Zanmi Kafe: Coffee Agroecology and Ant Diversity in Haiti

Geanina Fripp

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ABSTRACT

Zanmi Kafe is a coffee-based agroforestry reforestation project in the Central Plateau of Haiti, that aims to promote the adoption of more sustainable agroecosystems in order to improve livelihoods and foster community development. Coffee provides a livelihood for many small farmers throughout the tropics, however due to the high demand for coffee, many small coffee farms are undergoing agricultural intensification to increase coffee yields. Many studies have investigated the effects of the transformation of coffee agroecosystems from shaded to unshaded systems on biodiversity and ecosystem services. Sun coffee systems have been correlated with a decrease in biodiversity and ecosystem services while shade coffee systems support higher biodiversity and ecosystem services. Some coffee agroecosystems in the Central Plateau of Haiti are undergoing transformation from disturbed, unshaded to less disturbed, shaded systems. In this study we examined the ant fauna present on 15 farms in order to monitor future changes in the conditions of the agroecosystems. We also examined the coffee pests/diseases present to determine if there was an association between ant diversity and abundance and the presence of coffee pests/disease. We collected 21 species of ants from 17 genera and *Solenopsis geminata* was the dominant species on all the farms. We recorded the presence of coffee rust (*Hemileia vastatrix*), the coffee leaf miner (*Leucoptera coffeella*), and the green coffee scale (*Coccus viridis*) on the coffee seedlings. There was no statistically significant difference between the ant diversity and the abundance of *Solenopsis geminata* and the presence of coffee pests on the farms. However, a few trends were observed and future monitoring of the ant fauna and pests is critical in maintaining the health and production of the coffee trees.

Chapter 1: Coffee Agroforestry in Haiti

Zanmi Kafe: a coffee agroforestry pilot study in the Central Plateau of Haiti

Haiti, a mountainous Caribbean nation sharing the island of Hispaniola with the Dominican Republic, was dominated by lush subtropical vegetation prior to the arrival of Europeans (Girard 2010). In the native Taino language, Haiti means 'Green Island' (Girard 2010). Haiti suffers the effects of the unsustainable use of resources that began with the arrival of the Europeans and the establishment of the plantation system and continued through a long history of political instability (Girard 2010). Today, Haiti suffers from a legacy of environmental degradation due to a long history of deforestation and land clearing that ultimately lower agricultural productivity and perpetuate rural poverty. Political instability, poverty, rapid population growth and the use of charcoal as a primary fuel continue to encourage environmental degradation.

Deforestation has left Haiti with less than 2% of the original subtropical forest (Bannister and Nair 2003). Due to the lack of alternative fuels and the need for immediate income, farmers clear the forested hillsides for subsistence farming and cut trees for charcoal production and building materials. Clearing trees leaves steep hillsides vulnerable to erosion, limiting agricultural productivity and degrading water quality, contributing to poor health in the region. Despite the ecological services provided by trees in the long-term, subsistence farmers are concerned with meeting their short-term needs.

To address this self-reinforcing cycle, a coffee-based agroforestry reforestation project was launched in 2013 by Zanmi Kafe. Zanmi Kafe is a collaboration between Sewanee: The University of the South and Zanmi Agrikol, a Haitian non-profit agricultural organization that aims to promote the adoption of more sustainable agroecosystems in the Central Plateau region of Haiti. Strengthened by a long term relationship, Zanmi Kafe supplies farmers with coffee and shade tree seedlings, makes payments for carbon sequestration and offers technical support informed by on-farm agroecological research. The project documents social, economic, and environmental changes that result from shade grown coffee agroecosystems, while fostering cross-cultural relationships between Sewanee and Haitian students and farmers.

In the summer of 2013, Sewanee students working with Haitian farmers established a 16,000-seedling nursery comprised of coffee and other native shade tree seedlings (mango, sed, and acajou) in the zone of Bois Jolie, Haiti. Coffee was historically grown in the zone of Bois Jolie and the community chose to reintroduce it as the main cash crop in their agroecosystems. Shade trees planted alongside the coffee trees maintain the microclimate that coffee needs to grow. The coffee and shade tree seedlings were distributed in the summer of 2014 to the 45 farmers participating in the project to establish more sustainable agroecosystems. Prior to the distribution of the shade and coffee trees, the farms consisted of annual crop plants with few trees, exposing the soil to full sun, creating hot and dry conditions unsuitable for plant growth. In March 2015, spring break outreach students surveyed all the farms and recorded the survival rates and health of every seedling distributed in the summer of 2014. These data are critical in developing and implementing an integrated pest management program, as well as determining carbon sequestration rates to provide carbon payments to the farmers.

Payments for Ecosystem Services

The theoretical underpinning of the coffee-based agroforestry project is Payments for Ecosystem Services (PES). PES is a market-based tool that has emerged to encourage responsible, ecological land stewardship practices and to restore degraded lands. Through the use of monetary compensation, PES can provide a viable model for poverty alleviation, especially in developing countries where many ecosystem services are generated on rural lands (Milder *et al*. 2010) that have the highest rates of poverty (Bulte *et al*. 2008). Over 300 PES programs have been implemented worldwide with a recent focus on developing countries (Pattanayak *et al*. 2010). Poverty can result in short-term thinking and lead to the overexploitation of natural resources (Bulte *et al*. 2008). Through improving livelihoods, Payments for Ecosystem Services can benefit both ecosystem and human health.

Despite numerous reforestation efforts, severe environmental degradation continues in Haiti. Although there has been a recent focus on implementing PES programs in developing countries (Pattanayak *et al*. 2010), none have been implemented in Haiti. Two major obstacles to PES implementation in developing countries are program costs and effective monitoring. Verifying and monitoring projects can cost between $15,000 and $60,000, making it difficult for resource limited farmers to participate in carbon sequestration projects (Plan Vivo Foundation). Zanmi Kafe has developed a unique model of PES in order to encourage the maintenance of trees in Haiti. Farmers receive a carbon payment based on the number of healthy trees on their farm after a year of growth, determined through farm surveys conducted by Sewanee and Haitian students. After the first survey, 41% of coffee trees, 88% of mango trees, 88% of sed trees, and 75% of acajou trees, were accounted for. The carbon payments, equivalent to the revenue from one bag of charcoal, encourage farmers to maintain and protect young trees, while they are vulnerable to competing land uses. The base carbon payment was $30 US based on the 41% survival rate of the coffee seedlings. Farmers with survival rates higher than the community average, received additional payments of 50¢ per coffee and $1 US for canopy trees. The carbon payments come from Sewanee's Green Fee paid by all Sewanee students for sustainability projects. Through the provision of funds and our own monitoring of the farms, Zanmi Kafe has reduced PES program costs and ensured effective monitoring on all farms. Additionally, the Sewanee Student Government Association (SGA) supports this project on campus by holding events to raise awareness about the project and to encourage student involvement. In May 2015, the project celebrated a milestone with the distribution of the first carbon payments to 45 families. Zanmi Kafe has promised five years of carbon payments to the farmer, after which time the coffee will begin producing, providing an alternative source of income to the farmers. Through payments for ecosystem services, we hope to encourage farmers to maintain the trees, improving environmental conditions, health conditions, and livelihoods for their families and their community.

Chapter 2: Coffee Agroecology and Diversity

Introduction

Coffee production provides a livelihood for many households in the tropics, employing nearly 100 million people (Karp *et al.* 2013). Twenty million growers cultivate coffee on 10 million hectares of land in over 50 tropical countries (Karp *et al.* 2013). Latin America, including the Caribbean, is responsible for 34% of the world's coffee production (Perfecto and Armbrecht 2003).

Despite the agricultural intensification occurring across Latin America, many small, subsistence farmers continue to farm the steep slopes using traditional methods (Altieri 1999). 75% of the land farmed in Guatemala and El Salvador and 80% of the land farmed in Honduras, Haiti, and the Dominican Republic is situated on steep slopes (Altieri 1999). In Haiti and the Dominican Republic, this production accounts for 30% and 31%, respectively, of each country's agricultural output (Altieri 1999). Additionally, in Haiti 65% of the population is devoted to agricultural production (Altieri 1999).

