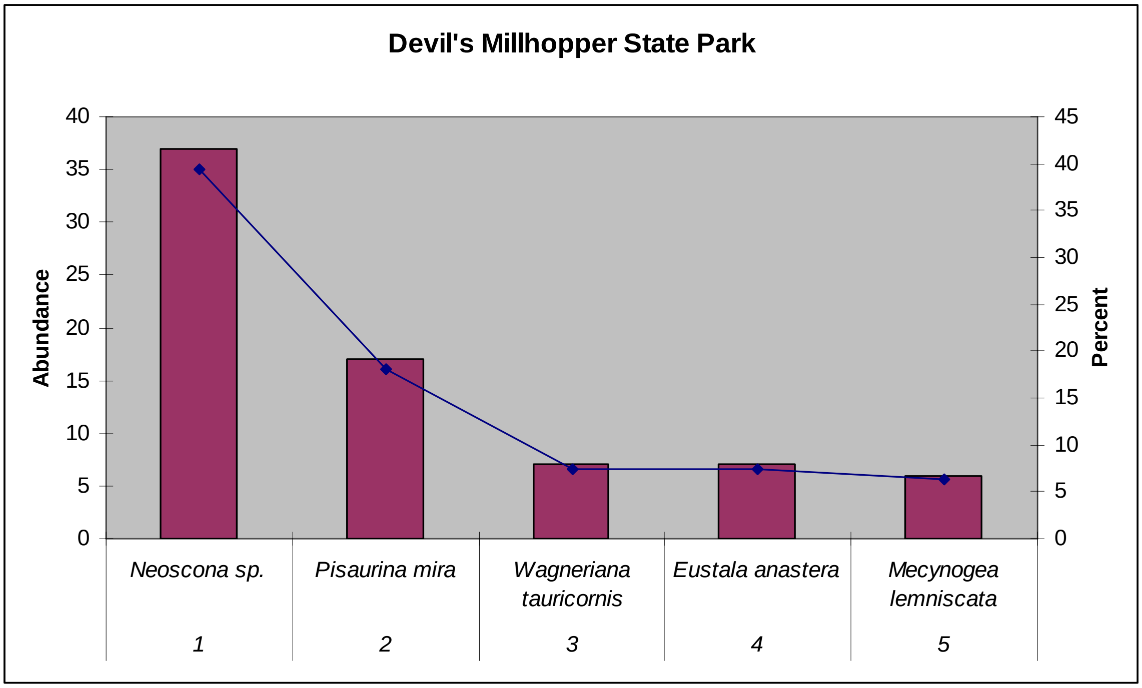

Figure 3-6. Five most abundant spider prey species at Devils' Millhopper State Park

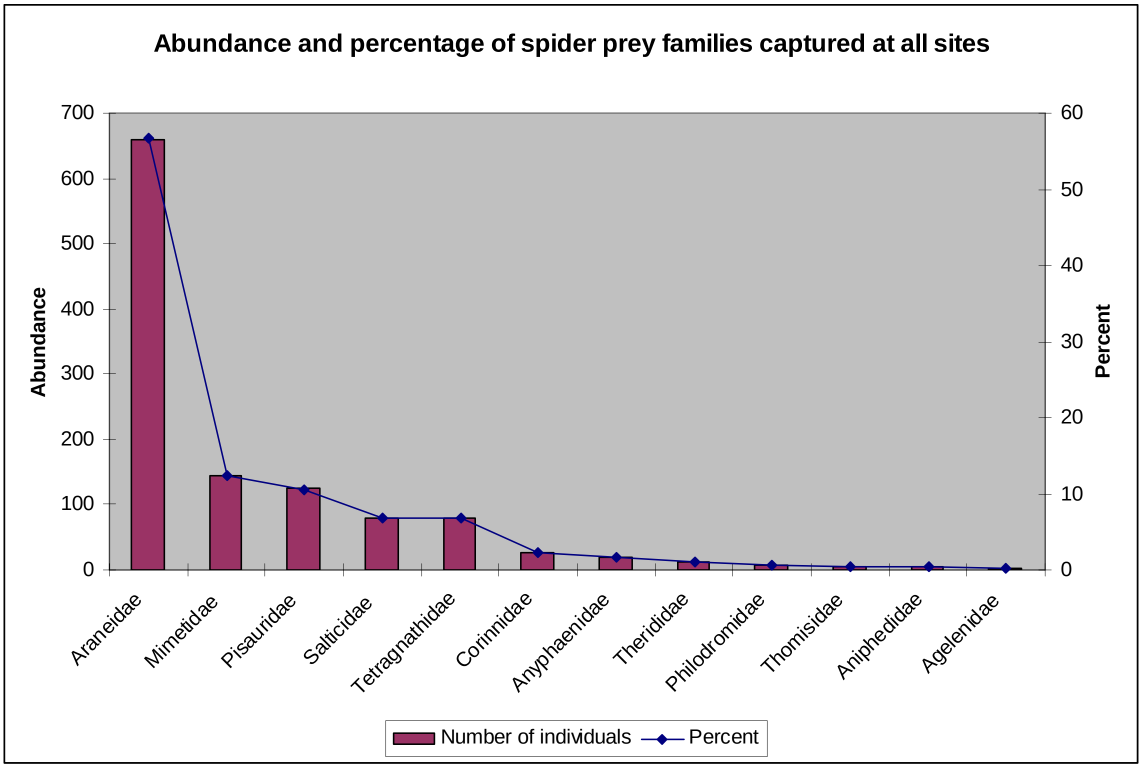

Figure 3-7. Abundance and percentage of spider prey families captured at all sites

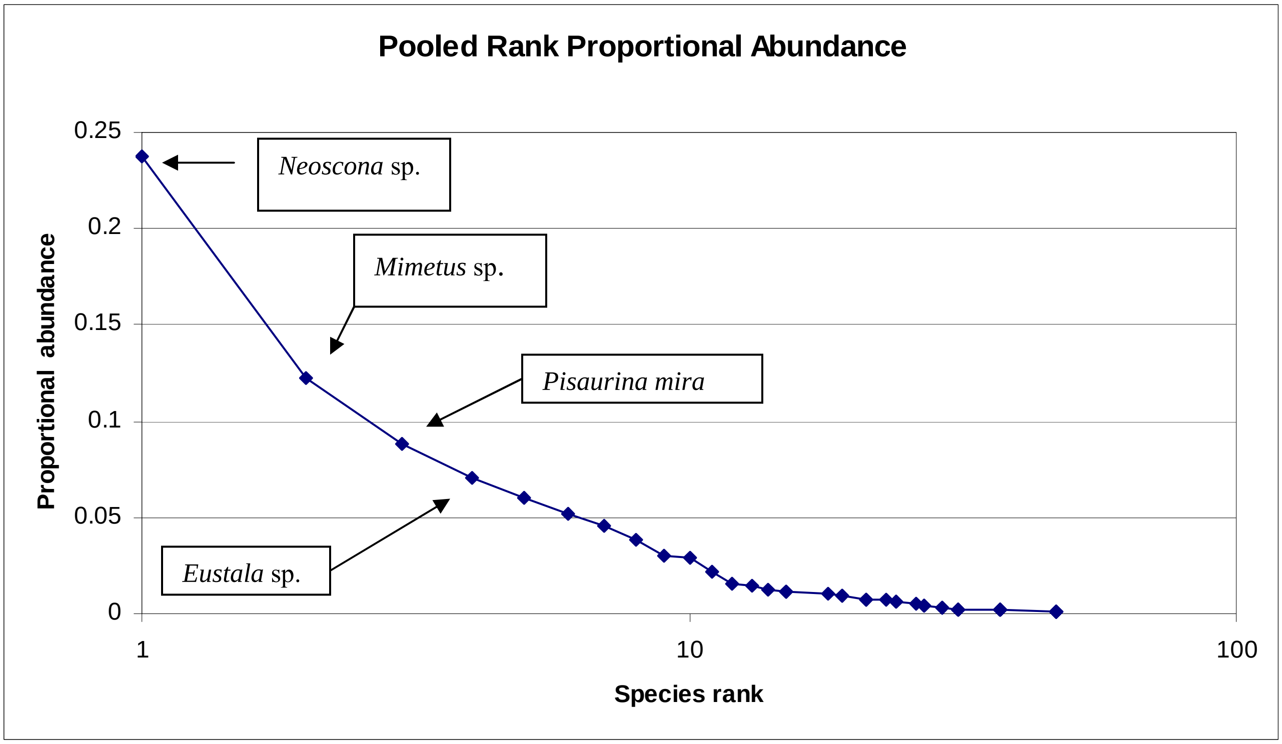

Figure 3-8 Pooled rank proportional abundance of spider species collected from five Florida state parks.

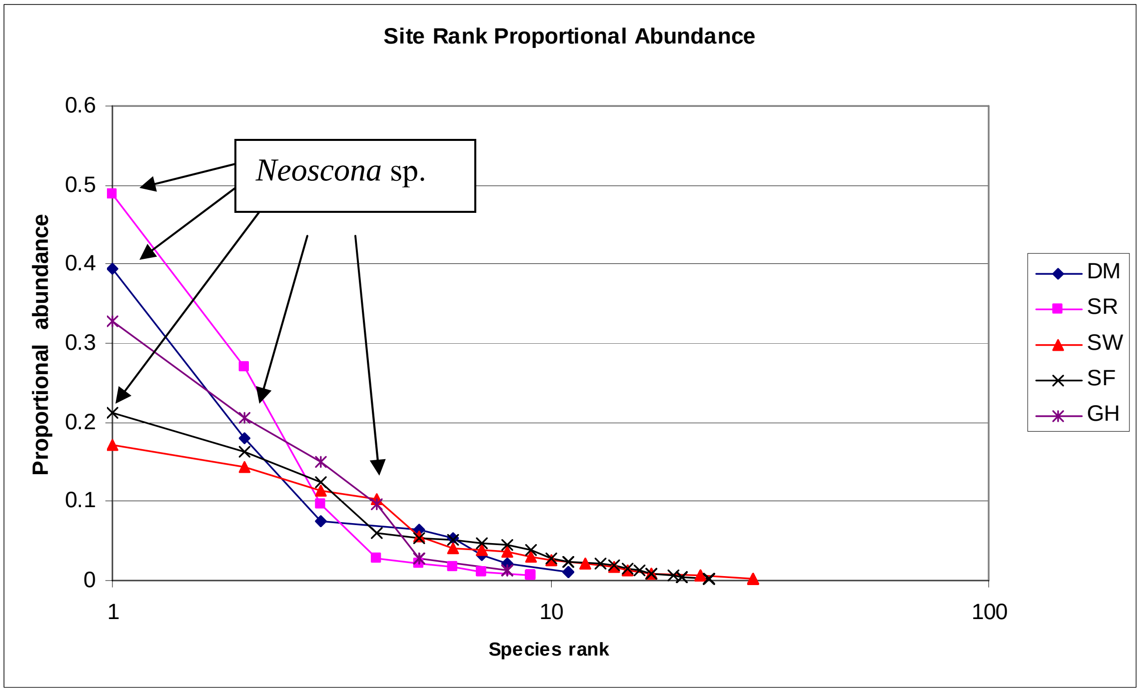

Figure 3-9. Site rank proportional abundance of spider species collected at each state park. DM = Devil's Millhopper State Park, SF = San Felasco State Park, GH = Mike Roess Gold Head Branch State Park, SR = Silver River State Park, SW = Suwannee River State Park

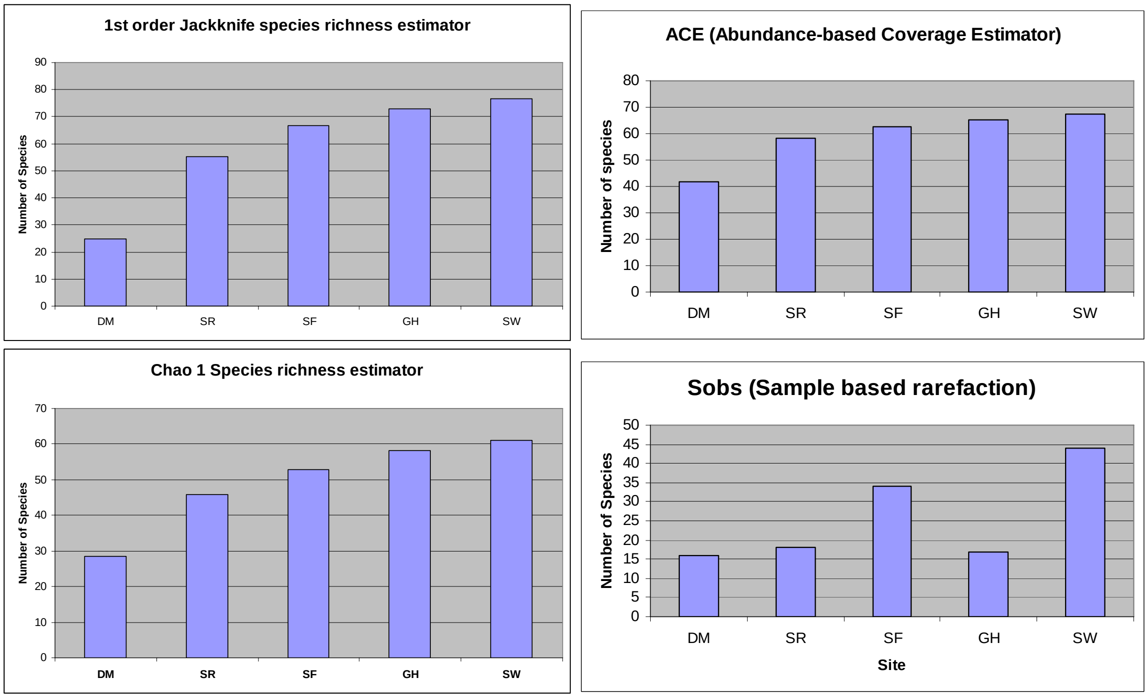

Figure 3-10. Species richness estimation for spider prey tabulated by site: DM = Devil's Millhopper State Park, SF = San Felasco State Park, GH = Mike Roess Gold Head Branch State Park, SR = Silver River State Park, SW = Suwannee River State Park

