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Conservation and pasture value of remnant trees in a tropical agroecosystem

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CONSERVATION AND PASTURE VALUE OF REMNANT TREES IN A TROPICAL AGROECOSYSTEM

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Ariel N. Rivers
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CONSERVATION AND PASTURE VALUE OF REMNANT TREES IN A TROPICAL AGROECOSYSTEM

by
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ABSTRACT

CONSERVATION AND PASTURE VALUE OF REMNANT TREES IN A TROPICAL AGROECOSYSTEM

by Ariel N. Rivers

Deforestation is continuing at a rapid rate in Central America, contributing to a loss of forest habitat and threatening many endemic species. In Matiguás, Nicaragua, as little as 10% of the original forest reserves remain, with cattle pastures now dominating the once forested landscape. The open pastures provide little habitat for endemic wildlife and limit the corridors for animal migration between remaining forest fragments in the region. Remnant pasture trees have the potential to conserve biodiversity at the landscape level, however, farmers prefer to remove the trees for fear that the shade will negatively affect pasture grasses, and thus reduce the available cattle forage. In order to test the hypotheses of the farmers, this study establishes a quantifiable relationship between pasture grasses and three tree species—*Albizia saman*, *Enterolobium cyclocarpum*, and *Guazuma ulmifolia*—between the months of February and May of 2008. Several tree characteristics were measured and related to pasture productivity and arthropod communities below the trees and within the open pasture, and a General Linear Model and a Wilcoxon signed rank test were used to compare the data. Results indicate that pasture productivity is not negatively impacted by trees, and that individual tree species affect both pasture grasses and arthropod communities differently. The findings of this study can provide guidance for planning environmentally focused silvopastoral systems and can guide future research efforts.

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will never forget the contributions they have made to my life path.

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Introduction

Global forest resources are declining at a rapid rate, threatening the conservation status of countless plant and animal species and disrupting many ecosystem processes necessary to maintain a healthy planet (UNEP 2002; Wassenaar et al. 2007). Forests play a significant role in the global carbon cycle, provide valuable protection for soil and water resources, and help to sustain biodiversity by providing habitat for both plant and animal species (WRI 2000; Wassenaar et al. 2007). Despite the important role of forests, deforestation is expected to continue, at an estimated rate of loss of 2 – 5% of all forest species per decade (FAO 2006; Wassenaar et al. 2007).

In Central America, where only 20% of the original primary vegetation remains (Myers et al. 2000), agricultural expansion, specifically for cattle production, is one of the major threats to remaining forests (Nicholson et al. 1995; FAO 2006; Wassenaar et al. 2007). Between 1961 and 2000, forest area in Central America declined by approximately 40% in relation to 1961 values, while both cattle population and pasture area increased to almost 150% relative to 1961 values (FAO 2006). A number of factors are responsible for deforestation in Central America, and livestock production may not actually cause a reduction in forest cover, however, cattle pastures are the primary land use replacing forests (Wassenaar et al. 2007).

Many researchers feel that large-scale cattle production is one of the most environmentally damaging agricultural activities, contributing to global warming and pollution in addition to land degradation (Nicholson et al. 2001; FAO 2006). Despite the negative attributes of animal agriculture however, livestock production plays a significant role in the social structures of many developing nations (Nicholson et al. 2001; FAO 2006). The financial risk and economic flexibility associated with cattle production is relatively low compared to other land uses (Wassenaar et al. 2007). Cattle also have the potential to consume foods inedible by humans, creating a food source from crop residues and other such wastes, and cattle serve as a measure of status to many people in the developing world (Nicholson et al. 2001; Kitalyi & Ong 2007). Animal agriculture is responsible for many environmental problems, but it is also a significant source of wealth and extremely important culturally for many people. With that in mind, a more ecologically responsible approach to livestock production is essential to address the associated environmental issues without disrupting the livelihoods of many rural communities.

Maintaining livestock production is necessary to sustain the human populations of certain communities, and with limited funding available for environmental preservation (Myers et al. 2000), agriculture must also play an increasingly significant role in conservation efforts. In any given region, remaining forest fragments are not necessarily adjacent, limiting migratory corridors for local fauna and thus further increasing the potential for regional extinctions (Vandermeer & Perfecto 2007). Areas that have already been converted to agricultural systems must provide connectivity between forest fragments in order to limit any future biodiversity losses (Dagang & Nair 2003; Vandermeer & Perfecto 2007). This is especially true in Central America due to the abundance of cattle pastures and their location between fragmented forest patches.