The traditional subsistence farms are small and vegetatively diverse, providing farmers with food, fuel, medicine and building material, while coffee and other cash crops provide a source of income (Mendez *et al.* 2010a). In addition to the social benefits of these farms, they provide ecological benefits. The vegetational diversity provides environmental services including carbon sequestration, biodiversity conservation, soil and water quality (reviewed by Jose 2009), erosion control, and pollination (reviewed by Jha *et al.* 2011). Erosion control is critical when farming occurs on steep slopes in order to protect the water sources below. Additionally, the farms may serve as a viable habitat for biodiversity. In Mexico, some coffee growing areas with traditional shaded agroecoystems have been identified as conservation hotspots due to the high species richness and endemism in those areas (Moguel and Toledo 1999). Thus, understanding the social and ecological benefits of coffee agroecosystems, as well as the ecological requirements for coffee production can inform more sustainable cultivation practices.

Coffee species and ecological requirements

Coffee cultivation originated in Ethiopia and rapidly spread throughout the world (Pendergrast 2010). The two most common species of coffee worldwide are *Coffea arabica* and *Coffea canephora* (robusta) (Jha *et al.* 2014). A third less common species is *Coffea liberica* (Waller *et al.* 2007). *C. arabica* is native to Ethiopia, *C. canephora* originated in West Africa, and *C. liberica* is indigenous to Western and Central Africa (Waller *et al.* 2007). Arabica is the most popular species while robusta, a cross between *C. arabica* and *C. liberica*, is known for its resistance to disease and contains double the caffeine content of arabica (Smith 1985). *Coffea arabusta*, a cross between *C. arabica* and *C. robusta*, was later developed in the Ivory Coast (Smith 1985). There are 103 species of *Coffea* with 41 species occurring in Africa, 14 in Cameroon and 16 in Tanzania, and 59 in Madagascar (Waller *et al.* 2007). However, as coffee systems undergo the transformation from shaded to sun systems, new cultivars such as Caturra and Catual have been developed to withstand full sun conditions (Waller *et al.* 2007).

Coffea species naturally occur in humid, evergreen forests where they grow under shady, seasonally moist conditions (Waller *et al.* 2007). Coffee grows best under shade with 30-40% light interception (Waller *et al.* 2007). The shade protects coffee plants from damaging winds and large variations in temperature that occur from day to night (Waller *et al.* 2007). Arabica grows best in elevations between 800-2000m (Jha *et al.* 2014) with temperatures between 15-25 degrees Celsius (Waller et al. 2007). Robusta grows best in lower elevations, up to 800m, and prefers warmer temperatures between 24-30 degrees Celsius (Jha *et al.* 2014). Coffee species prefer between 1100 and 2000 mm of rain annually and a 3-4-month dry season (Waller *et al.* 2007). Additionally, they prefer deep soils with a pH < 7 and can tolerate shallower soils with irrigation (Waller *et al.* 2007). Understanding the conditions under which coffee naturally grows are important for pest and disease management, as coffee pests and diseases are influenced by the conditions under which coffee is grown (Waller *et al*. 2007).

Coffee pests and diseases

Coffea species are highly susceptible to a wide range of pests and diseases, including stem and branch-borers, berry feeding insects, root and collar-feeding insects, foliage and shoot diseases, berry disease, and wilt disease among others (Waller *et al.* 2007). Coffee's susceptibility to pests is in part due to its perennial nature, providing pests with a stable supply (Waller *et al.* 2007). Additionally, *Coffea* species have been introduced in many parts of the world, attracting new pests from those areas (Waller *et al.* 2007). However, not all pests and diseases have the same damaging effect on coffee plants. The green coffee scale (*Coccus viridis*) and the coffee leaf mining moth (*Leucoptera coffeella*) are common coffee pests, however they do not often cause severe damage, although they have the potential to (Vandermeer *et al.* 2010). The coffee berry borer beetle (*Hypothenemus hampei)* and coffee rust (*Hemileia vastatrix*) however are known to have some of the most damaging effects on coffee plants.

The coffee berry borer (*Hypothenemus hampei)* is the most damaging insect pest of coffee worldwide, causing significant economic losses. The species causes about $500 million is damages annually (Trible and Carroll 2014) and has been reported to infest as much as 90% of a coffee farm (Jaramillo *et al.* 2006). However, the coffee berry borer only causes severe damage at elevations less than 1370m (Waller *et al.* 2007). Additionally, the species thrives under a high relative humidity (90-100%) and temperatures between 20-25 degrees Celsius (Baker *et al.* 1992). The small beetle causes damage to the berry by boring into the berry to lay its eggs, causing the berry to fall before it is ready (Jaramillo *et al.* 2006). The berry then provides a food source to the developing larvae (Jaramillo *et al.* 2006). Ants are the only known predators of the coffee berry borer that could serve as potential biological control agents. However, additional studies are necessary to understand if certain ant species could be manipulated to provide more robust control of the coffee berry borer (Bustillo 2002; Jaramillo *et al.* 2006; Gonthier *et al.* 2013; Morris *et al.* 2015). Currently, most control is achieved through the use of pesticides, primarily endosulfan and chlorpyrifos, and some biological control (Jaramillo *et al.* 2006). The toxicity of these pesticides to humans and the environment as well as the evolution of resistance to the pesticides by *H. hampei,* has stimulated research to find alternative methods of control (Jaramillo *et al.* 2006).

Coffee rust (*Hemileia vastatrix*) was the first disease of coffee to cause a global epidemic, damaging coffee plants worldwide (McCook 2006). However, the severity of the damage varied from place to place with some areas experiencing damage to 90% of the coffee plants (McCook 2006). In the 2012-2013 outbreak, several Latin American countries were faced with coffee yield losses between 10-70% (Jha *et al*. 2014). *Hemileia vastatrix* is a fungus that attacks primarily arabica coffee under favorable conditions, preferring temperatures between 15-28 degrees Celsius and liquid water to germinate (McCook 2006). When conditions are ideal, the spores can germinate in less than five hours (Avelino *et al.* 2004). Once the spore germinates on the leaf, it sends shoots into the leaf tissue which produces more spores, forming an orange pustule on the leaf (McCook 2006). The spores can then be dispersed by wind, rain, insects, animals, or people (McCook 2006). If the outbreak is severe and leaves are covered in pustules, the leaves will fall off the plants, reducing plant photosynthetic material (McCook 2006). In addition to microclimatic conditions, crop management techniques can influence the severity of the outbreak. However, no conclusions have been reached about whether shaded systems or sun systems promote the growth and spread of the disease more, as it is determined by the complex interaction between the management practice and wind, rainfall, leaf area, leaf wetness, light, temperature, fruit load, soil moisture and stomatal density (Avelino *et al.* 2004). Currently, most control is achieved through the use of fungicides with some studies investigating the possibility of hyperparasitic fungi to reduce the severity of rust outbreaks (Waller *et al.* 2007). However, shade coffee agroecosystems may provide more robust pest and disease control, as they harbor higher levels of biodiversity that may serve as natural predators of many coffee pests and diseases (Philpott and Armbrecht 2006).

Shade coffee agroecosystems as a biodiversity refuge

Shade coffee agroecosystems have been long studied agricultural systems as refuges for biodiversity. Early naturalists noted that they harbored a similar bird community as the forests, indicating their potential to protect biodiversity (Perfecto *et al.* 2014). Shade coffee agroecosystems range from traditional rustic systems to shaded monocultures. In the traditional rustic system, coffee trees are planted under the canopy of the original forest and thus requires minimal management (Moguel and Toledo 1999). In the traditional polyculture system, the original forest is manipulated to create favorable growing conditions for coffee in the understory by eliminating or promoting the growth of certain tree and plant species (Moguel and Toledo 1999). Some traditional coffee agroecosystems comprise up to 100 species of shade trees

(Perfecto *et al.* 1997). This diverse composition gives the agroecosystem a forest-like structure (Perfecto and Vandermeer 1996; Perfecto *et al.* 1997). The forest-like structure of traditional coffee agroecosystems maintains a similar understory microclimate due to the vegetational diversity, structural complexity, shaded canopy and leaf-litter cover (Perfecto and Vandermeer 1996; Perfecto *et al*. 1997). In the commercial polyculture, coffee is planted alongside shade trees than enhance coffee production (Moguel and Toledo 1999). The shaded monoculture involves growing coffee alongside one shade tree, usually a leguminous tree (Moguel and Toldeo 1999). Both of these systems are dependent on the use of agrochemicals and produce a higher agricultural output (Moguel and Toldeo 1999).