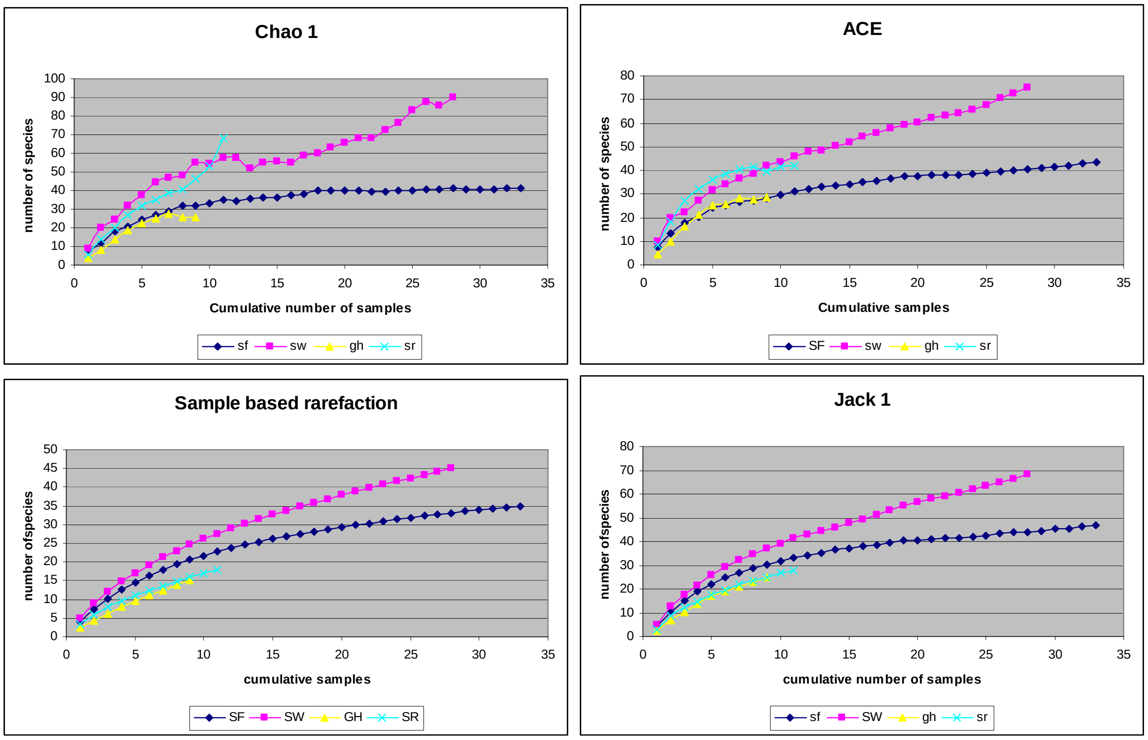

Figure 3-11. Species richness estimator performance for spider prey tabulated by site: DM = Devil's Millhopper State Park, SF = San Felasco State Park, GH = Mike Roess Gold Head Branch State Park, SR = Silver River State Park, SW = Suwannee River State Park

Table 3-1 Spiders found as prey in nests of *Trypoxylon lactitarse* in north central Florida

Family	**Genus**	**Species**	**DM**	**SR**	**SF**	**GH**	**SW**	**Sum**
Agelenidae	*Agelenopsis*	sp.	1	0	0	0	2	3
Aniphedidae		sp.	0	0	1	1	3	5
Anyphaenidae	*Hibana*	sp.	0	1	1	0	1	3
Anyphaenidae	*Hibana*	*velox*	0	0	10	0	3	13
Anyphaenidae	*Lupettiana*	*mordax*	2	0	1	0	1	4
Araneidae	*Acacesia*	*hamata*	1	0	2	0	5	8
Araneidae	*Araneus*	*bicentenareus*	0	1	11	0	1	13
Araneidae	*Araneus*	*juniperii*	0	0	3	0	15	18
Araneidae	*Araneus*	*miniatus*	1	0	1	1	9	12
Araneidae	*Araneus*	*pegnia*	1	1	2	1	8	13
Araneidae	*Araneus*	sp.	1	0	18	1	14	34
Araneidae	*Argiope*	*aurantia*	0	0	0	0	1	1
Araneidae	*Argiope*	sp.	0	0	0	0	1	1
Araneidae	*Eriophora*	*ravilla*	0	0	4	0	0	4
Araneidae	*Eustala*	*anastera*	0	5	25	0	5	35
Araneidae	*Eustala*	sp.	5	48	29	0	9	83
Araneidae	*Kaira*	*alba*	0	0	1	0	0	1
Araneidae	*Larina*	*directa*	1	0	0	0	1	2
Araneidae	*Mecynogea*	*lemniscata*	6	0	15	0	52	71
Araneidae	*Metapeira*	sp.	0	0	0	0	6	6
Araneidae	*Metazygia*	*zilloides*	0	1	0	0	0	1
Araneidae	*Metepeira*	*labyrinthea*	0	0	7	0	0	7
Araneidae	*Neoscona*	*arabesca*	0	0	6	0	3	9
Araneidae	*Neoscona*	*crucifera*	3	0	0	2	0	5
Araneidae	*Neoscona*	sp.	37	87	100	15	41	279
Araneidae	*Ocrepeira*	sp.	0	1	9	0	1	11
Araneidae	*Scoloderus*	sp.	0	1	0	0	0	1
Araneidae	*Wagneriana*	*tauricornis*	7	2	28	0	8	45
Araneida	*Parauixia*	sp.	0	0	1	0	1	2
Clubionidae	*Elaver*	*excepta*	0	0	1	1	0	2
Corinnidae	*Trachelas*	*similes*	0	0	1	1	0	2
Corinnidae	*Trachelas*	sp.	0	0	0	24	1	25
Mimetidae	*Mimetus*	sp.	7	17	58	0	62	144
Philodromidae	*Philodromus*	sp. 1	0	1	0	1	1	1
Philodromidae	*Philodromus*	sp. 2	0	2	0	0	1	3
Philodromidae	*Philodromus*	sp. 3	0	0	0	0	1	3
Pisauridae	*Dolomedes*	*albineus*	0	3	1	2	3	9
Pisauridae	*Dolomedes*	sp.	0	1	4	0	2	7
Pisauridae	*Pisaurina*	*mira*	17	0	76	0	11	104
Pisauridae	*Pisaurina*	sp.	0	0	0	0	2	2

Table 3-1 Continued.

Family	**Genus**	**Species**	**DM**	**SR**	**SF**	**GH**	**SW**	**Sum**
Salticidae	*Hentzia*	*mitrata*	0	0	0	0	2	0
Salticidae	*Lyssomanes*	*viridis*	0	0	0	7	13	15
Salticidae	*Metacyrba*	*floridana*	0	0	0	0	1	1
Salticidae	*Phidippus*	*pulcherrimus*	0	0	2	0	0	2
Salticidae	*Phidippus*	*regius*	0	0	0	1	0	1
Salticidae	*Platycryptus*	*undatus*	0	0	0	1	2	3
Salticidae	*Thiodina*	sp.	0	0	1	0	0	1
Salticidae	*Thiodina*	*sylvana*	2	1	24	7	20	54
Salticidae	*Zygoballus*	*sexpunctatus*	0	0	0	0	3	3
Segestriidae	*Ariadna*	*bicolor*	0	0	1	1	0	2
Tetragnathidae	*Leucauge*	*venusta*	0	4	11	0	2	2
Tetragnathidae	*Leucauge*	sp.	0	1	1	0	0	17
Tetragnathidae	*Nephila*	*clavipes*	2	0	24	0	37	61
Theridiidae	*Argyrodes*	sp.	0	0	0	0	1	1
Theridiidae	*Theridion*	sp.	0	0	7	11	0	11
Thomisidae	*Misumenops*	*oblongus*	0	0	0	0	2	11
Thomisidae	*Misumenops*	sp.	0	0	0	0	1	2
Thomisidae	*Synema*	*parvula*	0	0	0	0	2	2
Thomisidae	*Tmarus*	sp.	0	0	0	24	1	1
	Argyia	*giaparatia*	0	0	0	0	1	1
Total			94	178	467	73	361	1173

DM = Devil’s Millhopper State Park, SF = San Felasco State Park, GH = Mike Roess Gold Head Branch State Park, SR = Silver River State Park, SW = Suwannee River State Park

Table 3-2. Similarity indexes and comparisons for spider prey

Site	Observed shared species	Jaccard (Classic)	Chao-Jaccard raw abundance-based	Chao-Jaccard estimate abundance-based	Sorensen Classic	Chao-Sorensen raw abundance-based	Chao-Sorensen-estimate abundance-based
DM vs. SR	6	0.214	0.577	0.605	0.353	0.731	0.754
DM vs. SF	13	0.351	0.749	0.789	0.52	0.856	0.882
DM vs. GH	6	0.222	0.264	0.31	0.364	0.417	0.474
DM vs. SW	15	0.326	0.756	0.882	0.492	0.861	0.938
SR vs. SF	14	0.368	0.62	1.0	0.538	0.766	1.0
SR vs. GH	5	0.167	0.269	0.367	0.286	0.424	0.537
SR vs. SW	15	0.313	0.454	0.621	0.476	0.624	0.766
SF vs. GH	10	0.244	0.223	0.418	0.392	0.364	0.59
SF vs. SW	25	0.463	0.847	0.953	0.633	0.917	0.976
GH vs. SW	11	0.216	0.47	0.47	0.355	0.45	0.64

DM = Devil’s Millhopper State Park, SF = San Felasco State Park, GH = Mike Roess Gold Head Branch State Park, SR = Silver River State Park, SW = Suwannee River State Park

Table 3-3. Summary of diversity values for prey items tabulated by site

Statistic	DM	SR	SF	GH	SW
Individuals	94	178	467	73	361
Simpson index of diversity	6.81	9.4	9.69	10.13	10.25
Shannon index of diversity	2.21	2.65	2.78	2.87	2.91
Shannon evenness	0.735	0.594	0.755	0.735	0.772

DM = Devil’s Millhopper State Park, SF = San Felasco State Park, GH = Mike Roess Gold Head Branch State Park, SR = Silver River State Park, SW = Suwannee River State Park

CHAPTER 4
EFFECTS OF PRESCRIBED FIRE ON BIODIVERSITY AND SPECIES RICHNESS OF CAVITY NESTING HYMENOPTERA IN SUWANNEE RIVER STATE PARK, FLORIDA

Abstract

I examined the effect prescribed fire management had on the biodiversity and species richness of populations of trap-nesting Hymenoptera and associated arthropods in Florida. Four sandhill pine habitat sites (two burned sites and two unburned sites) at Suwannee River State Park were examined over a two-year period. For trap-nesting Hymenoptera, overall, species richness was different between treatment sites, and diversity was significantly different ($p < 0.05$) between burned and unburned sites. Overall diversity was not significantly different over time. Both unburned and burned sites showed similarity in species composition, which was especially high when an abundance-based estimate of similarity was used. When functional groups of trap-nesting Hymenoptera were analyzed (predators, parasitoids and pollen collectors), pollinators and parasitoids were not significantly different between burned and burned sites. Predators were more abundant ($p = 0.10$) in unburned habitat. Of the six most abundant species examined, *Trypoxylon lactitarse* (Hymenoptera: Sphecidae) was significantly more abundant on unburned sites ($p < 0.05$), while *Isodontia* spp. (*I. auripes and I. mexicana,* Hymenoptera: Sphecidae) were significantly more abundant on burned sites ($p < 0.05$). *Xylocopa virginica* (Hymenoptera: Anthophoridae) had significantly higher abundance on burned habitat than unburned habitat ($p = 0.10$). Chrysididae spp., Megachilidae spp. and *Monobia quadridens* (Hymenoptera: Vespidae) were not

significantly different, in terms of abundance, between burned and unburned sites. Overall, prescribed fire employed by the park service to maintain natural sandhill pine habitat has some impact on trap-nesting Hymenoptera and associated arthropods in terms species richness and diversity. Although diversity and species richness changes were determined, the use of trap-nesting Hymenoptera to detect community changes from small-scale fires such as prescribed fire on their own may not be an appropriate choice to detect community changes owing to the substantial flight ranges of these insects.

Introduction

Fire is an integral part of forest and grassland ecosystems throughout the United States. Urban sprawl has increased the wildland-urban interface, causing increased concerns about wildfire. Prescribed fire is a useful tool to reduce the intensity of wildfires and has been shown to be effective in reducing hazardous fuels, disposing of logging debris, preparing sites for seeding or planting, improving wildlife habitat, managing competing vegetation, controlling insects and disease, improving forage for grazing, enhancing appearance, improving access and in perpetuating fire-dependent species (Biswell 1999, Cumming 1964, DellaSala and Frost 2001, Fuller 1991, Helms 1979, Long *et. al.* 2005, Mutch 1994, Wade *et. al.* 1988). Prescribed fire is a proven, frequently used tool that works well in many aspects of wildland management. Many natural areas, including state parks, utilize prescribed fire to restore and preserve native habitat and plant communities in addition to reducing the risk of uncontrolled wildfire (Siemann *et al.* 1997, Daubenmire 1968, Hurlbert 1965). Many studies have been conducted to examine the effect of fire on animal and plant communities, with some examining arthropods. Fire not only causes direct mortality in arthropods (Fay and Samenson 1993, Bolton and Peck 1946, Miller 1978, Evans 1984), but also indirectly affects arthropod communities via changes in plant community composition and habitat alteration (Lawton 1983, Evans 1984). However, most invertebrate studies focus on terrestrial arthropods monitored via sweeping or pitfall traps (Bess 2002, Brand 2002, Niwa 2002, Clayton 2002, Fay 2003, and Koponen 2005) and overlook aerial insects. I examined the effect of prescribed fire on the community of trap-nesting Hymenoptera and associated arthropods. Trap-nesting hymenopterans are a diverse group of insects that include various functional groups and interspecies interactions. This diverse group includes predators, pollen specialists, and parasitoids. Fire may affect the various subgroups differently depending on the alteration of resources. I investigated the effect of fire on the biodiversity of these insects by using traps in Florida state parks that have regularly and recently use prescribed fire. I set out to investigate the following questions about these trap-nesting insects and associated arthropods: 1) Do overall diversity and species richness differ between burned and unburned sites? 2) Do overall diversity and species richness differ between the sampled years within burned sites? 3) In terms of species sampled, how similar are the burned and unburned sites? 4) Are sampled functional groups, in terms of abundance (predator, parasitoid and pollen specialists) affected by fire? 5) Which of the most abundant species, if any, are negatively or positively affected by fire in terms of abundance?

Methods and Materials

Tools and Trap Preparation.

The traps used in this study were fabricated from seasoned 37-mm x 86-mm x 2.4m pine/spruce timbers obtained from a local home improvement store. The pine/spruce timbers were cut into 100 10-cm-long blocks. Two cavities of one of five diameters (3.2, 4.8, 6.4, 7.9 or 12.7-mm) were drilled into each block. Cavities were drilled to a depth of

80 mm on each short side (the 37-mm side), offset approximately 10-mm from the center point. Traps were assembled using one block of each diameter with the smallest cavity on top and the largest on the bottom. Blocks were stacked so that no cavity was situated directly above or below a cavity in the adjacent block. The five blocks were bound together with strapping tape (3M® St Paul, MN), and 16-gauge wire was used to further bind the stack and suspend the trap from trees and shrubs at the field sites. Each bundle of five blocks was considered to be a single trap

Field Sites.

I set four trap lines at two locations in Suwannee River State Park in Suwannee County (30° 23.149′ N, 083° 10.108′ W). The habitats surveyed were burned and unburned sand hill habitat. Descriptions of this habitat can be found in Franz and Hall (1991). Sites that were burned within the current year were considered burned sites and sites that had significant understory growth resulting from at least three years free of fire were considered unburned. These unburned sites tended to have a thick understory and were slated for prescribed burn if possible in the next couple of seasons. Four subsites, two for each burn treatment, were established in the park. These subsites were designated burned 1, burned 2, unburned 1, and unburned 2. Neither of the unburned subsites was burned allowing for a two-year period of observation.

