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WEALTH OF WILD BEES IN FOUR HABITATS OF THE NATIONAL RECREATIONAL AREA OF THE RIVER CHATTAHOOCHEE, ATLANTA, GEORGIA, USA

PROFESSIONAL THESIS

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MELINA LOZANO DURAN

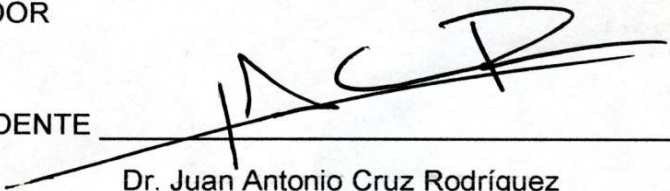
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La presente tesis titulada "RIQUEZA DE ABEJAS SILVESTRES EN CUATRO HÁBITATS DEL ÁREA RECREATIVA NACIONAL DE RÍO CHATTAHOOCHEE, ATLANTA, GEORGIA, EE.UU" fue realizada por la C. Melina Lozano Durán bajo la dirección del Dr. Juan Antonio Cruz Rodríguez, ha sido revisada y aprobada por el Jurado Examinador, como requisito parcial para obtener el título de INGENIERO EN AGROECOLOGÍA.

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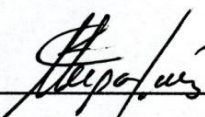
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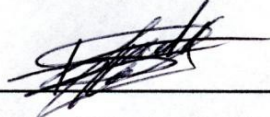
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IN MEMORY OF:

Priscilla Louise Nalls (1947-2013)

Elizabeth Shaw Phelps (1960-2014)

THANKS

I want to thank with all my heart my awesomer husband and companion Chris Barrow, to my mother Esperanza, to my lazy daddies Arturo and Don Jorge, to my even more tiresome brothers Matz and Alda, my life friend Itzel and older sister Brenda (Editor of Agrobiencia-COLPOS), to those who are far away but always close to "Los Barrow" and "Los Davises." THANK YOU for having supported me intellectually and spiritually and above all have believed in me with their love and patience. Also to my patient, patient (arriving to Zen), tutor the Balú (aka Juan Antonio) and my diverse and rich jury: Laura, Elia, Alejandro and David; who believed in my threat to title me in months, and they supported me and they endured! And also to those who inspired me when I arrived and left, Innocent and Ocampo.

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I dedicate this thesis to all those who are interested in the conservation and preservation of the valuable pollinator and non-pollinator species, that every being has a reason why, although it is not for our human and blind exploitation.

This curious world which we inhabit is more wonderful than it is convenient, more beautiful than it is useful, it is more to be admired and enjoyed than used.

Thoreau, 1837

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ABSTRACT

A comparative native bee species richness analysis was conducted in four different areas (IG, PL, WS and FF) in the Chattahoochee River National Recreation Area, located in the city of Atlanta, Georgia, USA. This research project comes from the collaborative efforts between CRNRA and the Coevolution Institute, to establish pollinator species status and developed conservation strategies. In each area, native bees were collected using the bee bowl sampling technique during an eight-month period; specimens were identified to species level by the Patuxent Wildlife Research Center (USGS). The species accumulation curves program (EstimateS V 8.2.0, 2012) and a cluster analysis of the program NTSYS pc (V.2.1, 2000) were used to estimate and compare the bee species richness. A total of 79 species were captured belonging to 26 genera and five families - eight new state records were recorded for Georgia. In the IG area (non- native invasive grasses), the highest bee species richness number was observed (55 species), while the indicator Chao2 estimated a maximum of 65 species; grasses and other small shrubs species can be found here and are managed with mechanical control. The PL (pipeline right-of-way / early successional field) and WS (emergent scrub / shrub wetland) areas both registered 50 species; however, Chao2 estimates 94 species in PL, and 83 species in WS. Both of these areas have herbaceous species and shrub species. FF (floodplain / seasonally flooded bottomland forest), where tree species are more prevalent and there is no invasive plant management control, only 13 species were captured and Chao2 estimated 18.4 species - the lowest species richness in comparison with the rest of the areas. Bee species richness and composition is clearly associated with the vegetation structure of each area. While mechanical control for invasive plant species is used, the IG area, with a simpler vegetation structure and more human impact, does not demonstrate the lowest species richness.

Key words: native bee species richness, vegetation structure, human impact, invasive vegetation.

GENERAL INTRODUCTION

It is estimated that one out of every three bites of food that people consume, come directly from the result of animal pollination. The most important pollinator group is bees, and due to the use of pesticides (insecticides and herbicides) and the destruction and fragmentation of natural and semi-natural habitats, which these species depend on for their reproduction and feeding, their populations are being seriously affected.

In 2006 the National Park Service of the United States (NPS), signed an Agreement of Understanding with the Coevolution Institute (MOU, 2007) which coordinates the North American Pollinator Protection Campaign (NAPPC), a unique coordination of international efforts that was designed in quantitative measures to reduce the extinction of species pollinators and the loss of their habitats. The Chattahoochee River National Recreation Area (CRNRA) is part of the NPS and is committed to promoting the conservation and proper management of populations of pollinating animals, through cooperation programs. In 2011 the Southeast Regional Office (SERO-NPS) proposed to start an inventory of native bee species to evaluate and compare species richness in the Cochran Shoals unit, the closest to the metropolitan area of the city of Atlanta.

Pollination is a biotic process that has a high economic and ecological value. First, it occurs in the context of agriculture and a wide variety of amenities result from this. At the global level, the animal pollination service is fundamental for 30% of the human diet and most fiber production (example, cotton), edible oils, alcoholic beverages, and medicines made with plants (Buchmann & Nabhan, 1996). In the ecological context, pollination is the basis of the world's terrestrial ecosystems functions, helping their diversity and its continuity. Protected natural areas are considered of great importance for ecological studies, since they are indicators of the state of the populations of fauna and flora (Droege, 2012). Besides, these areas have become ecological reservoirs, due to constant urban, agricultural and industrial development (Black *et al.*, 2007).

Based on the above, the present research project was proposed to initiate comparative analysis of the richness of native wild bees in four biologically distinct areas and with different management in the Cochran Shoals Unit.

The impact of the management systems for the control of invasive plants was evaluated, on the composition and richness of wild bees, an inventory was also expounded of wild bees, and a series of strategies were proposed to promote the conservation and protection of native wild bee species and their habitats in CRNRA.

This thesis is divided into two chapters. The first chapter covers the current situation of pollinating species, the most important groups and strategies for their conservation. The second chapter is developed based on the analysis of the wealth and composition of the species of bees that were found, information from CRNRA and structural characteristics and management of the collection areas; the methods used for the collection of insects, the analysis of results and their interpretation based on the control of plants invaders and plant structure; as well as proposals for protection and conservation of the bee species that were identified with this project.

1. POLLINATOR INSECTS: IMPORTANCE AND STRATEGIES FOR CONSERVATION

1.1 The function and status of pollinators

Pollination is an ecosystem service defined as the transfer of pollen from the anther (male organ) of a flower to the stigma (female organ) of the same or another individual of the same species; this process requires a biotic (animals) or abiotic (wind or water) vector for this transfer to be successful and the plant reproduce (Proctor *et al.* , 1996). Of the 240,000 plant species of the world, approximately 220,000 require animal pollination; among them are 70% of agricultural crops used for human consumption (Buchmann & Nabhan, 1997).

It is estimated that around 200,000 species of animals help plants flower to reproduce and there are many different pollination strategies. The first pollinating animals are believed to be species of beetles and flies, which is estimated to have appeared at the same time as the first flowering plants, 1.3 ago millions of years (Proctor *et al.*, 1996). Flowering plants have evolved with their respective pollinators, and have developed different strategies to attract specific pollinators. These strategies include sweet smells, striking and intense colors, and the promise of food in the form of nectar, pollen, or oils (Proctor *et al.*, 1996).

Among the animals that act as pollinators are birds, bats, bees, beetles, butterflies and flies. The availability of pollinators depends on the existence of a diverse range of habitats where they can feed and complete their reproductive cycles successfully (Buchmann & Nabhan, 1997).