Past research has demonstrated that shade coffee agroecosystems have the ability to conserve biodiversity. In the absence of forests, shaded coffee systems may provide critical habitat for many bird species. Sekercioglu *et al.* (2007) investigated the ability of scattered polyspecific shaded coffee systems with remnant trees from the native forest to conserve forest bird species. They reported that forest bird species persisted in the shaded coffee systems rather than traveling to the distant continuous forest. They suggest that the high diversity of fruit trees and the presence of remnant trees provided food and nesting sources as well as maintained a forest-like microclimate. However, shade coffee agroecosystems are under different levels of management, affecting vegetational diversity and structural complexity. Greenberg *et al*. (1997b) investigated the effects of rustic versus planted shade coffee agroecosystems and found that they both harbored a similarly high bird abundance and diversity (105 species). Additionally, both systems supported migrant bird species, indicating that coffee agroecosystems may provide an important habitat during migration, especially in areas that have experienced severe deforestation. However, in a quantitative review, Philpott *et al.* (2008) indicated that only rustic systems supported a high bird diversity, indicating that not all shade coffee agroecosystems may provide the same level of protection for biodiversity.

In addition to supporting bird diversity, shade coffee agroecosystems have sustained arthropod species. Perfecto *et al.* (1997) reported that traditional shade coffee agroecosystems in Costa Rica harbored a high abundance and diversity of beetles, ants and other hymenopterans. For ants, they recorded an average of 22 species and 539 individuals per tree. For beetles, they recorded an average of 18 species and 397 individuals per tree. They noted that the high arthropod diversity is similar to the arthropod diversity in tropical rain forests. In a review, Moguel and Toledo (1999) supported the findings of Perfecto *et al.* (1997), indicating a similarly high arthropod abundance and diversity in traditional Mexican coffee agroecosystems as in the tropical rain forests. Both Perfecto *et al.* (1997) and Moguel and Toledo (1999) suggest that the high vegetational diversity and structural complexity maintain a forest-like microclimate and provide food and nesting sites that can support arthropod biodiversity. Additionally, Mas and Dietsch (2004) investigated the butterfly diversity in varying levels of shade management as well as in the nearby forests in Mexico. They reported that the rustic system harbored the highest butterfly diversity and the most similar assemblage to the nearby forest, while the traditional polyculture and commercial polyculture supported a lower butterfly diversity. This study demonstrates similar findings as Philpott *et al.* (2008) for bird diversity, indicating that in order to protect biodiversity, conservationists should focus on restoring aspects of rustic systems across all management systems.

Coffee intensification and biodiversity loss

Throughout the tropics, coffee agroecosystems are undergoing transformation from shade coffee agroecosystems to intensive, sun coffee plantations. Sun coffee systems are characterized by chemically intensive monocultures of sun-resistant varieties grown under little or no shade (Perfecto and Snelling 1995). Initially, intensification was favored because it was considered a solution for eliminating fungal diseases, specifically coffee leaf rust (*Hemileia vastatrix*), that requires moist conditions to thrive (Perfecto *et al.* 1996). However, at that time, coffee leaf rust did not produce the level of damage that was predicted and intensification became favored for increased agricultural output (Perfecto *et al.* 1996). Today, we know that intensification supports higher agricultural yield in the short-term, but the negative effects on biodiversity and ecosystem services (reviewed by De Beenhouwer *et al.* 2013) may reduce output in the long-term.

Numerous studies have investigated the effects of agricultural intensification on bird and arthropod diversity. Wundurle and Latta (1996) found a decline in the abundance of forest bird species in the sun coffee systems of the Dominican Republic. Additionally, they reported that the sun coffee system harbored mostly open brushland bird species. Greenberg *et al.* (1997a) reported similar findings in Mexico, with the sun coffee systems being dominated by second-growth or edge species and few forest species present on the farms. They also found that the sun coffee systems supported a lower bird diversity. In a quantitative review, Philpott *et al.* (2008) found a significant decline in bird diversity across a coffee intensification gradient, with the sun coffee system suffering the greatest loss. Additionally, they reported an overall loss in forest and migrant bird species across management systems and a significant loss in resident bird species in the traditional polyculture and sun coffee systems. The decline in bird diversity was correlated with changes in tree species diversity, canopy cover, and canopy height. These studies suggest that sun coffee systems may provide habitat for some species, however not for the species that are threatened with habitat loss from forest clearing.

In addition to sustaining changes in bird diversity, intensive coffee systems have experienced changes in arthropod diversity. Most studies have investigated the effects of intensification on ant assemblages because they are easy organisms to study, however few studies have looked at other arthropods. In Costa Rica, Perfecto and Snelling (1995) found a decrease in ground-foraging ant species as coffee intensification increased. Sun coffee monocultures supported the lowest ant diversity but had a similar species composition. Perfecto *et al.* (1997) compared arthropod diversity in shaded and sun coffee systems in Costa Rica. In the sun coffee monoculture, they reported a 43% decrease in ant species and 65.2% decrease in ant abundance from the shaded coffee system. For beetles, they reported a 26% decrease in species and a 17% increase in abundance. Perfecto and Snelling (1995) and Perfecto *et al*. (1997) both suggest that the decrease in vegetational diversity and structural complexity may affect the microclimatic conditions and decrease food availability. Perfecto and Snelling (1995) additionally suggest that negative interspecific interactions may contribute to the the ant assemblages and the loss in ant diversity, while Perfecto *et al.* (1997) indicate that there may also be a decrease in nesting sites. Additional studies in Latin America have demonstrated a loss in ant diversity across the coffee intensification gradient (e.g. Nestel and Dickschen 1990; Perfecto *et al.* 1996; Perfecto and Vandermeer 2002; Armbrecht *et al.* 2005; Philpott *et al*. 2006). Conservation efforts should thus focus on restoring intensified coffee systems to diverse, shaded agroecosystems in order to provide an ideal habitat for threatened species and facilitate coffee output.

Chapter 3: Ant Diversity in Coffee Agroecosystems in the Central Plateau of Haiti

INTRODUCTION

The tropics have long been considered a hotspot for biodiversity. However, tropical forests have too often been the victim of severe deforestation. Much of the native forests have been converted to agriculture and agricultural intensification makes the land particularly susceptible to degradation (Philpott and Ambrecht 2006). As tropical landscapes became rapidly fragmented, conservation efforts were focused on preserved areas. However, preserved areas cannot protect all biodiversity and ecosystem services affected by the loss of native tropical forests (Sekercioglu *et al.* 2007). More recent research has demonstrated that properly managed agricultural lands can support biodiversity and may play a pivotal role in biodiversity conservation in fragmented landscapes (reviewed by Perfecto *et al.* 1996; Moguel and Toledo 1999; Perfecto and Armbrecht 2003; Philpott *et al*. 2008).

Coffee agroecosystems in the tropics fall along a cultivation gradient, ranging from rustic, vegetatively diverse shade coffee agroecosystems to sun monoculture plantations (Moguel and Toledo 1999). The diversity in coffee cultivation systems provide ideal model systems to understand the effects of agricultural intensification on biodiversity and ecosystem services (Perfecto *et al.* 2014). Many studies have indicated that shade coffee agroecosystems can serve as a refuge for biodiversity including arthropods, birds, and other vertebrates (reviewed by Perfecto *et al.* 1996; Moguel and Toledo 1999; Perfecto and Armbrecht 2003; Philpott *et al*. 2008). At the other end of the gradient, intensive sun coffee systems have been documented to contribute to biodiversity loss (Perfecto and Snelling 1995; Wundurle and Latta 1996; Greenberg *et al.* 1997a; Perfecto *et al.* 1997). Understanding the changes in biodiversity associated with the various cultivation techniques is of paramount importance as many organisms present in agricultural systems provide critical environmental services.