Field Placement

Transects were set up with ten traps placed approximately 10 m apart and were hung approximately 1.5 m off the ground on trees or limbs with placement on dead standing wood preferred. Transects were initially established (direction and distance from center of plot) randomly. Four transects were established in Suwannee River state park. Two transects were established in recently burned habitat (with smoldering still ongoing) and two additional transects were established in habitat that had not been burned in at least 3 years and had a significant understory of mixed broad leaf with some palmetto. Transects were in the field from April 2003 until January 2005.

Field Collection and Laboratory Rearing

Traps remained in the field for two years and were checked monthly. Preliminary field tests revealed that one-month intervals were sufficient to avoid trap saturation (no available cavities). Traps were considered occupied when insects were observed actively nesting, harboring or had sealed a cavity with mud or plant material. Occupied traps were removed and replaced with a new trap. These occupied traps were brought into the forest entomology lab at the University of Florida (Gainesville, FL) for processing. Occupied blocks were removed for observation while unoccupied blocks were reincorporated into replacement traps. Each occupied cavity was given a unique reference number.

Location, date of collection, diameter of cavity, and various notes describing the nature of the occupants and/or plug were recorded for each reference number. Occupied cavities were then covered with a 2, 4, 6, or 8-dram glass shell vial. The shell vials were attached to the wood section with masking tape (Duck®, Henkel Consumer Adhesive Inc., Akron OH) appropriate for wood application. These sections were then placed in a rearing room and observed daily for emergence. The rearing room was maintained as nearly as possible at outside mean temperatures for Gainesville, Florida.

When emergence occurred, the specimens were removed, preserved, and given the same reference number as the cavity from which they had emerged. Dates of emergence, identification of occupants, measurements, and notes were taken for each cavity at emergence. Remaining nest fragments and debris were kept for further analysis when possible. When an insect was harboring or actively tending a nest, it was captured, identified, and given a reference number corresponding to the cavity. The contents of the nest/cavity were then extracted and recorded. After the contents were extracted, the wood block was reused in replacement traps. These processed blocks were re-drilled to eliminate any alterations or markings (either physical or chemical) by the previous occupant prior to reuse.

Specimen Identifications

All specimens were identified by the author with some specimens identified and or verified by entomologists Jim Wiley[1], Lionel Stange[1], G. B. Edwards[1], John B. Heppner[1] and John M. Leavengood Jr. [1,2] (Florida State Collection of Arthropods[1], Gainesville, FL and University of Florida[2], Gainesville, FL) Voucher specimens have been deposited at the Florida State Collection of Arthropods in Gainesville, Florida.

Statistics and Calculations

I examined the difference between sites that were recently burned (treatment) and those that had not been burned (non-treatment). Sites were examined for differences in abundance of functional groups and abundance of the six most abundant species with Analysis of Variance (ANOVA) using a Generalized Linear Mixed Model (GLMM) and ANOVA using a Linear Mixed Model (LMM) was used to examine for differences in species diversity index values. All models were computed by George Papageorgiou of the IFAS statistical help lab at the University of Florida, Gainesville, Fl, using the GLIMMIX procedure and SAS system for mixed models (SAS Institute, Inc., Cary NC) .

In addition, similarity of species presence in different sites and diversity statistics were determined to further compare burned and unburned sites. Similarity was calculated with Jaccard’s similarity index (IS_j) (Southwood 1978). This index is the proportion of the combined set of species present at either site that are present in both sites. This value ranges from 0 to 1, with 0 meaning no similarity (no species in common) in both sites and 1 meaning all species are present at both sites. The value is calculated using the following equation:

$IS_J = c / (a + b + c)$

where c is the number of species common to both sites and a and b respectively are the species exclusive to those sites.

Similarity was also calculated with Sorensen's similarity index (IS_s) (Sorensen 1948). This index is the proportion of the combined set of species present at both sites that are present in both sites. This value ranges from 0 to 1, with 0 meaning no similarity (no species in common) in both sites and 1 meaning all species are present at both sites. The value is calculated using the following equation:

$IS_s = 2c / (a + b)$

where c is the number of species common to both sites and a and b are respectively the total number of species at each site.

Similarity was also calculated for estimated population (in order to correct for under sampling bias) using Chao-Jaccard abundance based estimate similarity index (Chao *et al* 2005).

Diversity was calculated using Simpson's index of Diversity and Simpson's index of dominance (Simpson 1949). Simpson's index of diversity value ranges from 1 to S, where S is the total number of species. Simpson's index of dominance ranges from 0-1.

Simpson's index of dominance, λ is given by:

$$\lambda = \sum_{i=1}^{s} (n / N)^2$$

where n is the total number of organisms of the i^{th} species and N is the total number of organisms of all species.

Simpson's Index of Diversity is given by: $1/\lambda$

Diversity was also calculated using the Shannon index (Shannon and Weaver 1949) H′, given by:

$H' = -\sum_{i=1}^{s} (n / N) \ln (n / N)$; where n is the total number of organisms of a particular species and N is the total number of organisms of all species.

Diversity is a combination of species richness (number of species) and evenness of species abundance. Therefore, Shannon's index of evenness, J (Pielou 1966), is given by:

$J = H' / \ln s$, where s is the total number of species

Species richness was estimated using rarefaction curves (Colwell *et al.* 2004). This estimate of species richness is based on a sub-sample of pooled species actually discovered.

In addition, two non-parametric species richness estimators, ACE (Abundance based Coverage Estimator: Chao *et al.* 2000, Chazdon *et al.* 1998) and Chao 1(Chao 1984) were used. These estimators produce estimates of total species richness including species not present in any sample. Most of the indices and all of the richness estimators were computed using EstimateS 7.5 (Colwell, 2005)

Results

Field sites

During the two years of trapping, I collected 471 nests (34 pillaged by ants) in burned areas and 700 nests (62 pillaged by ants) in unburned areas. These nests yielded 53 species from 25 families and 8 orders. These results are compiled in Table 4.1.

Subsites and sampling month

Rarefaction curves of observed species richness were produced for treatment sub-site (burned 1 and burned2; unburned1 and unburned2) in order to detect a possible site effect. The resulting curves reached an asymptote and had over-lapping 95% confidence intervals showing no significant difference, in terms of specie richness, between treatment sub-sites. The identification of no significant sub-site bias allowed for sub-sites to be pooled for further analysis. In addition, the statistical model used, mixed linear model, factors out possible subsite, temporal and positional effects.

In terms of sampling months, all but two analyses did not have a significant sampling month effect (Mixed linear model: $P > 0.10$). Two functional groups, predators and parasitoids, had a significant sampling month effect (Mixed linear model: $P_{predator} = 0.004$, $P_{parasitoid} = 0.02$).

Effect of burning on species richness

Actual observed species richness was 38 species in burned habitat and 44 species in unburned habitat. Rarefaction curves of observed species richness were produced for burned and unburned sites. The rarefaction curve estimated 35 species in burned habitat and 46 species in unburned habitat. The rarefaction curve, however, did not completely attain an asymptote and should be viewed with skepticism, especially since the estimate for burned habitat richness is lower than the observed richness. The Abundance based

Coverage Estimator (ACE) did not completely stabilize and its estimate of 46.84 species in burned habitat and 62.04 species in unburned habitat should also be viewed with skepticism. The Chao 1 estimate of species richness did stabilize and yielded estimates of 47.5 species in burned habitat and 68.5 species in unburned habitat.

Effect of burning on diversity

Overall, the values for the Simpson index of diversity were 13.0 in burned habitat and 3.38 in unburned habitat. Simpson's index of diversity values were significantly different between burned and unburned habitats (LMM: F = 5.13, df = 13, P = 0.041) with burned sites having a higher index of diversity. There was no significant month effect (LMM: F = 1.21, df = 13, P = 0.3655)

Shannon's index of diversity showed burned sites were somewhat more diverse than unburned sites (unburned = 2.17, burned = 2.87). Evenness in unburned sites was less even than burned sites (Shannon evenness: unburned = 0.57, burned = 0.79)

The rank proportional abundance curve (Figure 4-1) also shows that the species abundance in unburned plots was less even.

Similarity of burned and unburned

Similarity, measured by Sorensen's index yielded a value of 0.682. Jaccard's index yielded a value of 0.5181. In addition, Chao-Jaccard estimate similarity index, which provides similarity values based on estimated populations to correct for under-sampling, gave a value of 0.928.

Functional groups

In terms of abundance, the predator group was significantly different (at p = 0.10) between burned and unburned sites, with higher abundance in unburned sites (GLMM: F = 3.76, P = 0.0745) and has a significant month effect (GLMM: F = 4.78, P < 0.001).

Both pollinators and parasitoid groups did not differ between treatments (GLMM: pollinator: F = 0.95, df = 13, P = 0.3472; parasitoid F = 0.13, df = 13, P= 0.7277). Pollinators did not have a significant month effect (GLMM: F = 0.45, df = 13, P = 0.91), but parasitoids did have a significant month effect (GLMM: F = 3.13, df = 13, P = 0.02).

Most abundant species/ species groups

Of the six most abundant species, *Trypoxylon lactitarse* was significantly more abundant in unburned habitat and *Isodontia* spp. were significantly more abundant in burned habitat (Table 4-1). *Xylocopa virginica* was significantly more abundant in burned habitat at p = 0.10 (GLMM: *T. lactitarse* F = 12.85, df = 14, P < 0.01; *Isodontia* sp.: F = 11.18, df = 14, P < 0.01; *X. virginica:* F = 3.84, df = 28, P = 0.07). *Monobia quadridens,* Megachilidae species and Chrysididae species were not significantly different between burned and unburned sites (GLMM: *M. quadridens:* F = 1.50, df = 14, P > 0.10; Megachilidae sp: F = 0.40, df = 14, P > 0.10, Chrysididae: F = 0.89, df = 14, P > 0.10). None of the top six most abundant species showed a month effect (GLMM: P > 0.10)

Discussion

The major justifications for using prescribed fire in state parks and natural areas are prevention of uncontrollable wildfire and maintenance/ restoration of native/ natural habitat. The Florida state park system uses informational displays and signs to emphasize the importance of fire to maintain various native habitats such as sandhill pine and rockland pine habitats. Many consider biodiversity to be an important indicator of environmental health (Magurran 1988).

In terms of species richness (both observed and estimated), unburned sites had higher values than burn sites. The only estimator that stabilized, Chao 1, estimated higher species richness in unburned sites than burned sites. For this group, especially when lower sampling effort cannot be avoided the Chao1 estimator would seem to be the best choice as it stabilized earlier and we can therefore have confidence in the estimate. The Chao 1 estimator, however, assumes homogeneity and should not be used to compare site with large compositional differences.

The similarity indices were high, especially the abundance based Chao-Jaccard estimate index which had many sub-sites as completely similar. Of the similarity indices used, Jaccard's index consistently gave the lowest, most conservative, estimate. Choice of similarity index used should depend on several things. First sampling effort is a main concern, especially in areas that have a high level of dominance and rare species are frequently overlooked. In cases of small sampling effort or undersampling it would be prudent to use the Chao-Jaccard estimate similarity index in order to correct for this bias. Secondly, the level of identification is important and can skew similarity values. As in this case, there were some groups that are notoriously difficult to identify, even by authorities and this may influence the index value if they are pooled into a morpho-species or species group. In such cases the more conservative index, Jaccard's index and Chao-Jaccard estimate similarity index should be used so that similarity is not overestimated.

Depending only on species richness values, however, can be misleading, especially when investigating an event (such as fire in Florida) that the native fauna have evolved with and to which have possibly adapted. Such events would unlikely cause localized extinction (which would change species richness) but rather alter relative abundances and dominance of species that have adapted to fire in varying degrees (which is detected by diversity). Changes in species richness may have applications in situations where the event is one that has not evolved with the fauna such as exotic species introduction or anthropogenic disturbance. As seen here, the diversity of these insects was significantly different between burn treatment sites. In this situation, the relative abundance of *Trypoxylon lactitarse,* the overall most abundant species, was significantly less abundant in burned sites. In unburned sites *T. lactitarse* is much more dominant than in burned sites (Figure 4-1). *Trypoxylon lactitarse* is so dominant in unburned areas that it lowers the evenness values and therefore overall diversity, even though unburned sites had higher values of species richness. Although the burned sites had lower species richness than unburned sites, diversity was higher because of greater evenness values. Low or lowered evenness values can be seen as a sign of disturbance. This suggests that the unburned condition is actually the disturbed state for this habitat. This makes intuitive sense since the fauna have evolved with the yearly and regular intervals of fires that are suppressed by the park service. In essence, the disturbance is the removal of fire from the ecosystem by man.

In addition, any difference in sampling years may be the result of natural habitat succession after a fire event. Most habitats have succession periods that span years and continually change over decades (Siemann *et al.* 1997, Swengel 2001). Therefore, change in diversity may be a result of succession and not a difference in sample years (e.g. especially cold winter, drought, etc.). This idea is further supported since there was no temporal effect detected for the majority of the analyzed groups over the two-year sampling period and longer intervals are needed to detect the faunal response.

Focusing on functional groups, it was surprising to not see a difference in abundance for the pollinator group. Bee communities tend to respond positively, after the initial catastrophic mortality, post-burn in response to increased floral resources (Potts *et al.* 2003). Pollen group species should see an increase, minimally a difference in sampled years of the burned sites, but did not differ in abundance. Most likely, the scale of these small prescribed fires and the mobility of these insects eliminated any impact fire may have had.

The difference in predator and parasitoid diversity follow previous observations of reductions in abundance and resulting diversity in burned areas. These groups depend on abundance of prey items and these prey items tend to have varying response to fire. Bock and Bock (1991) showed that although all grasshoppers were affected by burning, certain groups suffered higher mortality and populations took longer to regenerate. Some prey groups may be better adapted to fire and these populations rebound quicker than other prey groups (Dunwiddie1991). Parasitoids and predators are dependant on prey population and their varying ability to respond to fire and this unequal return to previous abundance pattern will inherently affect the abundance patterns of predators. This should be especially true for spider-hunting wasps and parasitoids of predators.

Hymenoptera, especially bees and wasps, are generally strong fliers with flight ranges that can span kilometers and prescribed fire tend to be restricted to variously sized sections that are commonly 10 hectares or less. Newly burned areas are easily accessible by these insects from the surrounding unburned habitat. These prescribed fires do an excellent job of removing dead standing and felled wood, but rarely eliminate all such material (pers. obs.), especially in controlled burns that tend to be less intense than uncontrolled wildfire. Uncontrolled, intense wildfire may remove most dead timber but tend to kill younger trees and, in the cases of the fire crowning, may kill mature trees resulting in possible increased nesting sites. In the end, these insects use dead wood as nesting sites and are not completely deprived of this resource within burned sites. Furthermore, the preferred nesting sites and required materials for some species, such as resin and grasses, increase in abundance and availability in response to burning.

The nature of prescribed fire does not allow for controlled experimentation, and burn site establishment is dependent on weather and park management. In order to minimize a possible site bias, the sites chosen were initially (pre-burn) identical in terms of flora and habitat. In addition, repeated measures were used for statistical analysis to further minimize the possibility of a site bias confounding the results. Even though I am confident that the measures taken to reduce influence from a site bias were adequate, the possibility of sit effects cannot be completely disregarded.