The most important group of pollinators are insects, because they are the taxon larger and more diverse, and many of its species depend directly on pollen and nectar to survive and reproduce (Proctor *et al.*, 1996. Michener, 2002. Shepherd *et al.*, 2003). In tropical climate areas 95% of the vegetation requires entomophily pollination and in areas of temperate climate 75%. In addition, insects represent 25% of the diet of mammals and 95% of the diet of birds (Adamson, 2014).

It is estimated that pollination services generate 117 billion dollars a year around the world (Inouye, 2012). The economic estimate of the value of pollination of crops for human consumption by native wild bees is approximately 3 billion dollars a year in the United States alone (Mader *et al.*, 2011).

Unfortunately since 1990, the diversity of pollinating species is declining in an accelerated way, due to multiple factors such as diseases, parasites, habitat fragmentation, etc. (The Xerces Society, 2013). Some examples are bumblebees (*Bombus sp.*), honey-producing bees (*Apis mellifera*), butterflies (for example, *Lycaeides Mellissa samueli*) and bats (for example, *Myotis lucifugus*). The consequence is that agricultural and natural ecosystems are in danger, exposing us to the disappearance of native vegetation and a decrease of certain agricultural products of high nutritional value for the population (Bradbear, 2004).

The main cause of the loss of pollinating insects is the disappearance and fragmentation of natural and semi-natural areas due to the increase of certain agricultural practices and urban development (Buchmann & Nabhan, 1996). The loss of these habitats cause a decrease in the abundance and diversity of pollinators, In turn, the native flora receives fewer visits from the insects that pollinate them (Buchmann & Nabhan, 1996). In protected natural areas, the loss of insect pollinators can lead to the extinction of endemic and native plant species (Bradbear, 2004). This is why the conservation and restoration of natural areas and semi-natural is crucial for the preservation of pollinator diversity.

The causes that most contribute to the loss of diversity of pollinating species are: the use of insecticides and herbicides, the grazing and pruning of the banks of roads, and the destruction of natural vegetation (Shepherd *et al.*, 2003).

Due to the above, since mid-1990, scientists and agronomists around the world have expressed their concern and in 2003 a meeting organized by the FAO, established an International initiative for the conservation and sustainable management of pollinators, also known as the International Initiative for Pollinators (IPI).

In 2006, the National Park Service of the United States signed an Agreement of Understanding (MOU) with the Coevolution Institute. The latter coordinates the Campaign for the Protection of Pollinators of North America (NAPPC), which seeks a unique coordination of international efforts between Mexico, Canada and the United States, to reduce quantitatively the extinction of pollinating species and the loss of their habitats (MOU, 2007).

1.2 Consequences of the decline of pollinators in natural systems and agricultural

1.2.1 Natural Systems

In natural ecosystems, the effects of the decrease in the number of species pollination can lead to the extinction of native plant species and the loss of animals that feed on seeds and small fruits (Bradbear, 2004). Natural resource areas are not only important for pollinating animals, but also pollinators are of vital importance for the functioning of these ecosystems (Mader *et al.*, 2011).

The pollinator species are key for the proper functioning of the food chains, help in the production of food, and the cycle of nutrients, since they are prey to different organisms. For example, many migratory birds require of a diet of berries, fruits and seeds that come from plants that are pollinated by insects. In addition, larvae are a vital component in the diet of young birds (Buehler *et al.*, 2002). The ecological services they provide make them a key group in almost all terrestrial ecosystems (Kearns *et al.*, 1998).

The loss of the diversity of flowering plants and their habitat, due to the increase in urbanization, the expansion of intensive agriculture, the widespread use of chemical products (pesticides), climate change, diseases and parasites, have a negative impact on populations of pollinating animals (Committee on the Status of Pollinators in North America, 2006). While human activities increase, natural areas can play a decisive role as shelters for these animals (Black *et al.*, 2007).

In this way, it is vital that the authorities participate actively in the planning for the protection and conservation of pollinating insects. In addition, when carrying out the appropriate planning, not only will they be helping a certain pollinator group, but also they will be laying the foundations to protect ecosystems in general. Currently many organizations are dedicated to guiding all types of groups (state, local, and community and school organizations) that are interested in beginning conservation projects for pollinating insects. For example the Xerces Society and NAPPC (North America Pollinator Protection Campaign) have agreements with the National Autonomous University of Mexico and the Autonomous University of Puebla.

1.2.2 Agricultural Systems

Several research projects that have been carried out in North America have demonstrated that agricultural areas that are close to natural ecosystems tend to have a greater diversity and richness of pollinating insects, specifically wild bees, as well as an increase in the pollination of their crops (Mader *et al.*, 2011). In the US, high-value crops such as alfalfa, almonds, apple, canola, cherry and pears, among others, require the pollination of insects.

The European bee (*Apis mellifera*) was domesticated mainly for its production of honey and is currently the insect most used for pollination of crops in systems of agricultural production. However, due to diseases, parasites and high colony income costs (in the US territory for example, producers of almonds maintain hives of *A. mellifera* for pollination) the availability of these hives has been diminished (Park *et al.*, 2012). Another recent factor was the phenomenon called Colony Collapse Disorder (CCD), which is believed to be the result of a combination of factors such as: parasites (e.g. the mite *Varroa destructor*), diseases, exposure to pesticides through the crops, and certain current beekeeping practices (Shepherd *et al.*, 2003., Inouye, 2013).

Pollinating insects, especially native wild bees provide the pollination services in agricultural areas for no cost; improve productivity and profitability through higher yields and improvements in crop quality (Vaughan *et al.*, 2013).

In 2009, a survey of apple producers in New York, United States, and the results showed that 65% of producers observed that the CCD phenomenon had a negative impact on overall production. The study concluded that there must be an investment in the diversification of insect pollinators, since to depend on a single pollinating species implies great risk for apple production, and in the same way other crops that depend on entomophilous pollination (Park *et al.*, 2012)

In a study carried out with 41 agricultural crops, the production of fruits increased by 99% thanks to the visit of wild pollinators; Conversely it only increased by 14% with the visit of the European bee (Garibaldi *et al.*, 2013). Another study that contrasted the effectiveness of wild bee (*Osmia* spp.) pollination with that of *A. mellifera*, concluded that only 250 to 750 individuals of *Osmia lignaria* (blue orchard bee) are required to pollinate an acre of trees of apple, while 2.5

hives of *A. mellifera* would be needed (approximately 2000 workers), to pollinate the same crop (Bosch & Kemp, 2001).

The diversity of native bee species helps stabilize long-term pollination term, since the more species existing in a given area, the more likely that variable environmental conditions can be tolerated such as a wet and cold spring (Park *et al.*, 2013). In addition, when the diversity of wild bees is greater, and one of them disappears, either due to diseases, parasites, poisoning by pesticides or loss of habitat, the remainder will reproduce and pollinate (Park *et al.*, 2012).

1.3 Main groups of pollinators

It is known that approximately 10,000 vertebrate animals are capable of performing the pollination process; most of them are mammals like bats, monkeys, rodents, lemurs, squirrels, olingos and kinkajou, and birds like hummingbirds, warblers and some species of parrots. Insects are the group with which angiosperms have developed a greater number of co-evolutionary relationships over time. There are four important groups of insect pollinators: Coleoptera (beetles), Diptera (flies), Lepidoptera (butterflies and moths), and Hymenoptera (bees, wasps and ants) (Inouye, 2013).

Of all groups of pollinating insects, the Hymenoptera order and superfamily Apoidea are especially important; to this taxa belong the bees that are considered the most relevant pollinator group (Proctor *et al.* , 1996., Michener, 2000), because they depend intrinsically on pollen and nectar for each stage of their reproductive cycle. Bees actively transport and collect pollen, exhibit floral perseverance (they can forage in a species of flower multiple times a day), and forage regularly in areas that are close to their nests (Mader *et al.*, 2011).

More than 25 thousand species of Hymenoptera (bees, wasps and ants) are recognized as highly effective pollinators; to them you must add coleoptera and lepidoptera (moths, butterflies) that together make up the majority of pollination species that exist worldwide (Eardley, 2006).