In our study, we focused on ants as they are sensitive to habitat changes and have commonly been used as biological indicators of agroecosystem conditions (e.g. Nestel and Dickschen 1990; Perfecto and Snelling 1995; Perfecto *et al.* 1996,1997; Perfecto and Vandermeer 2002; Armbrecht *et al.* 2005; Philpott *et al*. 2006). Ant species have been associated with microclimatic conditions (e.g. Perfecto and Snelling 1995; Perfecto and Vandermeer 1997), soil quality (De Bruyn 1999), soil function (Sanabria *et al.* 2014), tillage practices and pesticide use (Peck *et al.* 1983) among many. Additionally, ant species provide numerous and valuable environmental services including pest control (e.g Gonthier *et al.* 2013; Morris *et al*. 2015), pollination (Philpott *et al.* 2006), and increased soil drainage, aeration, and cycling of organic matter and chemical nutrients (reviewed by Folgarait 1998). Pest control is especially important in coffee agroecosystems as coffee is highly susceptible to pests and diseases.

Haiti, a mountainous country sharing the island of Hispaniola with the Dominican Republic, suffers the effects of severe deforestation as many of the steep slopes have been cleared for subsistence farming. The farms continue to experience high disturbance as the farmers frequently cut down planted trees for charcoal and building materials. The subsistence farms are characterized by high vegetational diversity, with many annual crop plants, but low structural diversity due to the low numbers of trees. However, some farms in the Central Plateau of Haiti are undergoing transformation from disturbed, mostly unshaded subsistence farms to less disturbed, shaded coffee agroecosystems. As the farms undergo this transformation, biodiversity may respond to the changes in the agroecosystems. This study is the beginning of a long-term study to understand how this transformation may affect the ant diversity on the farms and it may help inform how properly managed agricultural lands can support biodiversity in Haiti. Additionally, this study serves as the first ant study in Haiti since Wheeler and Mann (1914) documented the ant diversity of few regions of the country. The goals of our study were to 1) produce baseline ant diversity data that can be used to track the changes in agroecosystem conditions and the ant fauna, 2) understand the pest/disease species present on the farms, and 3) determine if there is an association between ant diversity and abundance and the presence of pests/diseases on the coffee seedlings to develop and implement an integrated pest management program.

METHODS

Study Area

Bois Jolie is a zone located in the Central Plateau of Haiti which extends along both sides of the Guayamouc River south of the Massif du Nord and east of the Dominican Republic border. Upland elevations range 600-900 meters and are now dominated by grasses with forested fragments in rocky ravines. The rainy season extends from April through October, with maximal precipitation in May and June and a pronounced dry season from December through March. Average temperature is 25 degrees Celsius, with a maximum of 34 degrees Celsius in July and August (Service of Meteorology in the Haitian Ministry of Agriculture). Soils are derived from limestone and have a neutral to slightly alkaline pH and high base status, but are thin and rocky due to erosion on steep deforested slopes (McGrath, unpublished data).

There are approximately 3000 families living in Bois Jolie. Zanmi Kafe has been working with 45 families (Figure 1) since 2012. The 45 families volunteered to participate in the project after a village meeting was held to introduce Zanmi Kafe to them. The 15 families that were part of this study also volunteered to participate in this additional aspect of the project. The subsistence farms range in size from 0.5 to 2 ha**.** Prior to the start of the reforestation project, the farms were mostly unshaded and consisted of mostly annual crop species and few trees. Common crops grown on these farms include corn, millet, beans and peas, sugar cane, bananas, plantains, mango, citrus, avocado, native mahogany and acacia species, breadfruit, and coffee.

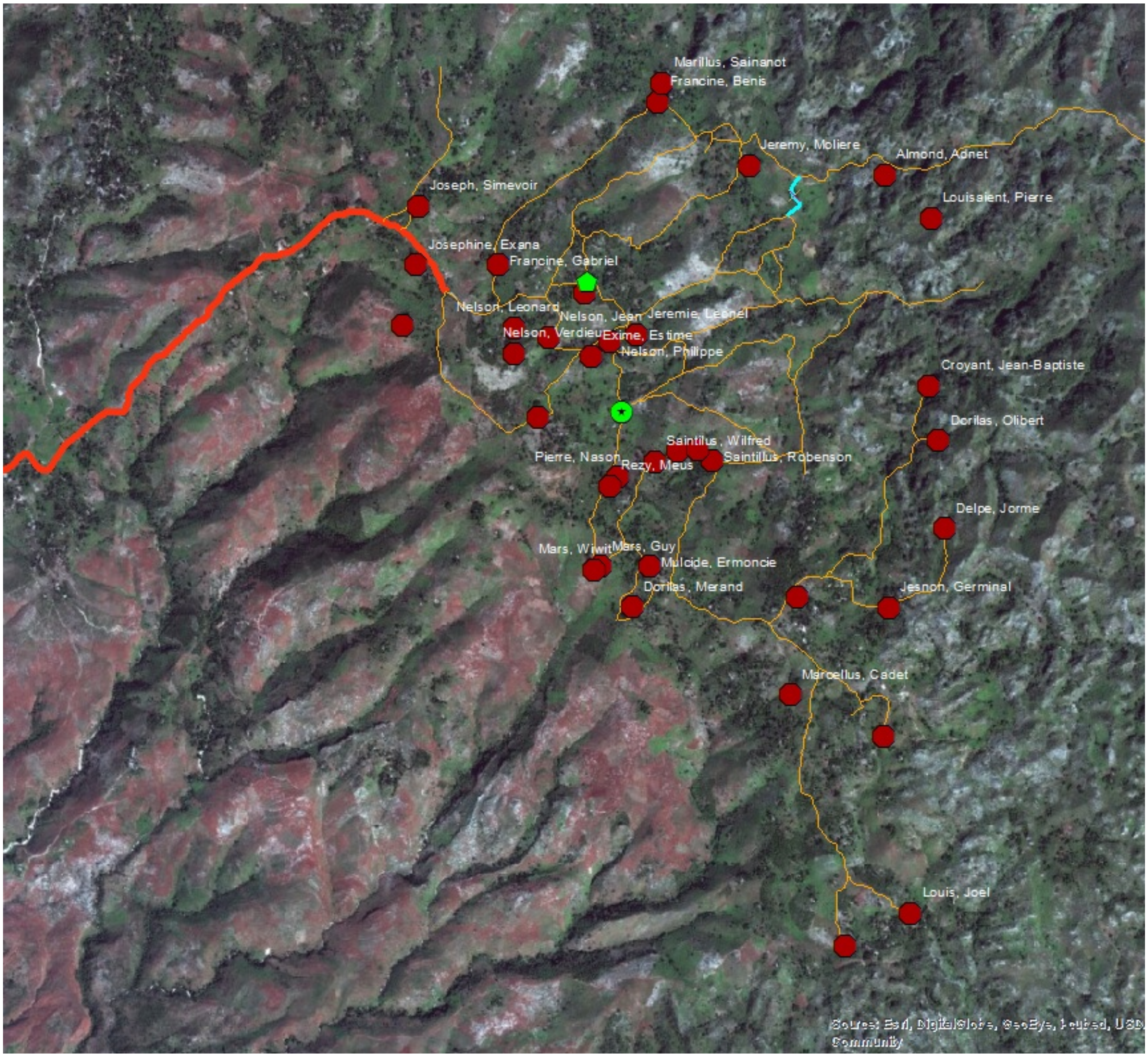

Figure 1. Aerial map of the zone of Bois Jolie, Haiti. GPS points indicate location of households participating in the Zanmi Kafe project.

Ant sampling

We sampled 15 farms over 5 weeks, every Friday and Saturday, May 22-June 19, 2015 between the hours of 08:00-15:00. The center of the farm was determined to lay out three 20-m transects, spaced 5-meters apart. If the farm was smaller than the 20x15m area needed for sampling, we started the transects at the beginning of the farm. We used two methods of collecting ant samples, bait traps and pitfall traps.

On each transect, three bait traps were set at 0, 10, and 20 meters (N=9). Four different bait types (honey, tuna, canned meat, and peanut butter) were placed on 5 x 5cm plastic sheets. Flags were used to mark each trap. Each bait trap was left for 30 minutes, and was checked at 10, 20 and 30 minutes. During each check, ant abundance was recorded and the bait to which they were attracted was noted. At the end of the 30-minute period, ants were collected using aspirators. The samples were killed and stored in labeled 10-ml centrifuge tubes filled with 70% ethanol.