Conclusion

Overall species richness and diversity did differ between burned and unburned sites, and sites were not different between sampling dates, indicating that burning affects trap-nesting hymenopterans and associated arthropods from burning treatment.

None of the three functional groups (pollinators, predators, and parasitoids) were affected by the burn treatment. Of the six most abundant species captured, only two were significantly different ($p < 0.05$) between burned and unburned habitat, with one more abundant in burned habitat and the other in unburned habitat.

Even though diversity and species richness changes were determined, the use of trap-nesting Hymenoptera on their own may not be an appropriate choice to detect community changes from small-scale fires such as prescribed fire. These insects are volant with substantial flight range and this flight range may allow these insects to respond to a source-sink of nesting materials (resin, grasses, and cavities), yet still forage beyond the scope of the relatively small scale of the prescribed fire and perhaps eliminate any effect the treatment may have had on these groups. In the case of wildfire, where the scale is usually exponentially larger, the species richness and diversity of these insects may be more indicative of the community as a whole.

Monitoring diversity and abundance of trap-nesting hymenopterans in unburned sandhill pine habitat, however, may be an appropriate application to monitor the community. When the community becomes less even with few species, such as *T. lactitarse* dominating the proportional abundance, this may be an indicator of disturbance and that a burn is needed to maintain the desired sandhill pine habitat.

Acknowledgements

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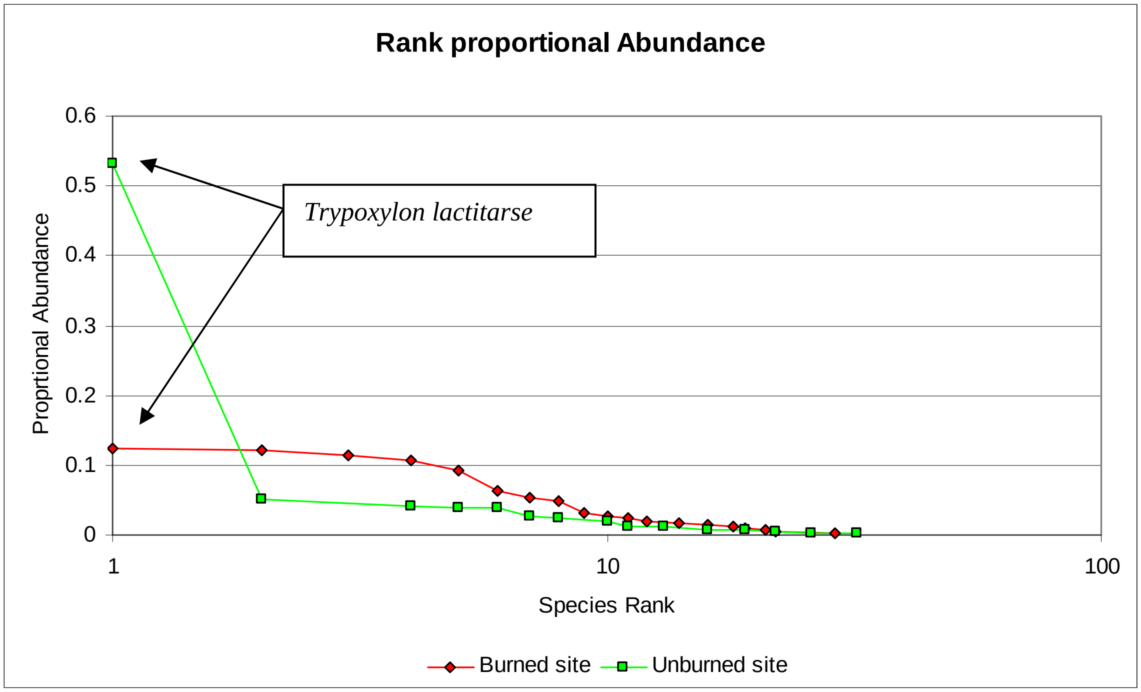

Figure 4-1. Rank proportional abundance of species in burned and unburned sandhill pine habitats

Table 4-1. Species trapped in burned and unburned sandhill pine habitat

				Number of nests in habitat		
Order	Family	Genus	Species	Functional group	Burned	Unburned
Araneida	Salticidae	*Platycryptus*	*undatus*	Predator	3	2
	Segestriidae	*Ariadna*	*bicolor*	Predator	2	4
	Clubionidae	*Elaver*	*excepta*	Predator	2	5
Blatteria	Blattaria		sp B		2	4
Coleoptera	Carabidae	*Cymindus*	*platycollis*	Parasitoid	0	2
	Tenebrionidae				0	1
	Cleridae	*Cymatodera*		Parasitoid	0	1
	Cleridae	*Lecontella*	*brunnea*	Parasitoid	1	0
	Cleridae	*Nemognatha*		Parasitoid	0	1
	Elateridae				0	1
Diptera	Bombyliidae	*Anthrax*	*analis*	Parasitoid	9	22
	Bombyliidae	*Anthrax*	*aterrimus*	Parasitoid	6	25
	Bombyliidae	*Lepidophora*	*lepidocera*	Parasitoid	4	2
	Bombyliidae	*Toxophora*	*amphitea*	Parasitoid	1	0
	Conopidae			Parasitoid	0	1
Orthoptera	Gryllidae	*Orocharis*	*luteolira*		14	7
Hymenoptera	Anthophoridae	*Xylocopa*	*virginica*	Pollen	7	1
	Formicidae	*Crematogaster*	Blk	Predator	6	26
	Formicidae	*Crematogaster*	Red	Predator	11	2
	Chrysididae			Parasitoid	40	33
	Ichneumonidae			Parasitoid	1	1
	Leucospidae			Parasitoid	1	0
	Megachilidae	*Dolicostelis*	*louisa*	Parasitoid	1	0
	Megachilidae	*Coelioxys*	*sayi*	Parasitoid	2	1
	Megachilidae	*Megachile*	*campanulae*	Pollen	1	0
	Megachilidae	*Megachile*	*georgica*	Pollen	7	5
	Megachilidae	*Megachile*	*mendica*	Pollen	9	1
	Megachilidae	*Megachile*	*xylocopoides*	Pollen	0	3
	Megachilidae	*Osmia*	*sandhouseae*	Pollen	2	0
	Mutillidae	*Sphaeropthalma*	*pensylvanica*	Pollen	1	0
	Pompilidae	*Ampulex*	*canaliculata*	Predator	1	0
	Pompilidae	*Dipogon*	*graenicheri*	Predator	1	3
	Sphecidae	*Isodontia*	*auripes*	Predator	60	9
	Sphecidae	*Isodontia*	*mexicana*	Predator	28	6
	Sphecidae	*Liris*	*beata*	Predator	0	1
	Sphecidae	*Podium*	*rufipes*	Predator	5	15
	Sphecidae	*Trypoxylon*	*clavatum*	Predator	0	12
	Sphecidae	*Trypoxylon*	*collinum*	Predator	21	17
	Sphecidae	*Trypoxylon*	*clavatum johanis*	Predator	4	15
	Sphecidae	*Trypoxylon*	*carinatum*	Predator	0	1
	Sphecidae	*Trypoxylon*	*lactitarse*	Predator	56	339
	Sphecidae	*Trypoxylon*	Red	Predator	1	3
	Sphecidae	*Trypoxylon*	Sm	Predator	0	3
	Vespidae	*Vespula*	*maculifrons*	Predator	2	1
	Vespidae	*Euodynerus*	*megaera*	Predator	13	7
	Vespidae	*Monobia*	*quadridens*	Predator	47	33
	Vespidae	*Stenodynerus*	Sp A	Predator	53	7
	Vespidae		Sp C	Predator	1	0
Lepidoptera	Pyralidae	*Uresiphita*	*reversalis*		0	2

Table 4-1 Continued. Species trapped in burned and unburned sandhill pine habitat

				Number of nests in habitat		
Order	Family	Genus	Species	Functional group	Burned	Unburned
	Noctuidae	*Cerma*	*cerintha*		0	1
	Noctuidae		sp B		0	4
Scorpionida	Buthidae	*Centruroides*	*hentzi*	Predator	12	0
Chilopoda	Scolopendridae	*Hemiscolopendra*	*punctiventris*	Predator	0	5

CHAPTER 5
BIOLOGY, PREY AND NESTS OF THE POTTER-WASP *Monobia quadridens* L. (HYMENOPTERA: VESPIDAE)

Abstract

I observed the potter wasp, *Monobia quadridens* L, nesting in predrilled wooden trap-nests at five state parks in north central Florida. Wasps nested mostly in 12.7-mm diameter cavities (97 of 129 nests) and occasionally nested in 7.9-mm diameter cavities (26 of 129 nests). Females rarely nested in 6.4-mm (5 of 129) and 4.8-mm diameter cavities (1 of 129). All cavities were 80-mm deep. Females used mud to make provisioned cells, partitions, intercalary cells, vestibular cells and a closure plug, yet did not line the inside of any cells with material. They constructed nests with an average of 1.69 provisioned cells (range = 1-3, SD = 0.47), a vestibular cell, and from 0-3 intercalary cells. All nests were solely provisioned with paralyzed caterpillars of *Macalla* sp. (*thrysisalis* or *phaeobasalis*) (Lepidoptera: Pyralidae). Cells with female brood had a mean length of 24.01 mm (range = 20-30, SD = 3.59 N= 16) while cells that resulted in males had a mean length of 18.22 mm (range = 14-25, SD =2.68, N = 23). Intercalary cells were highly variable with a mean of 13.45 mm, (range = 5-35, SD = 5.69, N = 28) as were vestibular cells with a mean of 12.78 mm (range = 1-35, SD= 9.055, N = 23). Resulting sex ratio of emerging adults was 1.2 males per female. In conclusion, nest architecture of *Monobia quadridens* is variable, females tend to nest in cavities with diameters greater than 7.9 mm, and females preyed on a single species of the Pyralid caterpillar, *Macalla* sp. (*thrysisalis / phaeobasalis*). This apparent prey specialization is

unique when compared to *M. quadridens* in other parts of its range and even to historical Florida data. Such a difference and possible shift of behavior within Florida warrants further study.

Introduction

Monobia quadridens is a common wasp in the eastern United States where it is reported from Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, West Virginia, District of Columbia, Virginia, North Carolina, South Carolina, Alabama, Georgia, Florida, Mississippi, Louisiana, Arkansas, Kentucky, Tennessee, Texas, Oklahoma, Kansas, New Mexico, Missouri, Indiana, Illinois and Ohio (Bequaert 1940). Specimens captured by Krombein (1967) at the Archbold Biological Station at Lake Placid, Florida (Highlands County) and specimens at the Florida State Collection of Arthropods in Gainesville, Florida indicate that it ranges throughout peninsular Florida, including the Florida Keys and Everglades National Park. This wasp normally nests in abandoned nests and burrows of other insects, such as carpenter bees that nest in clay banks and wood. In Florida, *Monobia quadridens* is the largest wasp that nested in traps.

When female *M. quadridens* find an acceptable cavity, they line the back end of the cavity with mud and suspend a single egg from the top of the cavity. Females hunt and paralyze caterpillars to provision the nest. When prey populations are sufficient, they tend to provision the same species of caterpillars (Krombein 1967). Females are also known to have a leisurely nesting rate taking up to a week to complete a nest with three provisioned cells and a single intercalary cell (Krombein 1967). Adults emerge from the nest two days to two weeks after completion of the nest, but actual development time is about 10-14 days.

Practically all recent research on *Monobia quadridens* has been on the biochemistry and physiology of organisms and proteins extracted from its hemolymph and little has been done to examine the ecology of the wasp. The objectives for this study are to determine the preferred nesting cavity diameter, determine what prey the females are provisioning, describe nest architecture, and determine emerging sex ratio of this wasp, *Monobia quadridens,* in north central Florida.

Methods and Materials

Tools and Trap Preparation

The traps used in this study were fabricated from seasoned 37 mm x 86 mm x 2.4m pine/spruce timbers obtained from a local home improvement store. The pine/spruce timbers were cut into 100 10-cm-long blocks. Two cavities of one of five diameters (3.2, 4.8, 6.4, 7.9, or 12.7-mm) were drilled into each block. Cavities were drilled to a depth of 80 mm on each short side (the 37-mm side), offset approximately 10-mm from the center point. Traps were assembled using one block of each diameter with the smallest cavity on top and the largest on the bottom. Blocks were stacked so that no cavity was situated directly above or below a cavity in the adjacent block. The five blocks were bound together with strapping tape (3M® St Paul, MN), and 16-gauge wire was used to further bind the stack and suspend the trap from trees and shrubs at the field sites. Each bundle of five blocks was considered to be a single trap.

Field Sites

I set traps at five locations: 1) Suwannee River State Park in Suwannee County (30° 23.149′ N, 083° 10.108′ W), 2) Mike Roess Gold Head Branch State Park in Clay County (29° 50.845′N, 081° 57.688′ W), 3) Devil’s Millhopper Geological State Park in Alachua County (29° 42.314′N, 082°23.6924′ W), 4) San Felasco Hammock Preserve State Park

(29° 42.860′ N, 082°27.656′ W) in Alachua County and 5) Silver River State Park in Marion County (29° 12.317′N, 082° 01.128′ W). The habitats surveyed at Suwannee River State Park were burned and unburned sand hill habitat, while the habitat at Mike Roess Gold Head Branch State Park was burned sand hill pineland and ravine. Sites at San Felasco Hammock Preserve State Park consisted of upland and mesic hardwood hammock. Surveyed areas of Devil's Millhopper Geological State Park consisted of pine flatwood habitat and sites at Silver River State Park consisted of river habitat and upland mesic forest. Descriptions of these habitats can be found in Franz and Hall (1991).

Field Placement

Transects were set up with ten traps placed approximately 10 m apart and hung approximately 1.5 m off the ground on trees or limbs with placement on dead standing wood preferred. Transects were initially established (direction and distance from center of plot) randomly. Four transects were established in Suwannee River State Park while three transects were established Mike Roess Gold Head Branch State Park. Three transects were established in San Felasco State Park but size constraints only allowed a single transect in Devil's Millhopper State Park. Finally, two transects were set up in Silver River State Park. Transects were in the field from April 2003 until January 2005.

Field Collection and Laboratory Rearing

Traps remained in the field two years and were checked monthly. Preliminary field tests revealed that one-month intervals were sufficient to avoid trap saturation (no available cavities). Traps were considered occupied when insects were observed actively nesting, harboring or had sealed a cavity with mud or plant material. Occupied traps were removed and replaced with a new trap. These occupied traps were brought into the forest entomology lab at the University of Florida in Gainesville, Fl for processing.

Occupied blocks were removed for observation while unoccupied blocks were reincorporated into replacement traps. Each occupied cavity was given a unique reference number.

Location, date of collection, diameter of cavity, and various notes describing the nature of the occupants and/or plug were recorded for each reference number. Occupied cavities were then covered with a 2, 4, 6, or 8-dram glass shell vial. The shell vials were attached to the wood section with Duck® (Henkel Consumer Adhesive Inc., Akron OH) masking tape appropriate for wood application. These sections were then placed in a rearing room and observed daily for emergence. The rearing room was maintained as nearly as possible at outside mean temperatures for Gainesville, FL.