Twenty thousand species are bees (Michener, 2007. Bartomeus *et al.*, 2013). Nineteen thousand five hundred species have been described today and of them around 3,500 are found in the continental United States and Canada, with an estimated of 500 more species that have not yet been described (Ascher & Pickering, 2011).

Bee species are separated into two groups, social bees and solitary bees. The primary difference between social bees like the bee European (*A. mellifera*) and bumblebees (*Bombus sp.*), is a queen that only works for reproduction, and the workers have the responsibility to feed and take care of the colony. However, 90% of bee species exhibit a solitary life, where each female builds and cares for its nest and is responsible for feeding its offspring (Park *et al.*, 2012). Seventy percent of solitary species build their nests on the ground; single adult bees are active for a relatively short time (weeks to months) during the active period, the females build their nest consisting of a tunnel with a series of chambers. The female provides each chamber with food (a mixture of pollen and nectar), where it will place an egg, seal the chamber, where it will develop into a larva and then a pupa, without the care of the female bee. After several months, under the ground, when the flight season arrives, the adult solitary bee emerges from its nest to restart the cycle (Park *et al.*, 2012).

1.4 Alternatives for conservation

When planning pollinator conservation strategies, it is difficult to execute a single management plan that provides ideal habitats for the wide range of pollinators that exist (Hoffman *et al.*, 2007). Planning for the conservation of pollinator species should have two fundamental characteristics: 1) the preservation of floral diversity floral and 2) the creation of nesting sites. However, when creating plans for the conservation of wild bees, it is also necessary to establish a plan for protection against pesticides, which when executed will favor other pollinator species within the same system (Shepherd *et al.*, 2003).

It is important that when executing these conservation strategies to consider the joint effort of the community. However, actions carried out by administrations (for example a community park or garden) provide the basis for the conservation of pollinators, through the careful application of ecosystem management system tools (Hoffman *et al.*, 2007).

When creating a conservation area, three important aspects should be taken into account: 1) the ecological attributes of the area, 2) the identification of species of wild bees or other pollinators, and 3) management strategies such as the use of pesticides (herbicides and pesticides), grazing practices, controlled burning of vegetation, and pruning (Black *et al.*, 2007).

According to Black *et al.*, (2007) it is of vital importance that biological inventories are carried out to identify plant resources and the habitat of pollinating species; special attention should be given to rare pollinator species and specialists, their reproductive cycles and the type of habitat they require. Specialist species with limited distribution should be given special attention in order to receive adequate protection

1.4.1 Diversity of flowers for foraging

Floral diversity helps maintain a diversity of pollinating species. The angiosperms that are pollinated by insects have specific characteristics such as the flowering period, colors, forms, layout, structure, size of the flower, and the type of pollen (Shepherd *et al.*, 2003). Bee species are particularly attracted to blue, purple, violet, white, and yellow flowers. A greater diversity of plants are more attractive for wild bees, since they provide them with more and better resources for foraging (Adamson *et al.*, 2013).

Another important factor to consider is that not all wild bees are active outside their nest in all seasons. Many species of solitary bees require flowering for only a few weeks, so in one season many different species of bees are observed. On the contrary, social bees can be active for months. Therefore, the diversity of flowers should be available throughout the year (Shepherd *et al.*, 2003).

Because of its foraging activity, bees are classified into two classes: polyleges (generalists) and oligoleges (specialists). The polyleges perform the activity of foraging in flowers of different species and the oligoleges perform their foraging activity in one, or in a few species of closely related plants within a genus, or several genera of a single family (Michener, 2000). Examples of oligoleges bees are in the families Andrenidae and Halictidae (Proctor *et al.*, 1996).

The best strategy is to grow plants with floral structures of different colors and shapes; it is recommended that the arrangement be in a mosaic of the same species; each area can have a diameter of up to one meter eighty, since bees learn to feed on one species of flower at a time (Wojcik *et al.*, 2008). I recommend the planning of a sowing scheme where three different flower species are selected for each season (Wojcik *et al.*, 2008).

1.4.2 The creation and protection of nest sites

A. Construction of artificial nests

It is estimated that 30% of North American native bees nest in small tunnels, such as hollow stems of plants and abandoned pits of other insects (such as beetles), on dead trunks and similar places (Mader et al., 2009). The construction of artificial nests is currently being promoted; these consist of wooden blocks with holes of different sizes, with the aim of attracting wild bee species and increasing their populations (Mader et al., 2009). These nests can be found commercially, such as those that were designed in 1960 for alfalfa producers, for *Megachile rotundata*, or can be built at home (Mader et al, 2009).

Preferably, it is recommended to buy blocks of untreated wood of 9 by 20 centimeters, making holes with a drill of different diameters (from 2.5 to 10 millimeters). For example, holes with a diameter of 6.5 millimeters should be 8 to 13 centimeters long, and holes with diameters greater than 6 millimeters should be 13 and 15 centimeters long. Because female bees control the sex of their offspring, and normally the tunnel ends with cells where the males are, then a deeper tunnel ensures more space for more female bees (Mader et al, 2009). It is important that the block has holes only on one side, since the bees do not build their nests in cavities with two exits. Each tunnel should be smooth and it is recommended that paper straws be built to enter each tunnel; at the end of the reproduction period the straw is removed to prevent diseases and parasites begin to reproduce, and for other bees to use the tunnels in the following season (Mader et al., 2009).

There is evidence that wild bees are attracted to dark colors so you can burn the outside of the block a bit (or cover it with soot) to make it look black. Finally, the place where the block will be placed must be protected from the elements (placing a small roof) and it is recommended to hang it from a building or resistant structure that is visible on the ground; it should be oriented towards the east and avoid covering it with vegetation (Mader et al., 2009).

B. Protection of nest sites

The use of mowers and weed trimmers can have a negative impact on the population of pollinating insects, since a lawn of uniform height is created, destroying micro topographic variations, such as unevenness, mounds and cavities that were used as nests by other animal species (Morris, 2000). These characteristics provide a structural diversity of the soil, and offer possible nesting sites for bee species, such as species of the genus *Bombus* that use burrows of abandoned rodents (Hoffman et al., 2007, Black et al., 2007).

According to Hoffman et al, (2007) three important aspects are considered when using mowers or weed trimmers: technique, season and scale. These considerations distinguish between a beneficial pruning regime and a harmful one. It is recommended to place a metal bar (flushing bar) on the mower or trimmer, at a minimum height of 30 to 40 centimeters above the soil, and reduce the speed to less than 12 km / hr. (Green, 2007). On banks where find unwanted vegetation but there is no risk of it becoming a problem, you can avoid cutting (or pruning) the vegetation in flowering season (Munguria & Thomas, 1992).

These practices reduce the disturbance of the nest area of some species of wild bees like *Bombus* sp. (Hoffman et al., 2007; Black et al., 2007). However, they are not effective for the conservation of bees that nest in the soil (for example some species of the family Halictidae); since these bees, being out of their nests, sinking, take points of reference to relocate their nests. The disorientation and not being able to find its nest, is another factor of high mortality of bees that nest in the soil (Shepherd et al., 2003). In the case of non-native vegetation, it is recommended to cut it frequently in sections (some species of bees forage on the flower of exotic species), especially if it is in bloom (Mckinney & Goodell, 2010).

Trunks of box elder (*Acer negundo*) and alder (*Sambucus* sp.) are preferred for the construction of nests by some species of solitary bees (Adamson et al., 2012). It is recommended to leave dead trunks of these species, as well as increase young woody shoots, cutting them every 2 to 3 years (Adamson et al., 2012).

Bushy scrub type vegetation is preferred as nesting sites for species such as *Ceratina* spp., *Megachile* spp. and *Osmia* spp. There are also bee species that build their nests successfully in areas that are periodically flooded like *Nomia* spp. (Cane, 1992).

1.4.3 Protection against pesticides

The effects and impact of the use of pesticides on wild and domesticated bees has been a subject of major controversy since CCD was identified in domesticated colonies of *A. mellifera*.