Pitfall traps were used to collect ants over a 24-hour period. Nine 118-ml Solo plastic containers were placed on the same transects at 0, 10, and 20 meters. The pitfall traps were set before the bait traps and were offset from the bait traps. Each container had a lid to prevent rainfall from entering the trap. Three 2-cm holes were punched along the top of the container to allow ant entry into the container. The traps contained 70% ethanol for killing and preservation and glycerol to inhibit ethanol evaporation. The traps were checked after 24 hours and the specimens were sieved from the alcohol and placed into labeled 10-ml centrifuge tubes filled with 70% ethanol.

Ant identification

Ant samples were identified on site using the Sewanee Haitian Ant Key created by David Lubertazzi, postdoctoral fellow at the Museum of Comparative Zoology at Harvard University and the world's leading expert on the ants of Hispaniola. Ants that were unidentifiable using the key, were labeled as separate morphospecies and preserved in 70% ethanol to be identified by David Lubertazzi.

Ant diversity analysis

EstimateS was used to calculate asymptotic species richness for incidence-based data. Chao 2 values were used to estimate the number of undetected species in correlation to the number of samples (Colwell 2005).

Pest and disease survey

We surveyed all 15 farms between March 16-18, 2015, nine months after outplanting, and recorded all the pests and/or diseases present on the coffee seedlings, as well as the proportion of all coffee seedlings affected by each pest and/or disease.

Ant and pest association analysis

To determine if there was a relationship between ant diversity and the presence of the coffee leaf miner and the green coffee scale, we conducted a student t-test. Similarly, to understand if there was an association between the number of *Solenopsis geminata* individuals and the presence of the coffee leaf miner and the green coffee scale, we performed a student t-test.

RESULTS

Ant diversity and abundance

We collected 3,455 individual ants and identified 21 species and morphospecies across 17 genera (Table 1). All ants were identified to genus, with 17 determined to species and four classified by morphospecies (Table 1). We recorded an average of 6.3 +/- 0.31 species per farm. Abundances varied greatly across farms. 55 individuals were attracted to the baits at Farm 1, while 635 individuals were attracted to the baits at Farm 11 (Figure 2). *Solenopsis geminata* was the most abundant with 1,716 individuals followed by *Pheidole subarmata* with 954 individuals. *Solenopsis geminata* was present on all 15 farms sampled and *Pheidole subarmata* was present on 14 farms (Table 1). In addition, we found queens of *Odontomachus bauri*, *Cyphomyrmex minutus*, and *Gnaptogenys* sp1.

Pests and diseases

Three coffee pests, coffee rust (*Hemileia vastatrix*), the coffee leaf miner (*Leucoptera coffeella*), and the green coffee scale (*Coccus viridis*) were recorded on 15 farms. Across farms, an average of 53+/-0.06% of all coffee plants were affected by some coffee rust, 17+/- 0.03% were affected by the coffee leaf miner, and 7 +/-0.06% were affected by the green coffee scale.

Ant and pest associations

Ant diversity on farms was similar in the presence of the coffee leaf miner (6.3 +/- 0.43 species) and in the absence of the coffee leaf miner (6 +/- 0.44 species) (Figure 4). A similar trend was observed for ant diversity on farms in the presence of scale (6.5 +/- 0.42 species) and the absence of scale (6 +/- 0.44 species) (Figure 5).

Solenopsis geminata abundance was higher on the farms without the coffee leaf miner (166.4 +/- 27.4 number of individuals) than without the coffee leaf miner (88.4 +/-31.8 number of individuals), but this was not a statistically significant difference (p=0.09) (Figure 6). On farms with the green coffee scale, *Solenopsis geminata* abundance was higher (126.2 +/- 34.5 number of individuals) than on farms without the green coffee scale (106.6 +/-31.4 number of individuals), but this difference was not statistically significant (p=0.68) (Figure 7).

Table 1. Ants collected on 15 farms in Bois Jolie, Haiti from May-June 2015. The ants were collected along three 20m transects per farm using nine pitfall traps and four different baits. Species marked with an asterisk are invasive.

Genus	**Species/Morphospecies**	**# Sites**	**Abundance**	**Native/ Exotic**	**Habitat**
Anochetus	*mayri* (Emery, 1884)	1	1	Native	Forest
Camponotus	sp1	1	1		
Cardiocondyla	*emeryi* (Forel, 1881)*	2	2	Exotic	Disturbed
	minutior (Forel, 1889)*	2	12	Exotic	Disturbed
Cyphomyrmex	*minutus* (Mayr, 1862)	5	5		Disturbed
Gnamptogenys	sp1	2	2		
Hypoponera	sp1	1	1		
Monomorium	*ebeninum (*Forel, 1891)	11	470		
	pharaonis (Linnaeus, 1758)	2	6	Exotic	Disturbed
Mycocepurus	*smithii* (Forel, 1893)	1	2	Native	Forest
Nylanderia	*steinheili* (Forel, 1893)	8	21		Forest
Odontomachus	*bauri* (Emery, 1892)	3	4	Native	Forest
Paratrechina	*longicornis* (Latreille, 1802)*	7	42	Exotic	Disturbed
Pheidole	*jelskii* (Mayr, 1884)	3	27	Native	Disturbed
	*subarmata (*Mayr, 1884)	14	954	Native	Forest and Disturbed
Pogonomyrmex	*schmitti (*Forel, 1901)	2	6	Native	Forest and Disturbed
Solenopsis	*geminata* (Fabricius, 1804)	15	1,716	Native	Disturbed
	sp1	2	34		
Tapinoma	*melanocephalum* (Fabricius, 1793)*	7	50	Exotic	Disturbed
Tetramorium	*caldarium* (Roger, 1857)	3	3	Exotic	Disturbed
Wasmannia	*auropunctata* (Roger, 1863)*	7	96	Exotic	Forest and Disturbed

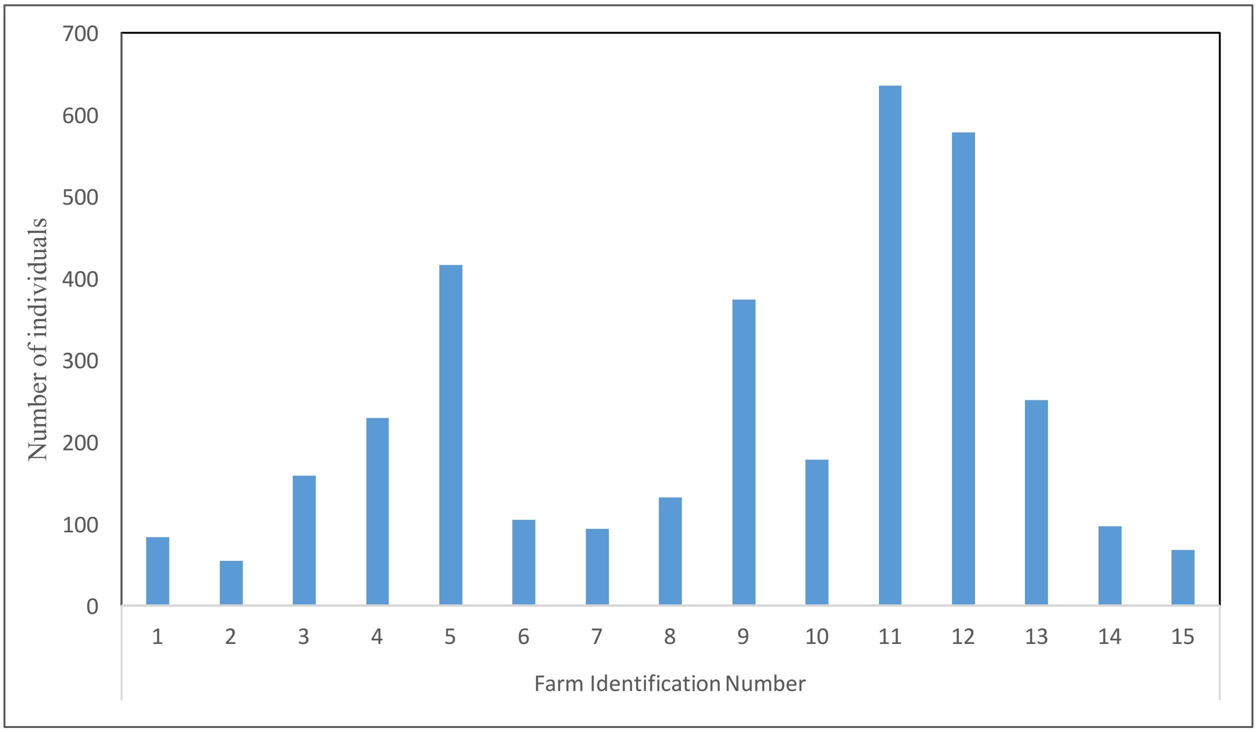

Figure 2. Ant abundances pooling all species on all 15 farms sampled between May-June 2015 in the zone of Bois Jolie, Haiti.