The primary means for increasing the environmental value of cattle pastures is to increase tree canopy cover in the field (Galindo-González et al. 2000; Estrada & Coates-Estrada 2001; Schonberg et al. 2004). By actively planting trees for use as posts in live fences, or by retaining trees that naturally regenerate in a pasture, farmers create a modified agricultural matrix often called a silvopastoral system (Dagang & Nair 2003; Harvey et al. 2005; Yamamoto et al. 2007). The incorporated trees provide a range of environmental and agricultural services that greatly benefit farmers, the most significant including an increase in soil nutrient reserves, erosion prevention, protection of the watershed, provision of forage and shade for the cattle, and a diversification of agricultural products in the case of fruit bearing tree species (Morrison 1991; Harvey & Haber 1999; Dagang & Nair 2003; Love 2004).

Although silvopastoral systems can benefit farmers, the adoption of such systems remains low (Dagang & Nair 2003). This study examines the relationship between pasture grasses and dispersed trees in order to assess the effect of trees on pasture productivity and endemic arthropod communities. With the assumption that each tree species will affect the pasture and arthropods differently, the intent of this study is to identify tree species that minimally impact pasture productivity as well as provide the greatest benefit to arthropods, as measured by the diversity and abundance of collected specimens below each tree. The information presented in this thesis can help to design livestock production systems that will not only contribute to conservation, but will support pasture productivity and limit farmer concern in regards to retaining trees within their pastures.

Background

Silvopastoral Systems

Silvopastoralism—very basically, a system in which woody plants, often trees, are grown in pastures grazed by livestock—is not an entirely new means of animal production, and producers in different regions implement various levels of tree canopy cover within their pastures. Live fences, in which trees are used as fence posts, are common among farmers in Costa Rica and Nicaragua, and together with dispersed pasture trees have frequently been cited for their contribution to increased productivity of pasture grasses (Harvey & Haber 1999; Pagiola et al. 2007), and increased production of milk by dairy cattle when pasture trees are present (Yamamoto et al. 2007). Among farmers participating in a payment for environmental services project in Matiguás, Nicaragua, Pagiola et al. (2007) identified eight different silvopastoral systems, ranging from fodder banks in which leguminous woody plants are used as supplemental fodder when grass forage is unavailable during the dry season, to improved pastures with various levels of canopy cover.

Improved pastures, such as those studied for this thesis, typically incorporate a variety of a non-native forage grass, including the perennial cultivars of *Brachiaria brizantha* and *Pennisetum purpureum.* Both grasses are drought tolerant and yield more edible forage than the native, natural pastures, and are reported to tolerate shade moderately well (Fisher et al. 1996; Andrade et al. 2008). Many farmers have selected the improved pasture grasses over the natural pastures for intensification purposes, as the drought tolerant grass species increase overall system productivity in seasonally dry areas (Schlönvoigt & Ibrahim 2001; Andrade et al. 2008).

Although improved pastures provide more edible forage than the native pastures, farmers are still concerned for the production of fodder during the water limited period in the seasonally dry tropics (Morrison et al. 1996; Zamora et al. 2001). Even in improved pastures, supplemental feed sources are often needed in order to meet the dietary needs of cattle, especially in the latter months of the dry season (Morrison et al. 1996; Ibrahim et al. 2001). As such, concern for the dry season should be high in the design of silvopastoral systems, and the incorporation of trees into pastures is known to enhance the efficiency of water use among pasture grasses under drought conditions (Hernández-Daumás & Russell 2001). Pastures trees are widely cited for increasing nutrient cycling in silvopastoral systems as well, contributing additional fruits and timber for farmers, and providing supplemental dry season fodder themselves (Morrison et al. 1996; Harvey & Haber 1999; Dagang & Nair 2003; Pagiola et al. 2007).

The importance of silvopastoral systems to the conservation of biodiversity is also becoming increasingly important according to researchers due to the sheer abundance of agroecosystems and the impending limitations regarding remaining pristine habitats (Dagang et al. 2003; Vandermeer & Perfecto 2007). Although the environmental value is one of the primary benefits of silvopastoral systems according to many researchers, as is the increased agricultural production associated with trees, many farmers feel these benefits are not pertinent to overall livestock production (Pagiola et al. 2007). Adoption of silvopastoral systems remains low (Dagang & Nair 2003; Pagiola et al. 2007);

however with the increased attention on silvopastoral systems for the preservation of biodiversity and current studies implementing payment for environmental services for such production systems (Pagiola et al. 2007), the necessity for appropriate planning of silvopastoral systems that contribute to increased diversity at the landscape level is considerably more important.

Diversity-Stability Theory

Researchers have long debated the significance of diversity within an ecosystem; however, it is well known that increasing diversity will increase stability regardless of whether or not the mechanism within natural ecosystems is understood (Doak et al. 1998; McCann 2000). As early as the 1970s, the importance of biodiversity in ecosystem stability was recognized, but researchers have more recently suggested that early hypotheses implying that simply increasing species diversity would lead to an increase in ecosystem stability was an oversimplification (McCann 2000). It is clear that diversity is important, but how that pertains to species diversity, interactions among species, or varying abundances of individual species is still a question (Doak et al. 1998; McCann 2000).