Numerous investigations have been carried out on the effect of a certain group of insecticides on the European bee. However, there is not enough information on the impact of the use of insecticides in wild bee populations. Of the studies that have been carried out, only comparative investigations have been made between *Bombus* sp. and *Apis* sp. Social bees were found to form colonies and have long periods of foraging with greater exposure, since many of these products remain in the vegetative structures of plants, especially in pollen and nectar, which is later consumed by the larvae of these species (Hopwood et al., 2012).

Management practices for the control of exotic species, regularly with the use of herbicides, are also considered a great risk for wild bee species. The presence of exotic species has a negative impact on wild bee populations as they displace the native species that forage (Hanula et al., 2011). Of these two situations, the problem of contamination by pesticides is more serious. However, studies on the impact of the use of herbicides on wild bee populations are still scarce (Mader et al., 2011). It is essential to initiate preventive measures, as the decline of pollinators is complex and not fully understood.

Three basic rules for the application of pesticides are considered: the first is to select the product with less toxicity; the second, use the correct method of application; and the third, choose the appropriate application season (Mader, 2011). The non-governmental organization Xerces Society, works to provide a series of recommendations related to this issue, using updated information provided by the US Environmental Protection Agency (EPA). Xerces also presents a non-exhaustive list of the less toxic herbicides, which function as regulators of unwanted vegetation growth (Mader, 2011). However, there is not enough evidence to prove that these herbicides will not cause future problems.

- Surfactant of low toxicity (except Pulse, Boost and Ethokem, by their trade names).

These types of agents are added to the spray backpack to modify the dispersion characteristics of

the herbicide that is being used, this helps to minimize the contamination of desired plants.

- Corn gluten, non-toxic.

This product is derived from the protein division of maize, which inhibits the formation of the root in grasses and broad-leaved weeds (eg *Sanguinalis* sp. Flag grass).

- Gibberellic acid (designated as biopesticide by the EPA, 1995).

It is a plant hormone that is used as a regulator of plants; stimulates cell division and lengthening which affects leaves and stem. It can also accelerate the maturation of the plant and the germination of the seed.

- Horticultural vinegar with low toxicity.

Some studies have shown that adding 10-20% vinegar in water can help control certain weeds by 80-100% (Daniels & Fults, 2002).

The application of any type of herbicide, requires the rigorous adherence to the instructions for the product. Herbicide should be applied only to the plant that you want to control, avoiding the use of spray applicators or the use of granules, since they can contaminate or eliminate desired vegetation; including plants that are used as nesting sites for various species of wild bees. In the case of using aspersion, the use of a spray backpack is recommended, having the largest caliber and low pressure (Mader et al., 2011).

The time of application of any herbicide is crucial for a successful control of the problematic plant. Many insects forage on exotic plants and that should be controlled, like Chinese privet (*Ligustrum sinense*), that is foraged by *A. mellifera* and possibly by native wild bees (Mckinney & Goodell, 2010). Due to this, the application of the herbicide is recommended when the invader and the desired plants are not in bloom and in the afternoon or evening when the insects are not foraging (Mader, 2011). High humidity conditions cause pesticides in general to persist in the environment for a longer time, thus, the application must be avoided in similar climatic

conditions (Mader, 2011).

CHAPTER CONCLUSIONS

The pollinator crisis suggests that certain pollinating species are declining at an accelerated rate. However, in order to know with certainty the state in which the species of wild bees are found, it is necessary to initiate monitoring studies in protected areas and to continue them for a minimum of 10 years. In addition, the conservation of pollinators should be used as a framework for the management and maintenance of these areas, which will lead to diverse communities of plants and habitats for a greater number of wildlife.

On the other hand, urban areas or adjacent areas can provide suitable habitats for diverse populations of pollinators, but there are few individuals and a low diversity compared to rural areas. However, these areas have the potential to become reservoirs of pollinating species, especially if the habitat and floristic composition remain heterogeneous, through the application of urban planning tools, focused on the conservation of pollinators.

Currently there are groups (NGOs) that have developed pollinator conservation tools; this information is aimed at the general population and does not focus on a group (academics and specialists); and so we can all make small changes that will eventually help the pollinating species on which we depend.

2. COMPARATIVE ANALYSIS OF THE ABUNDANCE OF WILD BEES IN THE CHATTAHOOCHEE RIVER NATIONAL RECREATIONAL AREA

2.1 Introduction

It is now known that pollinating insects face multiple threats of anthropogenic origin (Kearns et al., 1998). Among them are the loss and fragmentation of habitats, poisoning by use of pesticides, introduction of parasites and diseases, and the introduction of non-native pollinators and exotic plants. The intensification of agriculture through monocultures and other conventional

practices, as well as commercial and industrial urban development, are the most frequent causes of habitat loss and fragmentation. Even more problematic is that these urban and industrial developments are often located near areas with ample biodiversity (Shepherd et al., 2003).

In urban areas, the loss of natural ecosystems is perceptible and regularly what persists are areas of disturbance such as: margins of fields, hedges, steepness, and the edge of ditches and streams (Shepherd et al., 2003). These areas have become important habitats for certain species of pollinating insects, but unfortunately are dominated by invasive species that tend to displace native vegetation, from which many pollinating insects depend to complete their reproductive cycles (Shepherd et al., 2003). On the other hand, the visual effects of the loss of pollinators in natural ecosystems are less noticeable, because it is a slow process. However, the consequences lead to the extinction of native and endemic plants, and the loss of animals that eat seeds and fruits (Bradbear, 2004).

The Chattahoochee River National Recreation Area (CRNRA) is located in the metropolitan area of the City of Atlanta, which is considered one of the fastest growing cities in the United States. (CRNRA-GMP, 2009). The accelerated population growth brings with it the construction of industrial, commercial and housing complexes that surround the different units of the Recreation Area. Likewise, the number of visitors has increased causing an increase in the impacts to the pine-oak forests and in the floodplain (Allyson Read, CRNRA, pers., 2012). The demand for spaces within CRNRA causes the disturbance of the native vegetation and generates soil erosion, due to the high human impact. However, one of the greatest consequences is the dispersion of exotic plant species, which move from residential areas, threatening native species (Allyson Read, CRNRA, pers., 2012). This brings with it a concern for the state of the pollinating insects that inhabit the Recreational Area – primarily, what is the condition of the populations of native wild bees, which are the most important group of pollinating insects (Proctor et al., 1996., Shepherd et al., 1997., Michener, 2002.)

Cochran Shoals is one of the most southern of the 16 units that make up the Recreational Area and one of the closest to the City of Atlanta. This park unit receives a large number of visits per year compared to the other units. In addition to the constant human impact, the area is subject to the introduction of invasion of exotic plants, which threaten the different elements of flora and

fauna. To control the invasion, we resort to strategies of chemical and mechanical control, which have also aroused concern about their negative effects on populations of different organisms. In particular, that of native wild bees, which are known to offer an environmental service of great relevance both for the conservation of natural areas and for agriculture (Shepherd et al., 1997., Hall et al., 2010., Inouye, 2013). The introduced plants have invaded the flood zone along the river corridor. Examples include Bradford pear (*Pyrus calleryana*), eleagnus (*Eleagnus* spp.), mimosa (*Albizia julibrissin*), English ivy (*Hedera helix*), and Chinese privet (*Ligustrum sinense*).

In 2008, 8.1 hectares invaded with Chinese privet (*Ligustrum sinense*) were treated, using a mixture of Triclopyr 4E herbicide as a foliar treatment (with methylated oil seed surfactant). Since then, other areas invaded by Chinese privet have been periodically controlled, using chemical and mechanical control methods (Allyson Read, CRNRA, pers., 2012). However, in the bee collection areas, no invasive chemical control is carried out.

The National Park Service (NPS) and Coevolution Institute (both US organizations) signed an Understanding Agreement (MOU) in 2007. The objective of this agreement is to promote the conservation and proper management of pollinating animals, through cooperation programs between both institutions (MOU, 2007). Based on this agreement, a research project was proposed to initiate an inventory of wild native bees and identify the impact that the different management practices of each collection area have on the richness and composition of species.