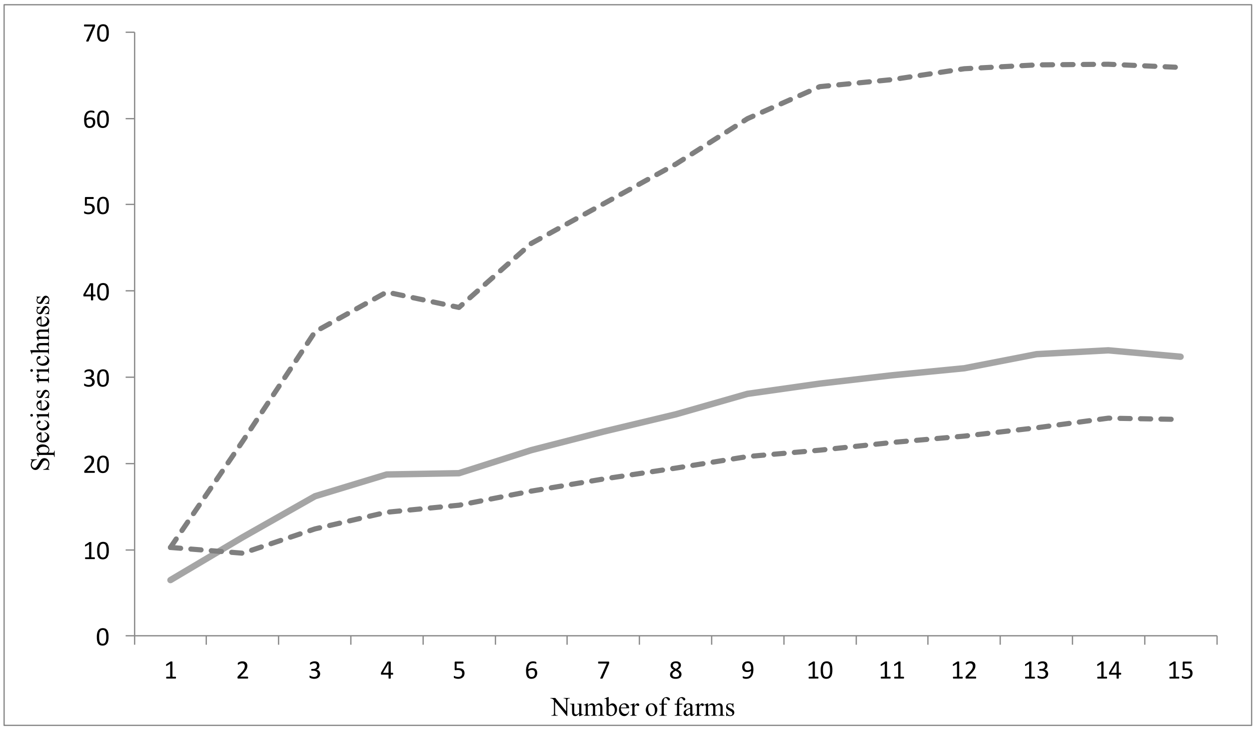

Figure 3. Asymptotic ant species richness estimation (95% confidence intervals) using Chao 2 for incidence-based data (N=15 farms). Data collected in the zone of Bois Jolie in the Central Plateau of Haiti.

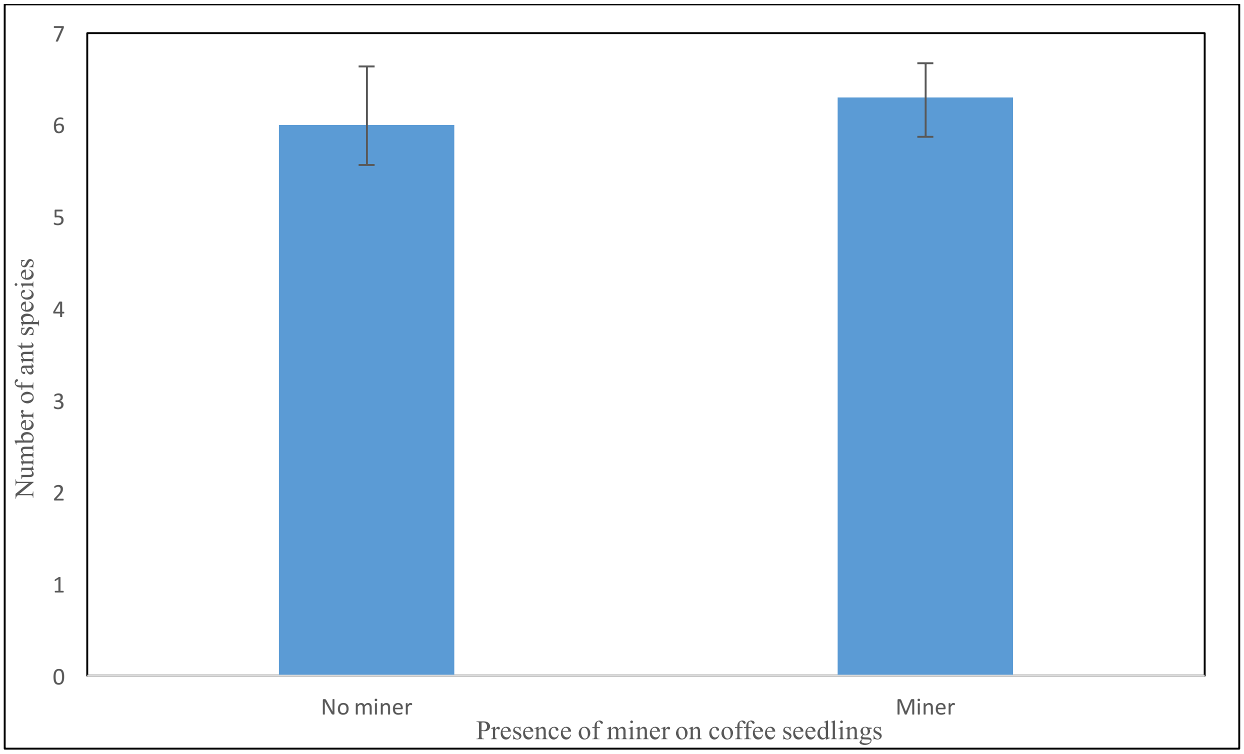

Figure 4. Mean number of ant species (+/- SE) on farms (N=15) with and without the coffee leaf miner present on coffee seedlings. Data collected between May-June 2015 in the zone of Bois Jolie, Haiti.