When emergence occurred, the specimens were removed, preserved and given the same reference number as the cavity from which they had emerged. Dates of emergence, identification of occupants, measurements and notes were taken for each cavity at emergence. When a female *M. quadridens* was harboring or actively tending a nest, it was captured, identified, and given a reference number corresponding to the cavity. The contents of the nest/cavity were then extracted and recorded. After the contents were extracted, the wood block was reused in replacement traps. These processed blocks were re-drilled to the next size diameter cavity to eliminate any alterations or markings (either physical or chemical) by the previous occupant prior to reuse. All adult *Monobia quadridens* that successfully emerged from cavities were curated and sexed.

Identifications

Monobia quadridens is readily distinguished from other vespid wasps. Specimen diagnostics are given in Appendix B and figures of both sexes of *Monobia quadridens* are given in Appendix A.

All cavity nesters and their prey were identified by the author with some specimens identified or verified by entomologists Jim Wiley[1], Lionel Stange[1], John B Heppner[1], John M. Leavengood Jr.[1,2] (Florida State Collection of Arthropods, Gainesville, FL and University of Florida[2], Gainesville, FL). Voucher specimens have been deposited at the Florida State Collection of Arthropods.

Statistical Analysis

Descriptive statistics (means, ranges, standard deviation) were calculated using Microsoft Excel statistical package. Chi-squared goodness of fit was used to examine nest diameter preference. The assumption was that wasps would nest equally in all acceptable diameters.

Results

Nest Architecture

Monobia quadridens nested in 129 cavities over the two-year period of observation, mostly nesting in 12.7-mm cavities (97 of 129 nests) and occasionally nesting in 7.9-mm cavities (26 of 129 nests). Females rarely nested in 6.4 mm-cavities (5 of 129) and 4.8-mm cavities (1 of 129). Females did not nest equally in all diameters (chi-squared contingency table, $\chi^2 = 184.51$, df = 3, $P < 0.001$) when the data were pooled. Females did not nest equally in all diameters at individual sites ($P < 0.001$: $\chi^2_{\text{Devil's Millhopper}} = 23.25$, $\chi^2_{\text{Goldhead}} = 134.56$, $\chi^2_{\text{San Felasco}} = 65.33$, $\chi^2_{\text{Suwannee River}} = 32.62$, and $P < .05$: and $\chi^2_{\text{Silver River}} = 8.2$) and during particular years ($P < 0.001$, $\chi^2_{2003} = 101.0$, $\chi^2_{2004} = 144.69$). See table 5.1 for a summary of nesting results.

Whenever females were observed plugging a cavity, the nests (n = 32) were later dissected to examine nest architecture. Females used mud to make the cell partitions and closing plug yet did not line the sides of cells with material. Nests averaged 1.69 provisioned cells (SD = 0.47, range 1-3, N= 32), with vestibular cells (an empty cell between the cavity opening and provisioned cells) and intercalary spaces (empty, unprovisioned spaces between provisioned cells and behind the vestibular cell). Cells with female brood had a mean length of 24.01 mm (SD= 3.59, range = 20-30, N= 16) while cells containing males had a mean length of 18.22 mm (SD = 2.68, range = 14-25, N = 23). Intercalary spaces were highly variable with a mean of 13.45 mm (SD = 5.69, range = 5-35, N = 28), as were vestibular cells with a mean of 12.78 mm (SD = 9.055, range = 1-35, N = 23). On average, nests had two provisioned cells usually separated by at least one intercalary space. Use of the intercalary spaces varied; some nests had an intercalary space in front of each provisioned cell while other nests had a single provisioned cell with multiple intercalary spaces leading to the vestibular cell. Nests had a mean of 1.28 (SD = 0.631,range = 0-3, N= 32) intercalary spaces per cavity.

Sex Ratio

I collected 129 nests of *Monobia quadridens* from traps. These nests yielded a sex ratio of 1.2 males per 1 female (N= 245).

Prey

Females suspended a single egg from the top of each cell with a filament and would then search for prey. All prey items were the caterpillar, *Macalla* sp. (*thrysisalis/ phaeobasalis*) (Lepidoptera: Pyralidae). These two species cannot be distinguished without rearing out to adult stage, but this is impossible since caterpillars have been paralyzed by the wasp. Females would position these paralyzed caterpillars longitudinally with the head toward the rear of the cavity. Developing larvae would leave caterpillar head capsules, allowing for prey confirmation after emergence. On average, there were 3.0, (SD = 0.67, range 2-5, N= 98) caterpillars per cell.

Discussion

Nest Architecture

Krombein (1967) reported that in some populations, including a central Florida population, females used agglutinated sand to construct partitions and plugs. None of the populations I observed used agglutinated sand although all trap lines were within 2 kilometers of a mud resource such as roads or bodies of water. Nests had a mean of 1.69 cells but in actuality nests usually had 2 provisioned cells in 80-mm long cavities, with occasional nests with a single provisioned cell lowering the mean. Bequaert (1940) reported that the typical pattern for solitary eumenid wasps, including *M. quadridens*, is a nest containing up to 12 cells in preexisting cavities. These cavities are usually burrows made by some other insect in clay banks or wood and do not usually have the confines of the traps used that had cavities only 80-mm long. Krombein (1967) reported that *M. quadridens* primarily nested in 12.7-mm diameter cavities with rare (2 of 78) occasions of nesting in 6.4-mm diameter cavities. He stated that most females are too large to enter a 6.4-mm cavity which restricts nesting activity to diameters larger than 6.4-mm. The Florida populations I observed were similar in this respect. *Monobia quadridens* mostly nested in 12.7-mm cavities with some in 7.9-mm cavities and rarely (5 of 129) in 6.4-mm cavities. I did trap an uncompleted nest in a 4.8-mm cavity, however the nest was abandoned after a single egg was laid and two caterpillars were provisioned. The single cell was not sealed and did not develop, yet since an egg was deposited and prey provisioned, the female most likely may have died and not necessarily absconded because the cavity was too small. The partial provisioning and oviposition, however, indicates that smaller *M. quadridens* could nest in diameters as small as 4.8 mm.

Cavity diameter did not seem to alter the size of male or female cells. In fact, one nest in a 7.9-mm cavity contained a provisioned cell that was at the top end of the size range (30mm) and provisioned cell per nest range (3.0). These nests in 7.9-mm cavities tended to use fewer and smaller non-provisioned elements (vestibule cells and intercalary spaces) perhaps compensating for loss of volume due to the smaller diameter. Of the nests dissected and examined for cell dimensions, only three nests were in 7.9-mm diameter cavities with the remaining nests being in 12.7-mm cavities. The other, rarely caught diameters (6.4-mm and 4.8-mm) cavities were not examined for cell dimensions.

Sex Ratio

Krombein (1967) observed a similar sex ratio of 1:1 (M: F, 65 males, 63 females) in a Florida population of *M. quadridens*. He observed female biased sex ratios of 1: 1.8 (M: F, N= 50) in Maryland and 1:1.6 (M: F, N= 41) in North Carolina. I found a male biased sex ratio of 1.2:1 (M: F) more similar to Krombein’s (1967) Florida observation. Sex ratios tend to be skewed in relation to resources demands, which intuitively may suggest for the differences in these populations. Our Florida populations were similar to each other while slightly differing from the more northern populations. These two different parts of the range intuitively have different habitats and prey, but Krombein’s (1967) reported sex ratios are not drastically skewed to suggest resource strain on the population.

Prey

The observed prey items provisioned by *Monobia quadridens* were identical for all sites. Over the entire two-year period and the 98 nests were prey were verified, only *Macalla* sp. (*thrysisalis* / *phaeobasalis*) (Lepidoptera: Pyralidae) was provisioned. Krombein et al. (1979) reported *Neophopteryx uvinella* (Rag.), *Neophopteryx*. sp., Phycitinae species, *Epipaschia superatilis* Clem., *Epipaschia*. sp. *Tetralopha asperatella* (Clem.), *Tetralopha* sp., Epipaschiinae species, *Desmia funeralis* (Hbn.), Pyraustinae species, *Stenoma schaegeri* Zell., *Stenoma* sp., Stenomidae species., *Psilocorsis* sp., Gelechiidae species., *Platynota* sp., and Tortricidae species. In Krombein's (1967) Florida population (Lake Placid), he found 9 species of prey from 4 families extracted from 11 nests, in North Carolina he found 4 species from 3 families extracted from 3 nests and in Maryland he found 4 species from 3 families extracted from 7 nests. All of the species were included in the list from Krombein *et al.* (1979).

Although our observed prey species, *Macalla* sp. (*thrysisalis / phaeobasalis*), was not previously reported, it is a member of the family (Pyralidae) previously reported as prey for *M. quadridens*. *Macalla thrysisalis* and *M. phaeobasalis* are the only *Macalla* sp. recorded from Florida (Kimball 1965). *Macalla thrysisalis* has only been recorded to feed on Mahogany and *M. phaeobasalis* on , but complete host ranges have not been explored for these species or many other species of Lepidoptera (Pers. Comm. J.B. Heppner Florida State Collection of Arthropods, Gainesville, Florida). The fact that my observed populations, however, only yielded a single species poses interesting questions that warrant further investigation. With relatively few samples Krombein (1967), obtained a fairly wide host range for *M. quadridens* spanning across families. He also stated that *M. quadridens* seem to concentrate on storing caterpillars of a single species when abundant, but the trend he observed was in short time periods and even then some cells would contain a singleton of another prey species. This activity would most likely be the result of a source sink, such as a population boom of a caterpillar species on a nearby host tree. Yet, my populations yielded only one species over the course of two years with 98 nests sampled during various times of the year. This strongly suggests that *M. quadridens* has been specializing on this prey species in these surveyed areas. Furthermore, has the Lake Placid, Florida population continued to be more of a generalist or has it become more of a specialist as its north Florida counterpart in the more than 30 years since Krombein surveyed them? Either way, such an event could provide interesting investigations into biogeography and evolutionary history for this species.

Krombein (1967) also reported *Lecontella cancellata* (LeC.), a Cleridae species and Dermestidae species as predators, but I did not observe any predator activity. A chrysidid wasp and an ichneumonid wasp were found parasitizing *M. quadridens.* Many unsuccessful pupae of cycloraphan flies, and occasionally the fly itself were commonly found in association with *M. quadridens* nests. Yet it is most likely that these flies emerged from the caterpillars that had been oviposited on prior to provisioning in the nest since the majority of larvae of *M. quadridens* successfully completed development. Furthermore, when *M. quadridens* successfully completed development the fly pupae did not complete development and when flies completed development adult *M. quadridens* were either slightly smaller or dead intact wasp larvae were found in the cell. These finding suggest that the maggots were competing for the provisioned caterpillar and not attacking the wasp larvae. There were no observations indicating that wasp larvae consumed the maggots.

Conclusion

The surveyed populations of *Monobia quadridens* were similar to observations in other parts of its range it terms of nest architecture, cavity preference, and sex ratio. Prey of this wasp, however, was quite different when compared to other populations. Not only was the prey provisioned at these sites not previously reported, but *M. quadridens* appears to be specializing on this caterpillar, *Macalla* sp. (*thrysisalis / phaeobasalis*), when in other populations *M. quadridens* was a generalist preying on various species from various families of caterpillars. I strongly suggest further examination of this observation focusing on biogeography and evolutionary history of this species.

Acknowledgements

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Table 5-1 Number nest diameters occupied by *Monobia quadridens*

Diameter (mm)	DM	SR	SF	GH	SW	Total
3.2	0	0	0	0	0	0
4.8	0	0	0	0	1	1
6.4	1	0	1	1	2	5
7.9	4	0	2	6	14	26
12.7	7	4	20	39	27	97

DM = Devil's Millhopper State Park, SF = San Felasco State Park, GH = Mike Roess Gold Head Branch State Park, SR = Silver River State Park, SW = Suwannee River State Park

CHAPTER 6
BIODIVERSITY OF TRAP-NESTING HYMENOPTERA OF FIVE NORTH FLORIDA STATE PARKS

Abstract

Maintaining biodiversity is one of multiple objectives of land managers of state parks and other natural areas. I surveyed the species richness and biodiversity of trap-nesting Hymenoptera using pre-drilled wooden trap-nests at five state parks in north central Florida. I found 85 species or species groups in total from all of the parks and provide estimates of over-all species richness based on this sampling for each park. Various values of biodiversity (Simpson's indices of diversity and dominance, Shannon's indices of diversity and evenness) are reported for each park. Surveying of trap-nesting Hymenoptera and obtaining their biodiversity values by using the described traps are practical methods for land managers that require minimal resources from park staff. This allows for practical replication of the survey by detecting changes in biodiversity of these insects. The inventory of species identified may also expand park faunal records.

Introduction

Loss of biodiversity in natural and protected areas is a major concern for natural area resource managers (Kramer 2005). The main source of this loss is the impact resulting from human land-use, including agriculture, development, waterway diversion and habitat fragmentation. As human populations grow and urban areas further encroach into rural areas, protected natural areas and parks formally isolated from such influences are increasingly becoming affected. With rapid urbanization and resulting impacts, it is becoming more important to establish inventories of current flora and fauna as benchmarks for future comparisons.

The objectives of this chapter are to: 1) Report the abundances and species richness of all trap-nesting hymenoptera and associated arthropods sampled at each of the five surveyed Florida State Parks 2) Determine, by using estimators, if the inventory offered can be considered adequate and, if adequate, estimate total species richness of trap-nesting hymenopterans and associated arthropods for each state park surveyed.

Methods and Materials

Tools and Trap Preparation

The traps used in this study were fabricated from seasoned 37-mm x 86-mm x 2.4-m pine/spruce timbers obtained from a local home improvement store. The pine/spruce timbers were cut into 100 10-cm-long blocks. Two cavities of one of five diameters (3.2, 4.8, 6.4, 7.9 or 12.7-mm) were drilled into each block. Cavities were drilled to a depth of 80 mm on each short side (the 37-mm side), offset approximately 10-mm from the center point. Traps were assembled using one block of each diameter with the smallest cavity on top and the largest on the bottom. Blocks were stacked so that no cavity was situated directly above or below a cavity in the adjacent block. The five blocks were bound together with strapping tape (3M® St Paul, Minnesota), and 16-gauge wire was used to further bind the stack and suspend the trap from trees and shrubs at the field sites. Each bundle of five blocks was considered to be a single trap.

Field Sites

I set trap nests at five locations: 1) Suwannee River State Park in Suwannee County (30° 23.149′ N, 083° 10.108′ W), 2) Mike Roess Gold Head Branch State Park in Clay County (29° 50.845′N, 081° 57.688′ W), 3) Devil’s Millhopper Geological State Park in

Alachua County (29° 42.314′N, 082°23.692′ W), 4) San Felasco Hammock Preserve State Park (29° 42.860′ N, 082°27.656′ W) in Alachua County and 5) Silver River State Park in Marion County (29° 12.317′N, 082° 01.128′ W). The habitats surveyed at Suwannee River State Park were burned and unburned sand hill habitat, while the habitat at Mike Roess Gold Head Branch State Park was burned sand hill pineland and ravine. Sites at San Felasco Hammock Preserve State Park consisted of upland and mesic hardwood hammock. The area surveyed at Devil's Millhopper Geological State Park was of pine flatwood habitat and sites at Silver River State Park consisted of river habitat and upland mesic forest. Descriptions of these habitats can be found in Franz and Hall (1991).