2.2 Background

It is estimated that 85% of the flowering plants around the world and 35% of the production of cultivated plants depend on animals for pollination (Hopwood, 2013). The animal pollination service for crops for human consumption around the world has an estimated economic value of \$117 billion dollars per year (Inouye, 2013). Another economic model calculated for the United States says that if the European bee (*Apis mellifera*) was the only bee species to provide pollination services (it only pollinates 63 crops) approximately \$1.6 to \$5.7 billion dollars in social benefits would be lost. This economic estimate does not take into account the pollination service of native wild bees (Inouye, 2013).

Pollination is just one of the many ecological services performed by natural agents such as wind,

water and animals. Pollination is the process in which biotic or abiotic agents transfer a pollen grain contained in the anthers (male organ) to the stigma (female organ) of the flower of the same species. If this transfer is successful, the pollen will germinate and its pollen tube will grow through the style where it will fertilize the egg and produce a seed (Inouye, 2013). As a consequence of the pollination process, in addition to the production of food and the plant reproduction of the world, materials for construction (wood) are obtained, climate regulation is assisted, erosion is controlled and nutrients are recycled (NAPPC, 2013).

In the last five years only the population of honey-producing bees (*Apis mellifera*) within the territory of the United States, has decreased by 30%. The phenomenon called CCD that is characterized by the abandonment of the colony by worker bees, has created an alert about the future of food production, especially the production of crops that depend on the services of the European bee (Inouye, 2013). Because of this, it is suspected that domesticated colonies of *A. mellifera* and native wild bee species share and are exposed to the same risks (Buchmann & Nabhan, 1996). The loss of European bee colonies has a direct impact on apiculture and the family economy of the beekeeper. From this point of view, declines in populations of wild bee species are difficult to quantify and identify. Currently, information on the distribution of wild bee species, their habitat and the ecological role they develop, both in natural and agricultural systems, remains insufficient (Buchmann & Nabhan, 1996); In the United States alone, state distribution levels for wild bees are not fully understood (Hall & Ascher, 2011).

There are four groups of important pollinating insects, but the Hymenoptera order is the most diverse group. Of all the species of this order, bees depend directly on pollen, nectar, and oils produced by angiosperms (Proctor et al., 1996). Both larva and adult require nectar and pollen to survive and develop (Michener, 2002). Pollinating insects usually inhabit natural or semi-natural areas, such as forests, grasslands, and shrublands (Shepherd et al., 1997. Inouye, 2013). It is estimated that there are 20,000 species of bees in the world (Michener, 2007. Bartomeus et al., 2013). 19,500 species have been currently described and of them around 3,500 are in the territory continental United States and Canada, with an estimated 500 more species that have not yet been described (Ascher & Pickering, 2011).

Currently it is recognized that although the pollinator-plant relationship can be specialized, the

service offered by pollinating species is more effective when there is a greater abundance and diversity of both species (Eardley, 2006).

2.3 Method

2.3.1 Characterization of the Study Area

The Chattahoochee River National Recreation Area (CRNRA) was established by the United States Congress in 1978. The creation decree establishes that: "Natural, scenic, recreational and historical resources and other valuable aspects found in the 77.23 kilometers of the Chattahoochee River segment and other adjacent land in the state of Georgia, should be preserved and protected from urban development or other uses that can substantially alter or destroy them "(CRNRA-DGM, 2003).

The Chattahoochee River corridor is considered an area of great biological diversity, since it is located in the physiographic province of Piedmont that gives it a wide range of terrestrial habitats: fields, plains, ravines, hills and cliffs. In addition, it has a variety of intercepting species from the physiographic provinces of the Piedmont and Appalachian. Flora studies have determined the presence of 982 plant species, which include algae, bryophytes (mosses), ferns, gymnosperms (pines, cedars), monocotyledons (rushes, orchids, grasses, etc.) and dicotyledons (willows, asters, hollies, maples, etc.). In addition, endemic plant species are documented, which gives great ecological value to the metropolitan area of Atlanta (CRNRA-GMP, 2009). They have also registered about 240 species of birds, and a wide range of small mammals, and larger species such as white-tailed deer (*Odocoileus virginianus*) (CRNRA-GMP, 2009).

CRNRA covers an area of approximately 2430 hectares and is divided into 16 land units along the banks of the Chattahoochee River. The area begins at Buford Dam at Lake Lanier, and continues downstream through four counties until it reaches Peachtree Creek near downtown Atlanta. The park provides outdoor recreation opportunities to more than 3 million visitors a year and represents an important resource for the metropolitan area of Atlanta (CRNRA-DGM, 2003).

The management of the parks is the responsibility of the National Park Service, and is currently incorporating practices for the protection of pollinating species and their habitats. Each park

defines specific management actions, such as the use of native species to improve the landscape and the restoration of ecosystems, as this ensures food and shelter for pollinating species.

For the most part, the type of soils in the Recreation Area is classified as arable land of first quality, classification determined by the Department of Agriculture (USDA) (CRNRA-GMP, 2009). This type of soil has the best combination of physical and chemical characteristics for the production of food, fodder, fibers, and production of oilseeds. This soil is preferred for the production of high-value crops such as fruits, vegetables and nuts; since it has an adequate combination of properties such as drainage, temperature, acidity, and balance in salt and sodium content, coupled with a good period of growth, humidity and that together produce high yields of harvest. Cochran Shoals has two types of soil according to the Soil Survey Geographic Database (SSURGO): Cartecay silty loam, silty variant (abbreviation Cw), and Toccoa soil (abbreviation Toc). Cw soil is characterized by poor drainage and moderate to rapid permeability, and thick alluvial clay sediments, with a pH of 5.5 or higher, are sometimes formed. The main quality of this soil is that its amount of clay and sand is relatively equal and are characteristic soils of floodplains. The Toc soil has a good to moderate drainage, with a composition of clay and sand, alluvium of igneous and metamorphic rocks, has an acidity that goes from strong to moderate. In the control plots there is a moderate to light acidity.

The Cochran Shoals unit (33.5448 LN and 84.2654 LO) has 392 hectares, which are surrounded to the south, west and north by dense urban, residential and commercial developments. This has a multi-use path (hiking, biking, etc.) from where you can appreciate the river. It also has a boardwalk within the wetland area and areas for observation for migratory birds, endemic plants, and other species of wildlife. In the wetland area, one can observe species such as wood duck (*Aix sponsa*), beaver (*Castor canadensis*), blue heron (*Ardea herodias*), muskrat (*Ondatra zibethicus*) and river otter (*Lutra canadensis*). Terrestrial plants found in this park unit include bloodroot (*Sanguinaria canadensis*), Solomon seal (*Polygonatum biflorum*), trilliums (*Trillium* spp.), and trout lilies (*Erythronium americanum*). Other plants are represented by wild indigo (*Baptisia alba*), sheep sorrel (*Rumex acetosella*), willow (*Salix nigra*), sedges (*Cyperus* spp.) etc. (CRNRA-GMP, 2009).

2.3.2 Study areas

The selection of study areas to carry out the collection of bees considered differences in the structure of the ecosystems of the Cochran Shoals unit, and the management systems for the control of invasive species. In addition, the selected areas are exposed to less human disturbance, which reduced the loss of traps and specimens.

Study areas according to their plant structure and management system are:

Area with exotic-invasive grasses (IG): Small grassland with *Festuca* sp. and bahiagrass (*Paspalum notatum*). This area is mowed regularly to keep a height of five to ten centimeters in length. This area has the greatest human impact. The type of soil is Toccoa (Toc). The study area measures approximately 1187.8 square meters, and has a radio approximately 20.27 meters.

Right of way of gas pipe with secondary vegetation (PL): This area is under a deeded easement with the Colonial Pipeline Company who mows and manages the vegetation of the area, preventing it from growing too much and compromising the safety of the gas pipeline. In this type of habitat, we find grasses (e.g. *Carex* spp.) and other herbaceous species (examples *Aster* spp., *Ranunculus* spp, *Solidago nemoralis*, etc.) (Table 2). According to park staff, different species of butterflies and other pollinating insects have been observed. This area is important because it provides an adequate habitat for pollinating insect species, as well as for some species of birds and small mammals. It has two types of soil: Cartecay (silty loam, silty variant, Cw) and Toccoa (Toc). The study area measures 2225.60 square meters, and has a radius of approximately 34.2 meters.