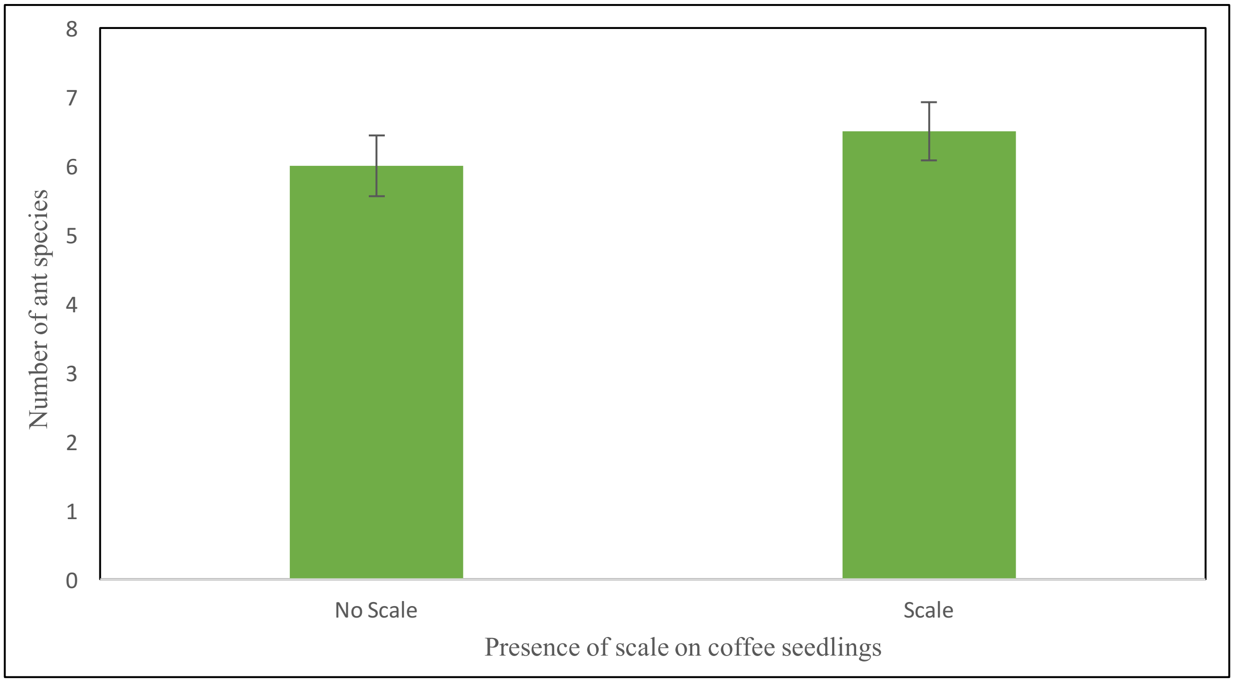

Figure 5. Mean number of ant species (+/- SE) on farms (N=15) with and without the green coffee scale present on coffee seedlings. Data collected between May-June 2015 in the zone of Bois Jolie, Haiti.

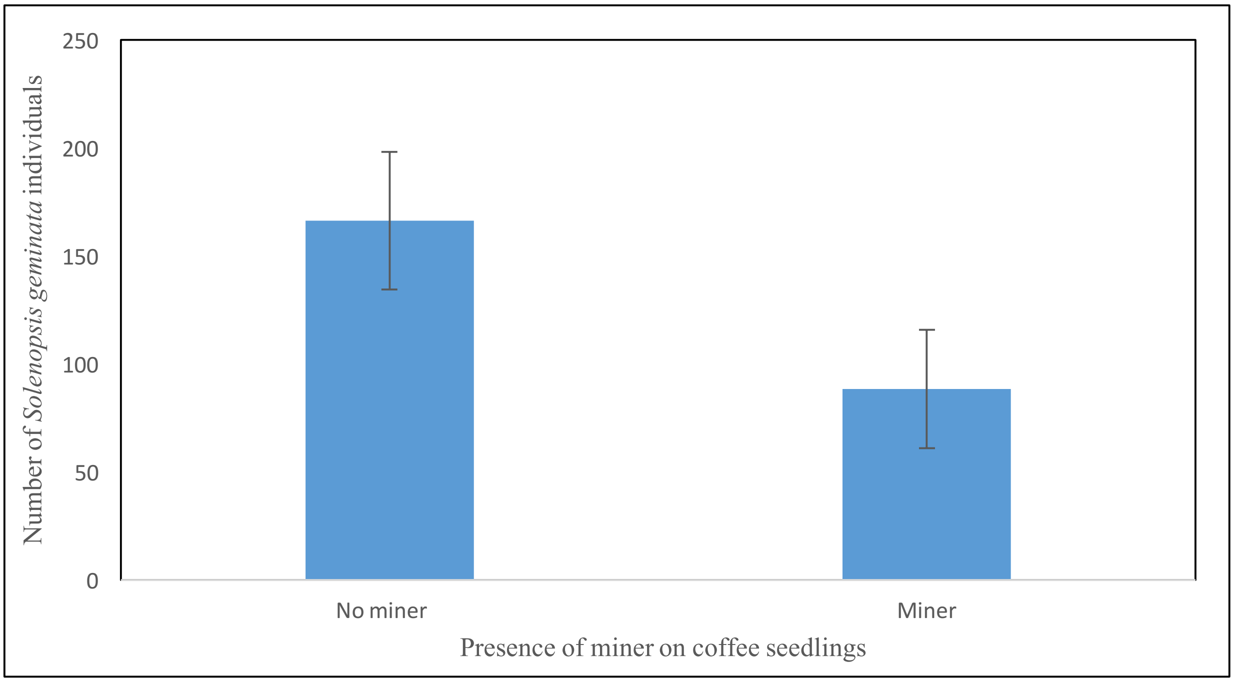

Figure 6. Mean number of *Solenopsis geminata* (+/- SE) on farms (N=15) with and without the coffee leaf miner present on coffee seedlings. Data collected between May-June 2015 in the zone of Bois Jolie, Haiti.

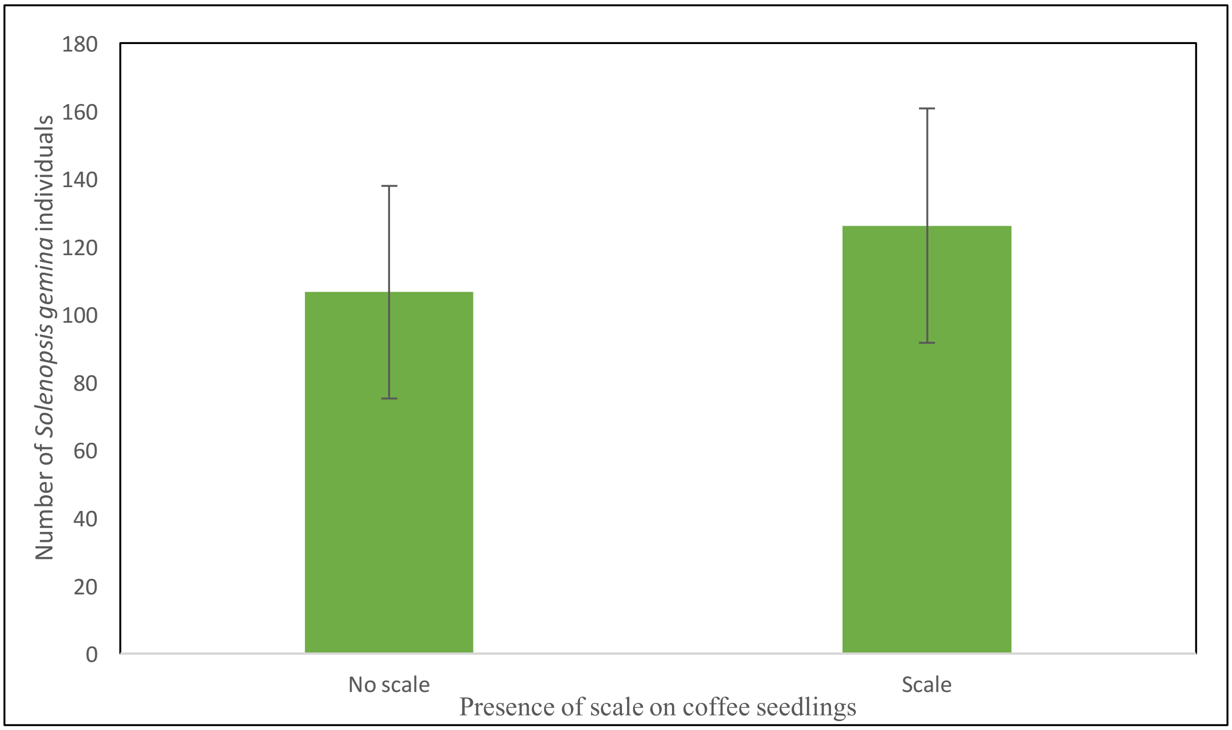

Figure 6. Mean number of *Solenopsis geminata* (+/- SE) on farms (N=15) with and without the green coffee scale present on coffee seedlings. Data collected between May-June 2015 in the zone of Bois Jolie, Haiti.