Empirical studies on the diversity-stability relationship have established that the stability of plant communities is directly associated with diversity in an ecosystem, based on the idea that variability is limited in overall community biomass (McCann 2000). Assuming that community biomass is simply the lumped sum of all biomasses of individual species, then some researchers have suggested that adding more species to a community will average the variation within the overall community biomass, therefore contributing to a more stable ecosystem (Doak et al. 1998). To define that further, Doak et al. (1998) suggested an inverse relationship between the variation in the properties of a community and species richness; as the variation in characteristics of a community decreases, the number of species necessary to maintain ecosystem stability must therefore increase.

Increasingly, researchers are also recognizing the role of individual species within ecosystems through the idea of functional diversity. With every individual species belonging to a different taxonomic group, which contributes differently to ecosystem processes (such as contributing to nutrient cycling), diversity in taxonomic groups is a factor in adequate ecosystem function (Tilman 2001). Although a wide variety of species characteristics are important to ecosystem function, some of the more significant include those that control limited resources, alter the organization of food webs, and protect the ecosystem from large-scale disturbances (Tilman 2001). Ecosystem processes are thus impacted, both positively and negatively, by the abundance of various different species occupying an ecosystem (Tilman 2001).

Diversity overall is also important to human altered landscapes, such as silvopastoral systems. Harvey and Haber (1999) have suggested that pasture trees contribute to vegetational complexity of farms; however this extends further to the role of trees in the overall agroecosystem. Researchers have identified the significant role live fences play in connecting the agricultural landscape and increasing the ecosystem functionality in terms of contributing habitat and resources for local fauna (Harvey et al. 2005). Since cattle pastures are one of the dominant forms of land use in Central

America, increasing the overall diversity of these systems contributes to increasing the stability of the overall ecosystem. However, increasing the functional diversity is also equally as important. Studies that identify the effect on grass productivity of individual tree species, and the functional characteristics of those trees, provide valuable data on the importance of individual tree species in these ecosystems.

Arthropods as Indicator Species

Due to the vast diversity within the Phylum Arthropoda, interest in conserving insects is of particular interest to researchers, with the most serious need for conservation in the tropics (Pyle et al. 1981). Knowledge regarding the distribution, habitats, and abundance of native insects is still relatively limited (Pyle et al. 1981), but with more than 30 million insect species on earth, their wide distribution and overall general abundance (Perfecto et al. 1997; Borror et al. 2005), the conservation of arthropods is no less important than that of more charismatic individuals such as birds.

In agroecosystems, epigeal (ground-dwelling) arthropods can serve as indicators of overall biodiversity (Duelli et al. 1999). Arthropods are easily collected in pitfall traps, allowing for standardization of a passive collection method among plots, and due to the abundances within catches, comparison based on statistical analysis is feasible (Duelli et al. 1999). Researchers have also proposed a number of reasons that arthropods are not efficient indicators in biodiversity evaluation, such as the poor correlation between predators (for example, spiders and parasitic wasps) and overall biodiversity, the need for a focus on rare and endangered species and not on common beneficial arthropods, and the cost and efforts associated with collecting and identifying specimens (Duelli et al. 1999).

However, arthropods also comprise the majority of the variability within many terrestrial ecosystems and are thus good indicators for quantitative biodiversity assessments (Duelli et al. 1999; Borror et al. 2005).

General abundance of arthropods has previously been used as a measure of higher trophic productivity based on the idea that a greater abundance of insects leads to a greater availability of prey (Tulp & Schekkerman 2008). Food-web structure is an important component in the general study of biodiversity and the stability of ecosystems (McCann 2000) and expanding the availability of prey in silvopastoral systems would greatly benefit passing migratory species, such as birds. A great deal of research on the availability of food in the predator-prey relationship in agriculture has focused on the control of pest arthropods, often by other arthropods (Straub et al. 2008), or has looked at bird abundance as it affects arthropod abundance (Gunnarsson et al. 2009). Increased abundance overall of arthropods could lead to an increase in higher trophic guilds, however, regardless of the application.

Related Research

Central American landscapes are a highly fragmented matrix of human occupied spaces, agroecosystems, and remaining natural habitats (Guevara et al. 1998). With the limited number of remaining forest fragments, forest animals are increasingly left with limited spaces to populate, as well as fewer corridors for migration between natural areas (Guevara et al. 1998; Vandermeer & Perfecto 2007). Researchers have noted that in highly fragmented landscapes, areas, such as cattle pastures that can host natural life are necessary for conservation (Guevara et al. 1998; Vandermeer & Perfecto 2007). Agroecosystems are increasingly important as conservation areas, and Vandermeer & Perfecto (2007) have suggested that the corridors provided by agriculture should be the primary focus for future conservation initiatives. Silvopastoral systems are one system by which forest fragments can remain connected, and are also a potential source of habitat for numerous species in their own right, thus maintaining some level of diversity at the landscape level.