Wetland area with emergent shrubs (WS): This habitat is associated with marginal areas between the forest and wetland area. It has a Toccoa soil type (Toc), with a wide range of grasses and other wetland plants, such as water reeds (*Scirpus* spp.) and sedges (*Carex* spp.). You can also find flood-resistant broadleaf plants such as bitter dock (*Rumex obtusifolius*) and climbing plants or vines (*Polygonum* spp.). Among the dominant species are box elder (*Acer negundo*), common buttonbush (*Cephalanthus occidentalis*), common juncus (*Juncus effusus*) and white oak (*Quercus alba*). The study area measures approximately 1187.8 square meters, and has an approximate radius of 31.75 meters.

Seasonally flooded lowland or floodplain forest (FF): This area provides adequate habitat for vertebrates such as frog (*Rana sphenoccephala*), toad (*Bufo americanus*) raccoon (*Procyon lotor*), Squirrel (*Sciurus carolinensis*) and deer (*Odocoileus virginianus*). Among the dominant vegetation are *Acer negundo*, *Sambucus canadensis*, *Carya* spp, among others (Table 2). In addition, the floodplain forest plays a very important role dissipating the water of the Chattahoochee River when it overflows. The sediment left by seasonal floods is rich in nutrients, turning the soil into a prime agricultural area, with Cartecay soil (silty loam, silty variant - Cw) (Allyson Read, CRNRA, pers. com, 2012). The study area measures 2208.28 square meters, and has an approximate radius of 34.3 meters.

2.3.3 Process of collecting and identifying bees

The bees were collected using the technique known as bowl or bee bowl traps ("bee bowls"), designed by Droege (2009). "Bee bowls" are small white or transparent bowls approximately 3.35 ounces. These bowls were painted blue, phosphorescent yellow, and white then filled with a liquid with low surface tension (water with soap). They are then placed in open areas, preferably without shadows, where the insects would see them while flying and be attracted by the colors (which resemble a flower). Once the insect lands on the surface, it is trapped in the solution and dies (Droege, 2010).

For this project, two modifications were made to the original technique. The first modification was to add propyl-glycol to the water/liquid soap solution (50: 50) (approximately one ounce) due to high summer temperatures that caused the water to evaporate quickly. The second modification occurred in the arrangement of the bowls that were placed in a circle, with the purpose of having a wider spectrum of capture. The bowls were filled daily with the liquid to a point one centimeter below the edge. The contents were emptied with the collected insects, and the bottles labelled.

In each habitat three circles of 30 bowls were placed - ten yellow, ten white and ten blue. The distance between the bowl circles was 20 meters, and the distance between bowls was five meters. A GPS unit was used to locate the center point of each circle of bowls and create a map of the study areas. Each bowl was left outdoors for a period of 24 hours for 6 days. In total, four collections of bees were obtained. The first series of collections was from April to the beginning

of May; the second at the end of June to the beginning of July; the third in August; and the fourth began at the end of September and was completed at the end of October 2011. Between each collection was approximately 45 days.

The captured specimens (four collections) were sent to the laboratory of the Patuxent Wildlife Research Center (USGS - Patuxent Wildlife Research Center), in the state of Maryland, for taxonomic determination by Dr. Sam Droege. The third collection was identified using the Discover Life key system (Ascher & Pickering, 2011) and the keys "The Bees of Florida" (Pascarella, 2006). Later taxonomic determination was coordinated with the USGS.

2.3.4 Comparative analysis of the richness of bees

The estimate of the species richness of bees in each area and in the whole unit was made using the EstimateS V. 8.1 sensu Colwell program (2004). To compare the values of richness between areas, species accumulation curves were constructed based on the number of individuals collected and not on the number of samples (Gotelli & Coldwell, 2001).

We also used the Chao 2 wealth estimator (Chao, 1987), which works with a set of asymmetric confidence intervals of 95%. These intervals are based on the log (sest-sobs) equation, which indicates that the lower confidence level cannot be less than the number of species observed, adjusting satisfactorily for non-observed species (Letcher, 2009).

The level of species richness was contrasted with the type of management and habitat conditions, in order to establish those that are favorable for the conservation of the wild bee species found. The management strategies currently employed by the Maintenance Division and the Natural Resources Management Division of CRNRA were considered in terms of vegetation management and pesticide use, in order to make a comparison with the management strategies and conservation of wild pollinating bees.

Additionally, a cluster analysis was performed, based on the similarity measure called Average Taxonomic Distance (Rohlf, 2000), included in the NTYSpC V.2.1 program (Rohlf, 2000) and the UPGMA hierarchical grouping method. (Unweight Pair Group Method with Arithmetic Mean) (Rohlf, 2000). This analysis was done to identify the degree of similarity that exists between

sites based on composition of bees, and based on the composition of plant species. For each case, the corresponding dendrogram was constructed.

According to the findings found in the literature review, the management strategies of each collection area were contrasted with protection and conservation strategies of wild pollinating bees to evaluate how they can be affecting the current management practices of the bee species that were identified, thus proposing management strategies for their conservation and protection.

2.4 Results

2.4.1 Abundance of species of the Cochran Shoals Unit

Based on the analysis of all the traps placed in the unit, a collection of 937 wild bees was obtained, belonging to 79 species and 26 genera, and five families (Table 1). Of the total species, 30% belong to the Andrenidae family, 29% to the Apidae family, 26% to the Halictidae family, 10% to the Megachilidae family, and two percent belong to the Colletidae family. The EstimateS V 8.1 sensu Colwell program (2004), based on the sampling effort, estimated an average richness of 77 bee species (CI = 69.24-87.76, 95%). However, the shape of the species accumulation curve indicates that if the effort of sampling (more traps for a longer period), species richness estimated could be higher. The Chao 2 estimator projects a maximum species richness of up to 94.91 (CI = 84.05-122.52, 95%).

2.4.2 Abundance of species in the collection areas

In IG (area with exotic-invasive grasses) a total of 373 bees belonging to 55 species, 21 genera and 5 families were captured (Table 1). The program estimated an average richness of 50 species (CI = 44.97-65.03, 95%); however, the Chao2 estimator projected a maximum richness of 65.5 species (CI = 58.11-90.49, 95%). Here we had the greatest number of species captured; the species of greater recurrence were *Calliopsis andreniformis*, *Lasioglossum coreopsis*, and *Lasioglossum tegulare*. Three species were exclusive - *Megachile rotundata*, *Osmia subfasciata* and *Lasioglossum cephalotes*. This last species is parasitic and not pollinating, like *Sphecodes* sp. and *Nomada imbricata*, which were also found in this area. Likewise, other species of non-pollinating bees, *Hylaeus affinis* and *Hylaeus* sp. In this area, the fescue (*Festuca* sp.) and

bahiagrass (*Paspalum notatum*) grasses were planted and mowed regularly to maintain a lawn at a height of five centimeters. The area is relatively small and has a water fountain, which generates a greater human presence.

In the PL area (gas pipeline right-of-way with secondary vegetation), 319 bees belonging to 50 species, 21 genera and 5 families were captured (Table 1). The program estimated a richness of 50 species (CI = 40.1-59.9, 95%), but the Chao2 estimator projects a possible maximum richness of 94.63 species (CI = 68.29-158.88). The shape of the curve is far from an asymptotic form which indicates that it is necessary to increase the sampling effort (a greater number of traps and a longer period of time) to have an adequate representation of the species richness of this area. The species with the highest recurrence in the sample were *Augochlorella aurata*, *Panurginus polytrichus* and *Ptilothrix bombiformis*. In addition, ten specimens of parasitic and non-pollinating bees were captured, such as *Hylaeus affinis*, *Sphecodes* sp., and *Coelioxys porterae*, which was exclusive to the area and only one specimen was captured (Table 1). This study area bisects the Cochran Shoals unit dividing it into north and south areas. The vegetation is mowed twice a year and there is no application of herbicides for weed control. This habitat is critical for pollinating species, and is a less aesthetic area for visitors (Allyson Read, CRNRA com.per. 2012).