DISCUSSION

We recorded 21 species and morphospecies of ants present on one-year-old coffee farms (Table 1), which serves as baseline data in order to provide a comparison as the coffee farms grow and mature into shaded coffee agroforests. Based on the species richness curve (Figure 3), we believe that the species recorded are representative of the ground foraging ant species that occur in the zone of Bois Jolie, Haiti. The ant diversity in the zone of Bois Jolie is low in comparison to Jaragua National Park in the Dominican Republic, where 64 species and morphospecies were present (Lubertazzi and Alpert 2014). However, we only sampled ground foraging ants and a future study could sample twig nesting ants to have a more complete understanding of the ant fauna occurring in the region.

Our study supported previous findings that *Solenopsis geminata* dominates in unshaded, disturbed agroecosystems. *S. geminata* is a generalist that commonly nests in agricultural fields and disturbed areas due to its microclimatic preferences for hot and dry conditions with temperatures ranging between 21-35 degrees Celsius (Nestel and Dickshen 1990). Risch and Carroll (1982a) investigated the effect of age and structural diversity of agricultural systems on the presence of *S. geminata*. They studied a forest milpa that was planted after cutting and burning a 40-year-old-forest and field milpa that was planted after plowing one-year-old second growth. They reported that after planting, the forest and field milpa, were both dominated by *S. geminata,* with the forest milpa colonized within five weeks of forest clearing. As the forest system matured, 14 different ant species were present in the forest milpa, while the field system continued to be dominated by *S. geminata*. Additionally, in the forest milpa the number of baits that were occupied by *S. geminata* fell from 90% to 26%. They suggest that the decline in *S. geminata* was due to unsuitable microclimatic conditions created by the growth of vegetation and the presence of shade. Nestel and Dickschen (1990) supported the findings of Risch and Carroll (1982a) reporting that *S. geminata* dominated in the sun coffee agroecosystems of Mexico, while it was rarely found in the in the forest habitats. In our study, *Solenopsis geminata* was the most abundant ant species on all 15 farms. The disturbed, unshaded conditions of the farms likely provided ideal microclimatic conditions for the species to thrive.

Numerous studies have suggested that *Solenopsis geminata* may serve as an important biological control agent in unshaded agroecosystems. In a baiting study, Risch and Carroll (1982a) reported that in the field milpa, *S. geminata* arrived to the baits within 40 minutes and removed all *Drosophila* flies within 100 minutes. In an exclusion experiment, Risch and Carroll (1982b) found that in the absence of *S. geminata,* the abundance of herbivores significantly increased indicating that *S. geminata* may be an important predator of crop pests. Nestel and Dickschen (1990) supported the findings of Risch and Carroll (1982a,b) reporting that *S. geminata* discovered the bait significantly faster in the sun coffee agroecosystems. More recently, Bustillo (2002) identified *Solenopsis* as a natural predator of the coffee berry borer. We investigated the association between the number of *Solenopsis geminata* individuals and the presence of the coffee leaf miner on coffee seedlings. Although we did not find a statistically significant difference in the *S. geminata* abundance between farms with and without the coffee leaf miner, farms without the coffee leaf miner had a higher abundance of *S. geminata*. A possible explanation for this finding is that *S. geminata* is already providing robust biological control against the coffee leaf miner. A future study could manipulate the abundance of the coffee leaf miner to understand how *S. geminata* responds to different levels of pests present. Additionally, the study could manipulate the number of *S. geminata* individuals to understand if higher abundances provide more effective control. The potential to manipulate *Solenopsis* *geminata* to serve as a biological control agent in the early stages of coffee growth could reduce the need for harmful pesticides.

However, caution has been given to the potential negative effects of the use of *Solenopsis geminata* as biological control in agroecosystems. Due to their seed-harvesting behaviors, they have the potential to affect crop production. In Nicaragua, *S. geminata* destroyed over 90% of the tomato seeds (Perfecto 1994). Risch and Carroll (1982a) also observed *S. geminata* feeding on the corn seeds after planting. They also reported *S. geminata* tending homopterans, which have the potential to affect plant growth and development. Additionally, Risch and Carroll (1982b) found that *S. geminata* significantly reduced predatory arthropods, having the potential to increase the abundance of other pests. We investigated the association between the number of *S. geminata* individuals and the presence of the green coffee scale on coffee seedlings. Although we did not find a statistically significant difference in the *S. geminata* abundance between farms with and without the green coffee scale, farms with the green coffee scale had a higher abundance of *S. geminata*. This is an important finding to monitor because if this trend continues, *S. geminata* could become a pest on the farms. Given these potential negative outcomes of implementing *S. geminata* as biological control, precaution has to be taken when making recommendations to famers.

Although *Solenopsis geminata* is a highly aggressive ant and its presence has been inversely correlated with ant diversity (Risch and Carroll 1982a; Trible and Carroll 2014), it has been seen to coexist with few species. Perfecto and Vandermeer (2011) found that *Solenopsis geminata* and *Pheidole subarmata* coexisted on pastures in Nicaragua. They demonstrate that the coexistence is mediated by the dominance/discovery tradeoff in which *P. subarmata* discovers the bait first but is then displaced by *S. geminata,* which is highly effective at defending large resources once discovered. In our study *S. geminata* and *P. subarmata,* the second most abundant ant in our study, coexisted on 14 of the 15 farms. Similar findings were demonstrated in sun coffee agroecosystems in Costa Rica by Perfecto (1994), in which *Solenopsis geminata* and *Pheidole radoszkowskii* coexisted due to the dominance/discovery tradeoff. These studies indicate that *Solenopsis geminata* can coexist with other species in areas where there are many resources, increasing ant diversity.

Few studies have indicated that increased ant diversity may provide more effective biological control, however most studies have focused on the coffee berry borer beetle (Bustillo 2002; Armbrecht *et al.* 2005; Armbrecht and Gallego 2007; Gonthier *et al*. 2013). To date, only two studies have investigated the association between ant diversity and the coffee leaf miner. Lomeli Flores (2007) identified 13 species from eight genera as natural predators of the coffee leaf miner. Two genera from the study were present on our farms, *Camponotus* and *Solenopis.* Lomeli Flores (2007) reported that *Camponotus* predated on the egg, larva and pupa stages, while *Solenopsis* only predated on the pupa, suggesting that increased diversity may provide more robust control. However, De La Mora *et al.* (2008) investigated the association between twig-nesting ant species and the damage to coffee plants caused by the coffee leaf miner. They did not find a significant association between the twig-nesting ant species richness and the incidence or severity of leaf miner damage. We investigated the relationship between ground foraging ant species and the presence of the coffee leaf miner. We found similar results to De La Mora *et al.* (2008), with there being no significant association between the ground foraging ant species richness and the presence of the coffee leaf miner. These studies indicate that experimental studies are needed to further understand the importance of increased ant diversity in pest control.

One limitation of our study is that we did not did not quantify the canopy cover of the farms. Although all the farms were new coffee agroecosystems, some farmers had a greater abundance of trees and other vegetation previously planted. A future study could quantify the canopy cover of the farms in order to understand if there is a significant difference in the canopy cover across the farms. This could be a contributing factor to the significant differences in ant abundances observed on the farms. Another limitation of the study is that we did not sample in forested fragments to understand how the ant diversity present on the farms compares with the ant diversity present in less disturbed, forested fragments which are more representative of natural systems. A future study could sample in forested fragments as well as in mature, shaded coffee agroecosystems to understand how the different systems vary in their ability to support ant diversity in Haiti. This may be especially important in Haiti where very few forested areas remain and agroecosystems may be the only remaining habitat for biodiversity.

CONCLUSION

Understanding the ant diversity present on the farms is of paramount importance as ants serve as biological control agents of debilitating coffee pests and disease. *Solenopsis geminata* may play a critical role in limiting herbivores as the young coffee plants grow and mature. By manipulating ants to serve as biocontrol, farmers can reduce their costs by eliminating the need for synthetic chemicals. Additionally, without the help of non-governmental organizations, many of these subsistence farmers would not be able to purchase expensive agroechemicals. The pest control provided by ants may thus increase the resiliency of the coffee systems to pests and allow coffee to yield more, increasing the household income of the farmers. Additionally, as the farms become shaded agroecosystems, they will provide additional environmental and social benefits to the farmers and the community.

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