Field Placement

Transects were set up with ten traps placed approximately 10 m apart and hung approximately 1.5 m off the ground on trees or limbs with placement on dead standing wood preferred. Transects were initially established (direction and distance from center of plot) randomly. Four transects were established in Suwannee River State Park while three transects were established Mike Roess Gold head Branch State Park. Three transects were established in San Felasco State Park but size constraints only allowed a single transect in Devil's Millhopper State Park. Finally, two transects were set up in Silver River State Park. Transects were in the field from April 2003 until January 2005.

Field Collection and Laboratory Rearing

Traps remained in the field two years and were checked monthly. Preliminary field tests revealed that one-month intervals were sufficient to avoid trap saturation (no available cavities). Traps were considered occupied when insects were observed actively nesting, harboring or had sealed a cavity with mud or plant material. Occupied traps were removed and replaced with a new trap. These occupied traps were brought into the forest entomology lab at the University of Florida in Gainesville, Fl, for processing. Occupied blocks were removed for observation while unoccupied blocks were reincorporated into replacement traps. Each occupied cavity was given a unique reference number.

Location, date of collection, diameter of cavity, and various notes describing the nature of the occupants and/or plug were recorded for each reference number. Occupied cavities were then covered with a 2, 4, 6, or 8-dram glass shell vial. The shell vials were attached to the wood section with Duck® (Henkel Consumer Adhesive Inc., Akron OH) masking tape appropriate for wood application. These sections were then placed in a rearing room and observed daily for emergence. The rearing room was maintained as nearly as possible at outside mean temperatures for Gainesville, FL.

When emergence occurred, the specimens were removed, preserved, and given the same reference number as the cavity from which they had emerged. Dates of emergence, identification of occupants, measurements, and notes were taken for each cavity at emergence. When an insect was harboring or actively tending a nest, it was captured, identified, and given a reference number corresponding to the cavity. The contents of the nest/cavity were then extracted and recorded. After the contents were extracted, the wood block was reused in replacement traps. These processed blocks were re-drilled to the next size diameter cavity to eliminate any alterations or markings (either physical or chemical) by the previous occupant prior to reuse.

Specimen Identifications

All specimens were identified by the author with some specimens identified and or verified by entomologists Jim Wiley[1], Lionel Stange[1], G. B. Edwards[1], John B. Heppner[1] and John M. Leavengood Jr. [1,2] (Florida State Collection of Arthropods[1], Gainesville, FL and University of Florida[2], Gainesville, FL). Voucher specimens have been deposited at the Florida State Collection of Arthropods in Gainesville, FL.

Statistical Analysis

Diversity was calculated using Simpson's index of diversity and Simpson's index of dominance (Simpson 1949). Simpson's index of diversity values ranges from 1 to S, where S is the total number of species. Simpson's index of dominance ranges from 0-1.

Simpson's index of dominance, λ, is given by:

$\lambda = \sum_{i=1}^{s} (n / N)^2$ where n is the total number of organisms of the i^{th} species and N is the total number of organisms of all species.

Simpson's Index of Diversity is given by: $1/\lambda$

Diversity was also calculated using the Shannon-index (Shannon and Weaver 1949) H′, given by:

$H' = - \sum_{i=1}^{s} (n / N) \ln (n / N)$ where n is the total number of organisms of a particular species and N is the total number of organisms of all species

Diversity is a combination of species richness (number of species) and evenness of species abundance. Therefore, Shannon's index of evenness, J (Pielou 1966), is given by: $J = H' / \ln s$ where s is the total number of species.

Shannon's diversity index and Simpson's diversity index can be produced in programs such as EstimateS 7.5 (Colwell, 2005).

Species richness was estimated using rarefaction curves (Colwell *et al.* 2004). This estimate of species richness is based on a sub-sample of pooled species actually discovered. In addition, three non-parametric species richness estimators, ACE

(Abundance based Coverage Estimator: Chao *et al.* 2000, Chazdon *et al.* 1998), first order jackknife (Burnham and Overton 1978, 1979, Smith and van Belle 1984, Heltshe and Forrester 1983) and Chao 1(Chao 1984) were used. These estimators produce estimates of total species richness including species not present in any sample. Most of the indices and all of the richness estimators were computed using EstimateS 7.5 (Colwell, 2005).

Similarity was calculated with Jaccard's similarity index (IS_j) (Southwood 1978). This index is the proportion of the combined set of species present at either site that are present in both sites. This value ranges from 0 to 1, with 0 meaning no similarity (no species in common) in both sites and 1 meaning all species are present at both sites. The value is calculated using the following equation:

$IS_J = c / (a + b + c)$

Where c is the number of species common to both sites and a and b respectively are the species exclusive to those sites

Similarity was also calculated with Sorensen's similarity index (IS_s) (Sorensen 1948). This index is the proportion of the combined set of species present at both sites that are present in both sites. This value ranges from 0 to 1, with 0 meaning no similarity (no species in common) in both sites and 1 meaning all species are present at both sites. The value is calculated using the following equation:

$IS_s = 2c / (a + b)$

where c is the number of species common to both sites and a and b are respectively the total number of species at each site `

Chao-Jaccard raw (uncorrected for unseen species) abundance based similarity index, Chao-Jaccard estimate (corrected for unseen species) abundance-based similarity index, Chao-Sorensen raw (uncorrected for unseen species) abundance based similarity, and Chao-Sorensen estimate (corrected for unseen species) abundance-based similarity (Chao *et al*. 2005) were calculated with EstimateS 7.5 (Colwell, 2005).

Results

Overall, I captured 85 species or species groups from 2953 nests captured at all of the sites surveyed. Broken down by park, I found 33 species at Devil's Millhopper S.P., 39 species at Silver River S. P., 40 species at San Felasco S. P., 54 species at Gold Head Branch S. P., and 53 species at Suwannee River S. P. (Figure 6-1). I provide an inventory of these trap-nesting Hymenoptera and associated arthropods, tabulated by park, in Table 6-1.

I calculated commonly used diversity statistics (Species richness, Simpson diversity, Shannon diversity, Shannon evenness) and species richness estimators (first order jackknife, ACE and Chao 1) from the nests captured from each of the five state parks surveyed (Figures 6-1, 6-2, 6-3, 6-4). Species richness estimators stabilized, suggesting sufficient sampling occurred to confidently estimate species richness for each of the sites. Species richness estimates ranged from 41.8 to 109 species. The lowest estimator (sample based rarefaction) estimated 41.8 species at Devil's Millhopper, 59.6 species Silver River, 70.9 species at San Felasco, 79 species at Mike Roess Gold Head Branch, and 85 species at Suwannee River. The higher (more conservative) estimates were 52.0 species at Devil's Millopper (ACE), 76.5 species at Silver River (1st order Jackknife), 92.2 species at San Felasco (1st order Jackknife), 102.6 species at Mike Roess

Goldhead Branch (1st order Jackknife), and 109 at Suwannee River(1st order Jackknife). See figure 6-4 for all estimates tabulated by site. All estimators stabilized except for the Jack 1 and ACE estimators at San Felasco (Figure 6-5).

Similarity of prey between sites, reported by Jaccard's similarity, Sorensen's similarity, Chao-Jaccard raw (uncorrected for unseen species) abundance based similarity, Chao-Sorensen raw (uncorrected for unseen species) abundance based similarity, Chao-Jaccard estimate (corrected for unseen species) abundance-based similarity, Chao-Sorensen estimate (corrected for unseen species) abundance-based similarity (Chao *et al*. 2005) indexes are summarized in Table 6-2. Overall, the classic formulas for Jaccard's and Sorensen's indices gave the lowest values with Jaccard's index being the lower of the pair. This is intuitive since these indices are calculated with actual observed species. All the Jaccard's indices, including the Chao versions, were more conservative by yielding lower values than their Sorensen counterparts. The only exception to this trend was two site comparisons, Goldhead vs. San Felasco were both estimate versions of Chao-Jaccard's and Chao-Sorensen's gave a value of 1.0 for complete similarity and Devil's Millhopper vs. San Felasco were the Jaccard estimate abundance-based was slightly higher (Table 6-2).

Discussion

The findings of this survey offer an inventory of trap-nesting Hymenoptera and the corresponding diversity values and estimates of overall species richness for each state park surveyed. Although the faunal list may not be expansive with only 85 observed species overall and a range of 33-54 species for each park, species richness estimators have been used to extrapolate total species richness for trap-nesting Hymenoptera of these sites. These extrapolating estimators provide a lower limit estimate for the amount of species in the sampled habitat, including unseen rare species. In essence, the estimated species richness value provided in Figure 6-1 is the minimum number of trap-nesting arthropods estimated to exist at that site.

All of the estimators for each of the sites stabilized suggesting sampling was sufficient and we can have confidence in these estimates of species richness (Figure 6-5), with the exception of two estimators (Jack 1 and ACE) at San Felasco.

These species richness estimates are useful when a complete taxonomic inventory is desired, especially when funding is an issue and an end point is needed. These species richness values are also useful and commonly used to gauge environmental well-being and monitor for change in that well-being, but relying only on this value can be misleading. Changes in species richness can indicate major changes in habitat well-being, but will not detect changes in community structure. Change in community structure can be detrimental to the overall health and sustainability of a particular habitat. There are numerous examples where two areas can have the same number of species but completely different community structure. One general scenario is where an exotic species may enter and completely dominate an area. This same habitat may have the exact same (or even higher richness if no species was driven out) amount of species richness but the exotic species may account for 80% of all of the individuals. In terms of species richness, exotic species may decrease (inhibition), increase (facilitation) or not affect the overall value (equivalency/ compensation). Changes to the ecosystem, measured via species richness, would go undetected if equivalency or compensation occurred in the monitored species assemblage (Sax *et al.* 2005). For an effective comparison or monitoring program it is essential to calculate diversity statistics (which factor in species densities) in addition to species richness. In the past, diversity statistics were complex and difficult to calculate, but computer software (usually the same program used to estimate species richness) can easily calculate these values.

San Felasco and Devil's Millhopper are geographically separated by less than 5 miles and they share similar habitat, yet species richness and diversity values for Devil's Millhopper were all lower than San Felasco. In fact, Devil's Millhopper consistently had the lowest species richness for all estimators (figure 6-4) and lowest diversity value (figures 6-2, 6-3) when compared to all other sites. Although protected, Devil's Millhopper has become an island of habitat from encroaching urbanization. The rapid growth of the city of Gainesville in the past twenty years has been substantial. Previously the park was far from the city and its effects, but now the suburbs and their effects fully border the park. For about a third of the park's main hiking trail, houses are 20-50 meters away and one part of the trail curves to avoid a support cable for a neighboring radio tower. Intuitively, it would seem that encroaching urbanization may have caused the low diversity and richness of Devil's Millhopper, but further study is needed before a definitive statement may be made. Devil's Millhopper is a unique system and therefore may be difficult to compare to other state parks. Future survey and comparison, therefore, may provide an insight to the effects of urbanization for this site.

Of the species richness estimators the Chao 1 estimator stabilized for all sites and gave the highest estimate for three of the five sites, while rarefaction (Sobs) always gave the lowest estimate. The Chao 1 estimator is a non-parametric estimator, which removes assumptions about the population, and Colwell and Coddington (1994) argue that these are superior to parametric estimators (like rarefaction). Although Chao 1 stabilized well at all sites, it provides an estimate of minimum richness and some of the assumptions with the procedure make it inappropriate to compare values between areas that have large compositional differences. Without a complete faunal list (complete species richness) for comparison, however, the true performance of these estimators for this group of insects cannot be determined. Further study such as King and Porter's (2005) evaluation of estimators for use in ant fauna is needed to fully examine performance of these estimators for cavity nesting Hymenoptera.

The Chao-Jaccard estimate abundance based and the Chao-Sorensen estimate abundance based similarity indexes show a higher degree of similarity between sites than their raw estimate counterparts. These estimate-based indexes are corrected for under-sampling bias and suggest that sites are more similar that the current observations reveal. According to Chao (2005), since under-sampling or limited sampling effort is the generally the case the Chao-Jaccard and Chao-Sorensen estimates would be the best choice especially were limited sampling is a concern and rare species make up a large proportion of the fauna. Of these two, the Chao-Jaccard estimates is generally the more conservative yielding (slightly) lower estimates of similarity with this data. The highest estimated similarity values were found for Silver River vs. San Felasco and Gold Head vs. San Felasco the lowest similarity was between Silver River and Suwannee River For the both the Jaccard and Sorensen's indices, Gold Head vs. Suwannee River and Devil's Millhopper vs. San Felasco were the most similar while Silver River vs. Gold Head were the most dissimilar. Based on the overall apparent habitat similarity between sites the trend reported by these classic indices seems appropriate. The estimate similarity values were high for all site comparisons and this is expected since the fauna sampled via traps that target cavity nesters, yet some of the comparisons yielded higher values than expected by results form their classic counterparts and apparent habitat comparison. For some non-parametric species richness estimators, such as Chao 1, assumptions are made about the populations that make it use inappropriate. Some of the sites are very different in habitat and such a bias would seem a problem, but Chao (2005) makes no mention of such a restraint for this estimator. When sampling is sufficient as determined by species richness estimators, however, I prefer the classic indices especially when habitats vary greatly.

The system used here may be a practical approach for conducting future faunal inventories of trap-nesting Hymenoptera. The simplicity of the trap system allows for practical replication. The traps themselves are of a simple design with all material available from a hardware or home improvement store. A small room or an outdoor area can be used to store traps while waiting for emergence. In addition, the manual skills needed to construct and maintain the traps are commonly required of park staff. The nature of the monthly sampling required adds a minimal amount of manual labor added to existing park workforce. Most “species” involved may be recognized easily with reference collections and some familiarity with insects. Species difficult to identify, such as species from the family Chrysididae, are entered as a group. Although genus and species level identification of the Chrysididae are extremely difficult for experts, this family as a group is easily distinguished from other trap-nesting Hymenoptera by amateurs. In addition, the method of capturing insects emerging from traps allows for minimum knowledge in entomology when outside help is available. Vials that receive emerging specimens confine and protect the specimen until it can be collected. Almost all the insects reported in this survey could be left in the vials for long periods of time without degrading the specimen quality for identification. Some nests that have many cells per nest, such as the Megachilidae, may have many specimens destroyed by siblings, but there usually are a couple of specimens in an acceptable condition for identification. This attribute of the trapping method allows for park staff to send specimens to universities or museums for identification by just adding alcohol to a vial. This would allow a park employee to completely carry out the field survey without any knowledge of entomology and never handling live insects. These attributes allow for the survey to be repeated without additional staff and at minimal cost to the institution. Such future comparisons may be excellent measurements of biodiversity and detecting change in these measurements. Such observations may be especially powerful when added to other low cost surveys such as bird watcher inventories. In addition, the normally complicated task of using species richness estimators has been simplified through availability of free computer software such as EstimateS (Colwell, 2005).