In WS (wetland area with emergent vegetation), 211 bees were captured belonging to 50 species, 20 genera and five families (Table 1). The program estimated a richness of 50 species (CI = 40.95 - 59.05, 95%), and the Chao2 estimator projected a maximum richness of 83 species (CI = 63.49-130.74, 95%). The most recurrent capture species were *Calliopsis andreniformis* and *Ceratina dupla*. In addition, it captured the parasitic and non-pollinating species *Nomada denticulata*, *Nomada imbricata* and *Nomada obliterated*, and the non-pollinating species *Hylaeus affinis* and *Hylaeus modestus* (Table 1). The species *Holcopasites calliopsidis* was captured only in this habitat and is the kleptoparasite species of *Calliopsis andreniformis*. Because WS is flooded most of the year, there were some difficulties in collecting. Thus, in order to carry out the collection and avoid the flooding of the traps, a circle of traps was placed on the margin of the wetland, at the transition to the forest or floodplain. In WS visitors are not encouraged to walk, but occasionally some people interested in bird watching go through the area. Currently CRNRA does not have a management system for this area.

The FF area (seasonal floodplain forest or floodplain) is located parallel to the PL area. In this area, 34 bees belonging to 13 species, eight genera and five families were captured (Table 1). The program estimated a wealth of 18.4 species (CI = 8.71-17.29, 95%) that could be the maximum possible value since the Chao2 estimator projected a wealth of 18.4 species (CI = 14.16-38.07, 95%). The species richness is lower compared to the other areas, because the closed canopy limits the development of herbaceous plants that are an important source of foraging for wild bees (Sam Droege, USGS pers. com., 2013). The dominant vegetation of the area are species such as *Acer negundo*, *Acer rubrum* and *Quercus alba* (Table 2). Currently the management plan for this habitat considers letting the forest grow naturally; however, a chemical control of Chinese privet (*Ligustrum sinense*) was carried out near the study area in 2008 (Allyson Read, CRNRA, per. com., 2012). Recurrent species captured were *Lasioglossum oblongum*, *Augochlorella aurata* and *Lasioglossum mitchelli*. In addition, three specimens of non-pollinating bee species *Hylaeus* sp. were captured (Picture 1).

2.4.3 Conglomerate analysis of the species richness in the study areas

The dendrogram was constructed based on the Average Taxonomic Distance (DTP), groups the sites with the greatest similarity in their composition of species, which means that at a greater distance from the groupings of the areas, the differences in composition increase. In this sense, the PL and IG areas are grouped at a distance of 60.26, which is the least magnitude in the dendrogram and share 37 species. Both have a high number of species of the family Halictidae, which includes the most common species of the temperate zones of the world (Michener, 2009). These two areas are characterized by the predominance of grasses and herbaceous species with open canopy. In both locations, the control of plants is done mechanically.

The WS area is grouped with PL and IG with a distance of 62.99 since it shares only 13 species with these areas. The WS areas shares with the IG a similar number of species of the family Megachilidae that, if compared with the rest of the bee families, has a great variety of nesting styles (Cane et al., 2007). This site also has a well-developed herbaceous layer and a greater number of bushes and trees, which generates a moderately closed canopy. Finally, the FF area is grouped with the rest of the areas with a distance of 71.18, since it only shares eight species with the rest of the areas. Due to the presence of trees and no management of the vegetation, there is a

closed canopy and less development of herbaceous plants.

The cluster analysis of the floristic composition (Table 2) shows that the areas with the largest canopy opening (PL, IG and WS) are grouped by virtue of sharing grass and other herbaceous species. With the same sampling effort, more bee species were collected in these areas than in FF, in which there is a predominance of trees. It should be noted that unlike the previous dendrogram, the greatest similarity is found between the areas IG and WS, because in PL there is a more intense handling because the pipe line must remain free of plants with stems and thick roots. If the two dendrograms are compared, it is possible to establish that the differences in the richness of species of wild bees, follows more to the changes in the structure of the vegetation than to the type of handling for the control of plant invaders. In addition, it is important to highlight that the management system of the IG and PL areas does not negatively influence the species richness.

2.4.4 New bee records for the state of Georgia

Eight species of bees that had not been documented for the state of Georgia were captured - Four species belonging to the Megachilidae Family: *Osmia collinsiae*, *Osmia subfasciata*, *Coelioxys porterae* and *Megachile rotundata*. Two species of the family Apidae were captured - *Holcopasites calliopsidis* and *Nomada obliterate*. From the Halictidae family, *Lasioglossum cephalotes* and *Lasioglossum oblongum* were captured.

The Megachilidae family is the second largest family of bees and contains more than 4000 registered species (Michener, 2007; Ascher & Pickering, 2011). The Apidae family are best known as social bees (*Apis*, *Bombus*, *Melipona* and *Trigona*). The Halictidae family includes some of the most common bees, which are distributed in the temperate zones of the world (Michener, 2007). Many of the species contained in this family are semi-social, which means that they do not form colonies or work together, but that they nest in dense groups in areas where the soil has certain physical characteristics, such as a loose sandy soil (Cane, 1992). The IG area has similar characteristics and obtained the largest number of specimens belonging to this family (162 specimens).

Osmia collinsiae is distributed from Minnesota to Maine and from southern Illinois to North

Carolina. The species *Osmia subfasciata*, is found from Florida to North Carolina. *Coelioxys porterae* (a parasitic bee) is distributed from Wisconsin to Maine, and in southern North Carolina. And *Megachile rotundata*, is an introduced species from Europe; sometimes they are bred in Canada and transported as pupae to the US for pollination of the alfalfa crop (Inouye, 2013), and it is likely that they have now established themselves in the region and nest locally (Sam Droege, USGS, com .pers., 2013).

Holcopasites calliopsidis is a parasitic bee with a distribution from Minnesota to Michigan, and southern Tennessee. *Nomada obliterated* has a distribution from Minnesota to New York and has been documented in South Carolina. *Lasioglossum cephalotes* is a parasitic bee that is distributed from Minnesota to New York and Connecticut, to the southern region of North Carolina. *Lasioglossum oblongum* has a distribution from Minnesota to Nova Scotia to southern Louisiana and Georgia. All the information on the distribution of the mentioned species was obtained from Mitchell (1960 and 1962).

2.5 Discussion

Evaluations conducted in the Cochran Shoals unit indicate that this site has a high richness of native wild bees, and according to USGS specialists, it can be rated, on a scale of 0 to 10, with a value between 7 and 8 (Sam Droege, pers. com., 2014). Also, the results show that even in areas with strong urban influence there is a great possibility of finding populations of wild bees. In addition, and given the presence of several habitats in the unit, eight species were found that had not been documented for the state of Georgia and some species that could be considered rare for the area. Therefore, it is indispensable that the management of the Recreation Area establish management programs that maintain a high diversity of plants and protect nesting sites.

The family Halictidae was the one that presented the highest number of specimens as expected. This family is the one with the highest number of known species around the world (Michener, 2002). The Andrenidae family was noted for having the highest number of species collected; it is characterized by the fact that its species nest in the soil, especially in sandy soils, near or under herbaceous plants (Mader et al., 2011). This coincides with the results in the IG area where 162 specimens belonging to the family Halictidae were captured, and in addition the highest number

of bees of the genus *Lasioglossum* (133 specimens) was obtained compared with the other areas. Species of this genus nest in places with loose sandy soils found in floodplains (Mader et al., 2011).

The majority of the bees captured were solitary native species and pollinators, although it is important to note that 10 parasitic non-pollinating species were collected. This is important because in the last 140 years, the northeastern area of the United States has presented a decrease in the abundance of native bees of the genus *Bombus* (Bartomeus et al., 2013), which is one of the most important groups of social-pollinating bees around the world. At this time, it is not possible to establish the degree to which the loss of species has affected the other groups of bees since the studies are scarce and not continuous. However, the presence of exotic bees, as in the case of *Megachile rotundata*, and the appearance of infectious diseases in species of the genus *Bombus*, transmitted by *A. mellifera* (not native to the USA), increase the concern of a pollinator crisis (Fürst et al., 2014).