Acknowledgements

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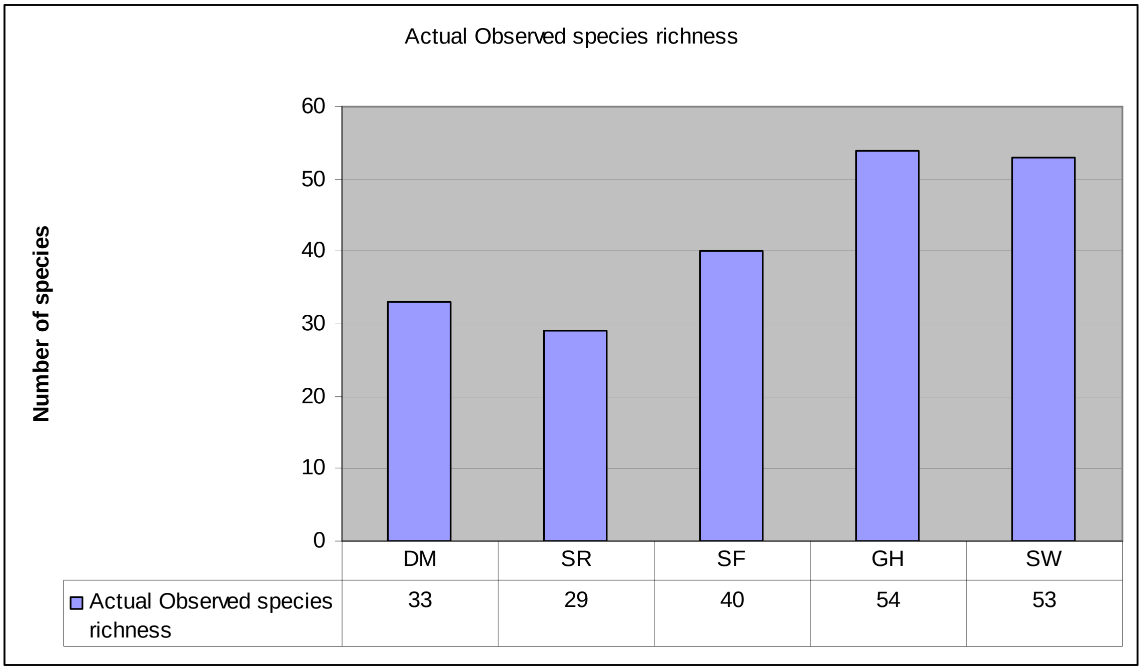

Figure 6-1. Actual observed species richness, tabulated by site. DM = Devil's Millhopper State Park, SF = San Felasco State Park, GH = Mike Roess Gold Head Branch State Park, SR = Silver River State Park, SW = Suwannee River State Park

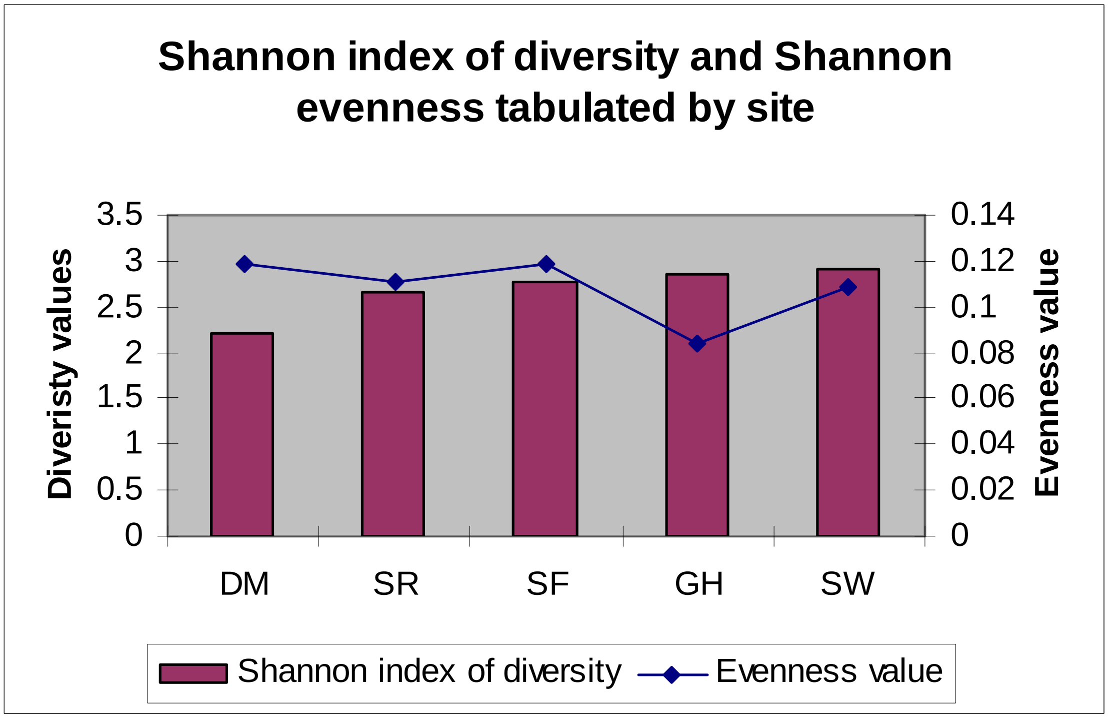

Figure 6-2. Shannon index of diversity and Shannon evenness values for trap nesting Hymenoptera and associated arthropods at five state parks. DM = Devil's Millhopper State Park, SF = San Felasco State Park, GH = Mike Roess Gold Head Branch State Park, SR = Silver River State Park, SW = Suwannee River State Park

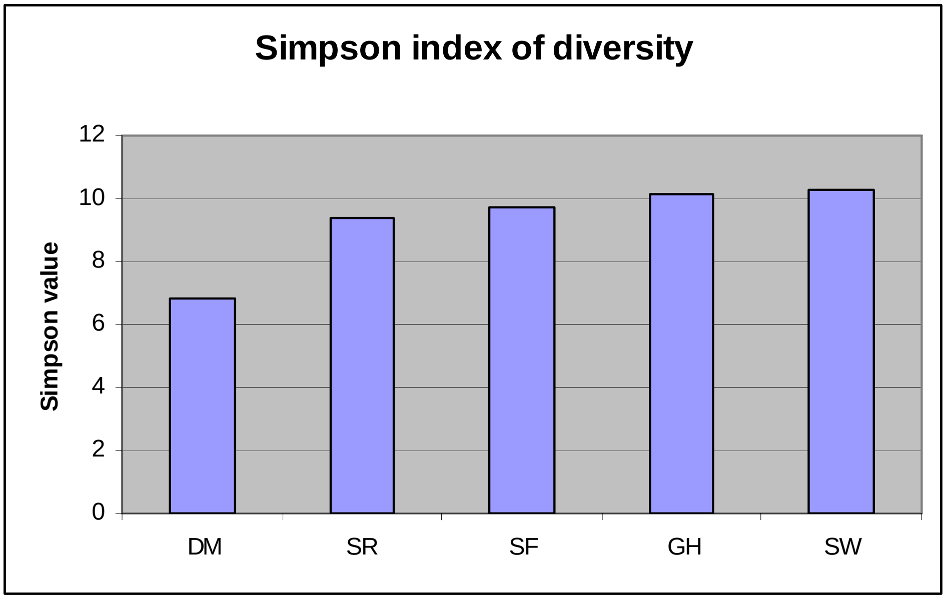

Figure 6-3. Simpson index of diversity for trap nesting Hymenoptera and associated arthropods at five state parks. DM = Devil's Millhopper State Park, SF = San Felasco State Park, GH = Mike Roess Gold Head Branch State Park, SR = Silver River State Park, SW = Suwannee River State Park

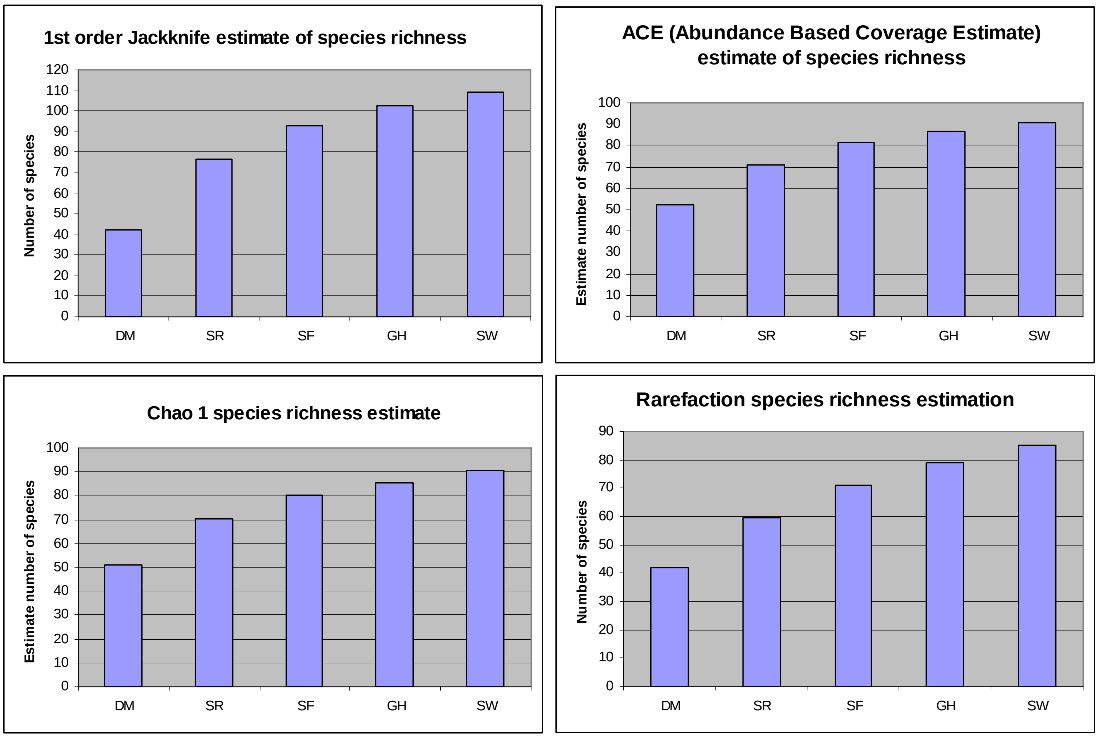

Figure 6-4. Species richness estimators tabulated by site. DM = Devil's Millhopper State Park, SF = San Felasco State Park, GH = Mike Roess Gold Head Branch State Park, SR = Silver River State Park, SW = Suwannee River State Park

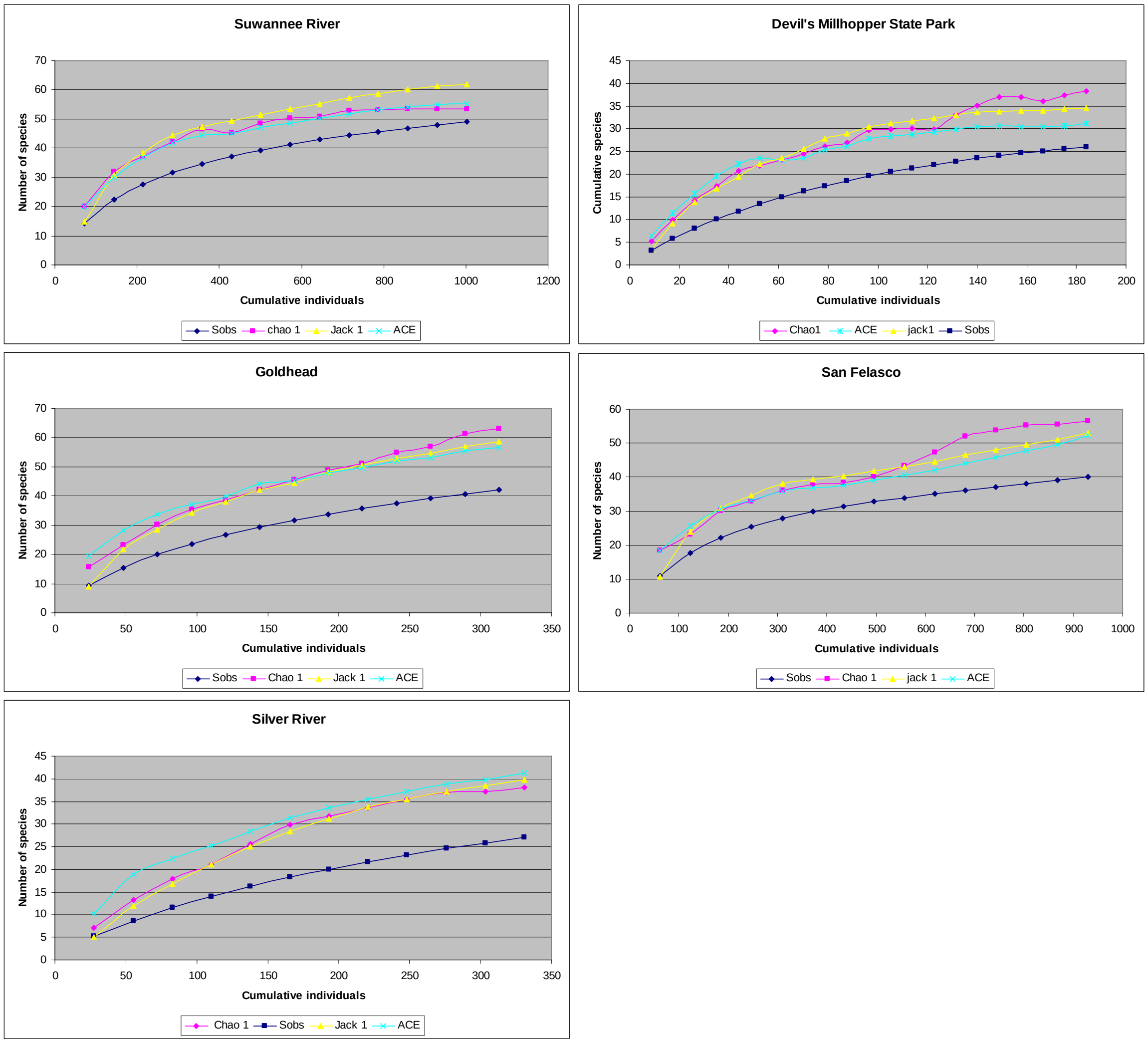

Figure 6-5. Species richness estimator performance per site

Table 6-1. Summary of trap-nesting arthropods captured in five state parks

				Number of nests at site				
Order	Family	Genus	Species	DM	SR	SF	GH	SW
Araneae	Salticidae	*Phillipus*	*regians*	0	1	0	0	0
	Salticidae	*Platycryptus*	*undatus*					
	Segestriidae	*Ariadna*	*bicolor*	0	0	6	1	2
	Clubionidae	*Elaver*	*excepta*	10	5	20	16	2
Blatttodea	Blattaria	*Eurycotis*	*floridans*	0	0	5	0	0
	Blattaria		Sp A	4	0	10	0	0
	Blattaria		Sp B	0	0	0	2	2
	Blattaria		Sp C	0	0	2	0	0
Coleoptera	Carabidae	*Cymindus*	*platycollis*	0	0	0	0	2
	Carabidae			0	0	0	1	0
	Elateridae			0	0	0	1	1
	Tenebrionidae	*Platydema*	*flavipes*	0	0	1	1	0
	Tenebrionidae			0	0	5	3	1
	Trogossitidae			0	0	0	1	0
	Trogossitidae	*Airora*	*cylindrica*	0	0	1	0	0
	Cleridae	*Cymatodera*		0	0	0	1	1
	Cleridae	*Lecontella*	*brunnea*	0	0	0	0	1
	Meloidae	*Nemognatha*	*punctulata*	3	0	0	0	1
	Elateridae			0	0	0	3	1
	Rhipiphoridae	*Macrosiagon*	*cruentum*	1	0	0	0	0
Diptera	Bombyliidae	*Anthrax*	*analis*	3	4	11	4	9
	Bombyliidae	*Anthrax*	*aterrimus*	1	4	9	7	6
	Bombyliidae	*Lepidophora*	*lepidocera*	1	2	5	9	4
	Bombyliidae	*Toxophora*	*amphitea*	0	0	0	5	1
	Tachinidae			0	0	0	1	0
Hemiptera	Egg mass			0	2	0	0	0
	Conopidae			0	0	0	1	1
Hymenoptera	Anthophoridae	*Xylocopa*	*virginica*	0	0	1	10	7
	Chrysididae			4	7	31	33	73
	Leucospidae			0	0	0	1	1
	Formicidae	*Crematogaster*	Blk	3	1	16	2	32
	Formicidae	*Crematogaster*	Red	0	0	1	0	13
	Formicidae	*Crematogaster*	Red/blk	0	0	0	3	0
	Formicidae	*Crematogaster*	*minutissima*	0	0	5	0	0
	Formicidae	*Camponotus*	Red	2	1	7	10	0
	Formicidae	*Camponotus*	black	0	0	2	3	0
	Formicidae	*Pseudomrymex*		12	1	31	4	0
	Ichneumonidae			1	0	1	2	2
	Megachilidae	*Dolicostelis*	*louisa*	0	0	0	1	2
	Megachilidae	*Coelioxys*	*sayi*	0	0	0	0	3
	Megachilidae	*Coelioxys*	*dolichos*	0	0	0	2	0
	Megachilidae	*Coelioxys*	*texana*	0	0	0	1	0
	Megachilidae	*Coelioxys*		1	1	0	1	0
	Megachilidae	*Megachile*	*campanulae*	0	1	0	0	1
	Megachilidae	*Megachile*	*mendica*	9	0	0	4	10
	Megachilidae	*Heriades*	*carinata*	0	0	0	2	2
	Megachilidae	*Megachile*	*c. wilmingtoni*	0	0	0	5	0
	Megachilidae	*Megachile*	*georgica*	2	10	0	10	12
	Megachilidae	*Megachile*	*pruina*	0	0	0	1	0
	Megachilidae	*Megachile*	*rubi*	0	0	0	4	0

Table 6-1, Continued. Summary of trap-nesting arthropods captured

				Number of nests at site				
Order	Family	Genus	Species	DM	SR	SF	GH	SW
	Megachilidae	*Megachile*	*xylocopoides*	5	2	2	2	3
	Megachilidae	*Osmia*	*sandhouseae*	0	0	0	0	2
	Mutillidae	*Sphaeropthalma*	*pensylvanica*	0	0	7	1	1
	Pompilidae	*Ampulex*	*canaliculata*	0	0	0	0	1
	Pompilidae	*Dipogon*	*graenicheri*	5	7	35	6	4
	Sphecidae	*Isodontia*	*auripes*	6	0	1	19	62
	Sphecidae	*Isodontia*	*mexicana*	2	0	1	55	35
	Sphecidae	*Liris*	*beata*	0	0	0	0	1
	Sphecidae	*Podium*	*rufipes*	3	0	8	7	20
	Sphecidae	*Trypoxylon*	*clavatum*	1	0	0	0	12
	Sphecidae	*Trypoxylon*	*collinum*	6	0	19	17	38
	Sphecidae	*Trypoxylon*	*clavatum. johanis*	6	2	12	31	19
	Sphecidae	*Trypoxylon*	*carinatum*	3	5	12	0	1
	Sphecidae	*Trypoxylon*	*johnsonii*	0	0	13	1	0
	Sphecidae	*Trypoxylon*	*lactitarse*	76	249	510	13	392
	Sphecidae	*Trypoxylon*	Red	0	0	1	0	4
	Sphecidae	*Trypoxylon*	Small	2	1	2	0	3
	Vespidae	*Ancistocerus*	*sp.*	0	1	3	0	0
	Vespidae	*Monobia*	*quadridens*	22	4	48	97	80
	Vespidae	*Vespula*	*maculifrons*	0	0	0	0	3
	Vespidae	*Euodynerus*	*megaera*	13	0	24	5	30
	Vespidae	*Stenodynerus*	sp A	0	0	1	54	58
	Vespidae	*Stenodynerus*	sp B	0	18	0	7	0
	Vespidae		sp C	2	0	0	0	1
	Vespidae	*Pacnodynerus*	*erynnis*	2	1	0	28	0
Isoptera				0	0	0	2	0
Lepidoptera	Pyralidae	*Uresiphita*	*reversalis*	0	0	0	0	4
	Noctuidae	*Cerma*	*cerintha*	0	0	0	0	1
	Noctuidae	*Litoprosus*	*frutilis*	0	2	0	0	0
	Noctuidae		sp B			1		4
Orthoptera	Gryllidae	*Orocharis*	*luteolira*	3	1	6	7	21
Orthoptera	Egg mass			1	2			
Scorpiones	Buthidae	*Centruroides*	*hentzi*	0	0	0	2	12
Scolopendromorpha	Scolopendridae	*Hemiscolopendra*	*punctiventris*	0	2	0	0	5
	Scolopendridae	*Scolopendra*	*viridis*	0	2	0	0	0

DM = Devil's Millhopper State Park, SF = San Felasco State Park, GH = Mike Roess Gold Head Branch State Park, SR = Silver River State Park, SW = Suwannee River State Park

Table 6-2. Similarity indexes and comparisons for trap-nesting Hymenoptera

Site	Observed shared species	Jaccard (Classic)	Chao-Jaccard raw abundance based	Chao-Jaccard estimate abundance based	Sorensen Classic	Chao-Sorensen raw abundance-based	Chao-Sorensen-estimate abundance-based
DM vs. SR	16	0.432	0.714	0.945	0.604	0.833	0.972
DM vs. SF	23	0.535	0.869	0.996	0.697	0.930	0.998
DM vs. GH	20	0.345	0.589	0.945	0.513	0.741	0.972
DM vs. SW	22	0.373	0.695	0.781	0.543	0.820	0.877
SR vs. SF	19	0.396	0.804	0.925	0.567	0.891	0.961
SR vs. GH	17	0.274	0.578	0.867	0.43	0.732	0.929
SR vs. SW	19	0.302	0.621	0.701	0.463	0.766	0.924
SF vs. GH	27	0.415	0.768	1.0	0.587	0.869	1.0
SF vs. SW	29	0.439	0.814	0.900	0.611	0.897	0.947
GH vs. SW	39	0.574	0.833	0.879	0.729	0.909	0.936

DM = Devil's Millhopper State Park, SF = San Felasco State Park, GH = Mike Roess Gold Head Branch State Park, SR = Silver River State Park, SW = Suwannee River State Park

APPENDIX A
ADDITIONAL FIGURES AND SPECIMEN PHOTO GUIDE

Figure A-1. Traps

Figure A-2. Rearing room

The following figures are intended to aid in identification of species frequently captured in traps. Figures A-1 through A-7 are reference photographs for diagnostic and identification guides provided in appendix B. The remaining figures are photographs of commonly captured species, provided strictly a reference or starting point. Identification of specimens should be executed using experts, diagnostic keys, monographs and other sources in the scientific literature.

Figure A-3. Male *Monobia quadridens*

Figure A-4. Female *Monobia quadridens*

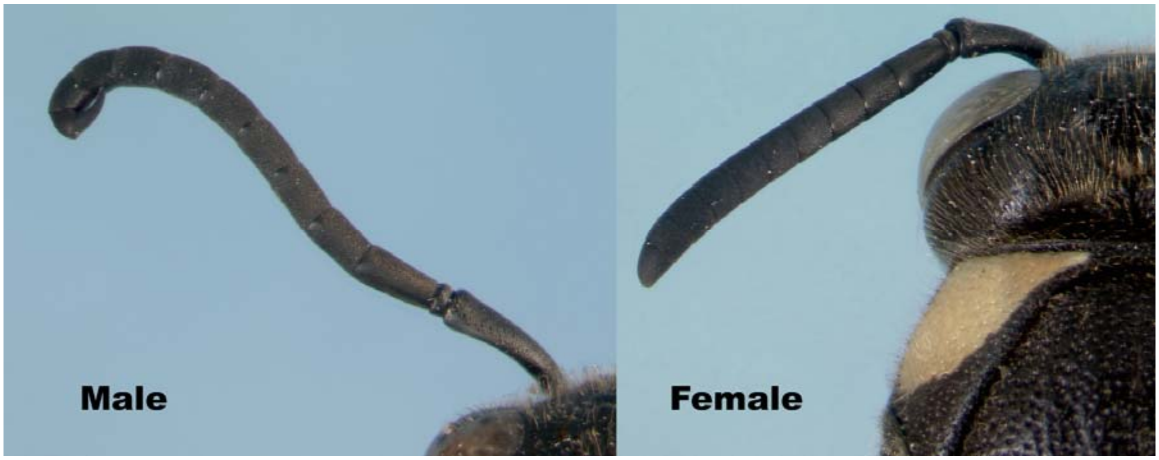

Figure A-5. Antenna of *Monobia quadridens*

Figure A-6. Male Isodontia auripes

Figure A-7. Female Isodontia auripes

Figure A-8. Male Isodontia mexicana

Figure A-9. Female Isodontia mexicana

Figure A-10. *Anthrax analis*

Figure A-11. *Anthrax aterrimus*

Figure A-12. *Lepidophora lepidocera*

Figure A-13. *Toxophora amphitea*

Figure A-14. A wasp in the family Chrysididae

Figure A-15. A series of Chrysidid wasps demonstrating variation in size and color

Figure A-16. *Lecontella brunnea*

Figure A-17. *Macrosigon cruentum*

Figure A-18. *Nemognatha punctulata*

Figure A-19. *Ancistorcerus*

Figure A-20. *Euodynerus megaera*

Figure A-21. *Pacnodynerus erynnis*

Figure A-22. *Stenodynerus* sp A

Figure A-23. *Stenodynerus* sp b

Figure A-24. *Camponotus* Red

Figure A-25. *Camponotus* Black

Figure A-26. *Crematogaster minutissima* Top: worker Bottom: Queen

Figure A-27. *Crematogaster* species

Figure A-28. *Pseudomyrmex* species

Figure A-29. A wasp of the family Leucospididae

Figure A-30. *Dolicostelis louisa*

Figure A-31. *Coelioxys sayi*

Figure A-32 .*Coelioxys dolichos*

Figure A-33. *Coelioxys texana*

Figure A-34 .*Megachile campanulae*

Figure A-35. *Megachile mendica*

Figure A-36. *Megachile c. wilmingtoni*

Figure A-37. *Megachile georgica*

Figure A-38 . *Megachile xylocopoides* female

Figure A-39. *Megachile xylocopoides* male

Figure A-40. *Osmia sandhouseae*

Figure A-41. *Sphaeropthalma pensylvanica floridensis*

Figure A-42. *Orocharis luteolira*

Figure A-43. *Ampulex canaliculata*

Figure A-44. Liris beata

Figure A-45. *Podium rufipes*

Figure A-46. *Trypoxylon clavatum clavatum*

Figure A-47. Face of *Trypoxylon c. clavatum.* Note golden vessiture

Figure A-48. *Trypoxylon carinatum*

Figure A-49. Trypoxylon clavatum johannis

Figure A-50. Trypoxylon collinum collinum

Figure A-51. *Trypoxylon johnsoni*

Figure A-52. *Trypoxylon lactitarse*

Figure A-53. *Vespula maculifrons*

Figure A-54. *Xylocopa virginica*, male

Figure A-55. *Xylocopa virginica*, female

Figure A-56. *Cerma cerintha*

Figure A-57. *Litoprosopus frutilis*

Figure A-58. *Uresphita reversali*

Figure A-59. *Centruiodes hentzi*

APPENDIX B
SELECTED SPECIMEN DIAGNOSTICS AND IDENTIFICATION

Specimen Diagnostics And Identifications For *Monobia Quadridens* (Adapted from Bequaert 1940)

Pronotum extensively and most of postscutellum creamy-yellow; propodium with lateral angles pointed; propodium black, with the exception of a small spot on the dorsal areas; wings dark violaceous.

Male: (Figure A-3) Antennae 13-segmented, last segment folded back as a hook (Figure A-5). Clypeus distinctly bidentate. Clypeus creamy-yellow (except for denticles), sometimes with areas or patterns of orange-red.

Female: (Figure A-4) Antennae 11-segmented, last segment normal, not folded back as a hook as in male (Figure A-5). Clypeus distinctly bidentate and totally black, the anterior margin slightly concave.

Specimen Diagnostics and Identification for *Isodontia auripes* and *Isodontia mexicana*

Isodontia auripes and *I. mexicana* occur sympatrically and it is important to distinguish between the two species. The following diagnostic description (Adapted from Bohart and Menke (1963)) provides characters to distinguish between the species and sexes of each species.

Isodontia auripes: black; apex of hind femur, tibia and tarsi reddish brown; wings dark violaceous;

Male: (Figure A-6) Average length 18mm; antenna with eleven flagellomeres; abdomen with seven visible tergites.

Female (Figure A-7): Average length 19mm; antenna with ten flagellomeres; abdomen with six visible tergites.

Isodontia mexicana: black; legs black; wings clear in cellular area, suffused with brown along anterior margin, veins black brown

Male (Figure A-8): Average length 16mm; antenna with eleven flagellomeres; abdomen with seven visible tergites.

Female: (Figure A-9) Average length 17mm; antenna with ten flagellomeres; abdomen with six visible tergites.

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BIOGRAPHICAL SKETCH

David Serrano was born in Miami, Florida, in 1977 to Cuban immigrants. He graduated high school in 1995 in Miami. He then attended the University of Miami where he earned a Bachelor of Science (major: biology; minor: chemistry). Through many volunteer projects and supervised projects at the University of Miami he discovered his love for ecology and biology. His experiences with Drs. Keith D. Waddington, Theodore H. Fleming, David Janos, Michael S. Gaines and Paul R. Neal helped guide David to his current career. David accepted a teaching assistantship at the University of Florida, Department of Entomology and Nematology, in the Fall of 1999. After earning his Master of Science he remained at the University of Florida. He accepted a Minority Alumni Fellowship and began his PhD program in the fall 2001. David has a daughter, Isabella Carin Serrano (born May 4th 2001). David married Esther Sarah Dunn (UF, Doctor of Plant Medicine 2005) on January 15th, 2006.