According to the analysis of the species accumulation curves, it is probable that the bee richness is greater in the study area. To further investigate, a greater sampling effort must be made, and a monitoring program must be implemented to monitor fluctuations in the size of the populations. In addition, the sampling time for bees should start in March, at the beginning of spring, which is the time when bees emerge and make their first flight; this study was started in early April. Also, it is likely that the collection technique (with "bee bowls" or bee bowls), has influenced the low capture of species of the genera *Apis* and *Bombus*, since the natural abundance of these groups in the study areas is much greater than what the capture number suggests (Doug Yanega, UCR, pers. com, 2013).

2.5.1 Control of invasive plants

According to those responsible for the Recreation Area, the introduction of invasive plants to Cochran Shoals causes the gradual loss of native vegetation. This directly and indirectly impacts the pollinator species, since many of them have evolved jointly with plant species (Proctor et al., 1997; Shepherd et al., 2003). In addition, the management of non-native vegetation with chemical control can also destroy native vegetation, including that on which pollinators forage (Shepherd et al., 2003).

Chinese privet (*Ligustrum sinense*) is the most problematic invasive species in Cochran Shoals. This shrub has a negative impact on many pollinating insects because its canopy blocks the entry of solar rays that results in low temperatures at ground level and displaces other herbaceous plants (Mckinney & Goodell, 2010). Its blooms may benefit certain species of insects, but it reduces the floral diversity on which many pollinating insects depend (Mckinney & Goodell, 2010).

Weed control studies show that mechanical control of non-native plants, especially invasive shrubs, provides immediate benefits for native pollinators (Hanula et al., 2011). Currently the use of a certain group of pesticides (commercial systemic insecticides Imidacloprid and Clothianidin) pose long term negative impacts on species of *Apis* sp. and *Bombus* sp. (mainly to domesticated colonies for the pollination of crops) (Hopwood et al., 2012). However, no studies on the impact of the application of herbicides on wild bee species have been conducted (Mader et al, 2011).

It is probable that the chemical control of *Ligustrum sinense* does not strongly affect the species of wild bees native to the unit, because it is carried out in short periods and at intervals of two to three years. In addition, herbicides with a low level of toxicity (Triclopyr 4E) and vegetable oils along with foliar treatment with glyphosate and methylated seed oil surfactant are used. Nevertheless, it is known that glyphosate has a negative impact on the organisms found in the soil, and currently there is no information on the interaction that this has on the species of wild bees that nest in the ground.

2.5.2 Influence of the structural characteristics of the vegetation in the study areas and the degree of human disturbance

The IG and PL areas, in which the greatest number of specimens and species were collected, incur the greatest human impact. The IG area does not have a wide diversity of flower species, since introduced grasses predominate and are mowed regularly. Lawns have low levels of nectar and pollen, and are the classic example of wind pollination (Gemmill & Martins, 2004). However, the cover of the grass is not uniform and there are sites of bare soil, where aggregations of wild bees that nest in the ground (possibly belonging to the Andrenidae family) were observed. In addition, it is known that some species of bees of the families Apidae and

Halictidae nest under grasses or other herbaceous plants (Gemmill & Martins, 2004).

The WS area presents a greater diversity of flowering plants such as *Eupatorium purpureum*, *Solanum americanum*, *Liriodendron tulipifera* and *Sambucus canadensis*, which have been documented as sources of nectar and pollen for wild bee species (Shepherd et al., 2003. Mader et al., 2011). It has also been found that species such as *Acer negundo* and *Sambucus canadensis*, are used by some species of bees for nesting (Adamson et al., 2012). It is possible that given the proximity of these two areas (see Figure 5) the species collected in IG also visited WS.

Evaluations carried out in regions of Europe indicate that areas with high human impact, such as roadsides, have between 11 and 17 species of bees nesting in the ground, mainly bumblebees. In addition, 25 to 60 species of butterflies have been documented in these areas (Hopwood, 2013). In this sense, the lower species richness and number of specimens collected in the FF area is explained mainly by the closed canopy and that there is no resource management leading to a very low human impact. Furthermore, these types of habitats are considered unnatural areas for the foraging of wild bee species.

It is presumed that in the Unit there is no evident negative effect of human intervention and chemical control of invaders on the populations of wild bees, and according to the results, a significant amount of native species are protected. It is possible that the areas where there is greater human intervention are areas of high biological diversity (Vandermeer et al., 2007). Thus, contrary to the idea of the negative impact of human intervention on ecosystems, it is possible that these activities benefit the species richness of bees with certain protection and conservation guidelines. In addition, many species, both plant and animal, have adapted to their new environments and reproduce successfully in them.

The areas where conservation strategies for wild bees can be implemented are PL, IG and WS. However, in PL agreements must be made with the company that manages the pipeline to ensure that it complies with the guidelines for management and conservation of rights of way. The Integrated Roadside Vegetation Management program (IRVM) offers a series of integral strategies that consider controlled burning, regulated mowing, control of invasive plants, use of mechanical controls and reduced use of herbicides, which promote the long-term creation of well-established plant communities with a predominance of native species (Brandt et al., 2011).

2.6 Proposal of conservation strategies for wild bee species

In protected natural areas, three factors are considered in the practice of land use management that increase the degradation of habitats for pollinating insects: vegetation mowing and pruning use of all-terrain vehicles, and chemical control of non-native vegetation (Shepherd et al., 2003).

The use of mowers and weed trimmers can have a significant impact on pollinating insect populations, as it reduces the flora and limits the opportunities for foraging. Likewise, the use of all-terrain vehicles causes severe degradation of habitats, especially in dune or sand areas, where some pollinator species build their nests. Vegetation management for non-native plant species using chemical control can also destroy native vegetation, including that used by pollinators for foraging (Shepherd et al., 2003).

When using mowers or trimmers, technique, season and scale are decisive factors that distinguish a beneficial mowing regimen and a damaging one (Hoffman et al., 2007). It is recommended to place a metal bar (flushing bar), in the mower or trimmer, at a minimum height of 30 to 40 centimeters above the ground, and reduce the speed to less than 12 km / hr. (Green, 2007).

For the Cochran Shoals unit a table was created with technical proposals for each collection area (Table 3) that recommends the creation of a diversity of flowers for foraging, reintroducing native species, protection of nest sites of wild bees in each study area, and the use of mechanical control for the management of invasive shrubs (e.g. *Ligustrum sinense*). The use of four alternative low-toxicity herbicides for pollinating insects is also suggested (see Chapter 1, section 1.4.3). In addition, regarding the creation of areas for foraging, it is recommended to plant native flowers for all areas, for each season of the year (Table 4).

In the PL and IG habitats, cutting vegetation in the flowering season (spring and summer) should be avoided (Table 3). For the PL habitat, it is recommended to change the mowing season to autumn or winter, when the flowers have died or are dormant (Munguria & Thomas, 1992).

Another alternative management for PL is to divide it into a certain number of plots and cut during the flowering season, the vegetation of each plot separately. In this way, several species of flowering plants would be conserved since they are not eliminated all at the same time. If

successful in the application of the proposed conservation techniques, these will positively affect other pollinator species that were not identified with this project.

CHAPTER CONCLUSIONS

The richness of species in the different habitats of CRNRA is directly related to the structure of the vegetation and is increased by decreasing canopy cover. Additionally, the site with the highest degree of human intervention does not have the least species richness, because the control of plant species is carried out through mechanical processes.

In terms of research, the species richness in each of the areas could be greater than estimated with the sampling effort made; however, it is recommended that this project be followed up through a larger and longer-term sampling effort, increasing the number of traps and initiating collections in other CRNRA Units. It should be noted that according to the results of the collection, where species of the genus *Bombus* were poorly represented, it is recommended to add other collection techniques such as an entomological net and/or the use of a malaise trap in addition to the bee bowls.

The inventory of wild bees obtained will serve as a basis to identify patterns of change in bee populations. In addition, the new records for the state of Georgia suggest the need to increase collection efforts and thereby identify changes in the distribution patterns of bee species.

The proposed conservation strategies will operate appropriately to the extent that environmental education will be promoted in relation to the importance of protecting different species of pollinators, in particular bees, with members of the Natural Resources Management Division and the Maintenance Division of CRNRA, and with visitors.