In a survey of isolated pasture trees in Costa Rica, Harvey and Haber (1999) identified 5583 trees in 190 different species, with 90% of these species known to provide food for forest fauna. The trees were either allowed to remain at the time of forest clearing or retained after naturally regenerating, with farmers citing 19 different uses of the pasture trees, including shade for cattle, increase in organic inputs, and an increase in farm value (Harvey & Haber 1999). The trees contribute to on-farm diversity themselves, and support epiphytic diversity as well, further contributing to the vegetational complexity within the pastures (Harvey & Haber 1999). Researchers also suggest that isolated pasture trees act as a resource for future restoration efforts, as the seed rain below remnant trees is much higher than within open pasture areas, and remnant trees act as a reserve of forest genetic material as they are often the oldest living structures in many disturbed habitats (Harvey & Haber 1999; Manning et al. 2006).

Guevara et al. (1998) suggest that dispersed pasture trees represent a fragmented forest canopy, with each tree acting as a microhabitat within itself, supporting epiphytes, insects, birds and bats (Heitz-Seifert et al. 1996; Galindo-González et al. 2000;

Schonberg et al. 2004). Epiphytes, non-parasitic plants that grow on trees and other woody plants instead of in the soil, are known to require small areas in order to maintain high levels of diversity (Nieder et al. 2001). In the Otonga Reserve in Ecuador, a branch area of twenty square meters contained 109 species of epiphytes compared to only 67 species of terrestrial plants in a nearby area five times as large (Nieder at al. 2001). Researchers thus suggest that the plant diversity within a forest is often based on that of epiphytes, and the importance of such plants extends to their ability to provide food and habitat for rainforest fauna (Nieder et al. 2001; Heitz 2005). Heitz (2005) found that trees within coffee plantations support high levels of epiphyte diversity, and are an important landscape component in epiphyte conservation. However, Heitz (2005) also found that not all coffee plantations support epiphyte diversity equally, depending on a variety of factors, such as tree size, density of trees, and frequency of pruning. Due to the importance of epiphytes for the preservation of overall biodiversity, epiphyte coverage within remnant pasture trees is considerable in affecting the conservation role of any given tree species at the landscape level.

Many researchers have generically investigated the conservation value of remnant trees, however very few have quantified the effects of these trees on arthropod communities in cattle pastures. Dunn (2000) studied trees in fallow agricultural fields and fields under yam and cassava cultivation in Ghana, and found higher levels of Formicidae species richness and Coleoptera abundance near the trees as compared to within the open fields. The study's results may not extend to cattle pastures of Central America however, considering the drastic differences between cultivated fields and livestock production systems. Similarly, Perfecto et al. (1997) identified the importance of remnant trees to arthropods in coffee agroecosystems in Costa Rica; however, the researchers only reported data on Coleoptera and Hymenoptera (further identified to Formicidae and non-Formicids). Thus the conclusion of the study, that remnant trees positively impact arthropods, is somewhat arbitrary considering information was only reported for three taxonomic groups, and does not extend to other beneficial taxa such as spiders (Perfecto et al. 1997). Again, coffee agroecosystems differ substantially in comparison to cattle pastures, so the results may not apply in silvopastoral systems. Many other researchers have similarly evaluated arthropod communities, for example, Lumsden and Bennett (2005) collected insects to assess prey availability in pastures of south-eastern Australia, but many of these studies are limited to remnant trees in general and do not identify individual tree species as the predominant force in driving ecosystem differences. Further, many studies of arthropod communities in agroecosystems are limited to agricultural production practices other than cattle pastures.

Remnant pasture trees can act as a very important resource for environmental preservation, as such, it is necessary to collaborate with farmers in deforested areas to address the conservation value of silvopastoral systems. Many farmers lack appropriate information regarding the effect of trees on pasture, and Morrison (1991) found that in Jamaica, farmers are hesitant to increase canopy cover in cattle pastures due to farmer concern for the loss of grass productivity. Further, one of the primary reasons farmers own cattle in Central America is the relatively low input of labor necessary to manage livestock as compared to other farming activities (Morrison et al. 1996; Dagang & Nair

2003; Love 2004). It has been suggested that one of the primary reasons adoption of silvopastoral systems remains low is the increase in labor necessary to manage the additional vegetation, especially initially when trees and woody fodder banks are first planted (Morrison et al. 1996; Dagang & Nair 2003; Love 2004). Identification of specific tree species that could enhance the productivity of the agricultural system while minimally impacting the labor patterns of farmers would be hugely beneficial for promoting silvopastoral systems. Addressing the needs of individual farmers is very important in silvopastoral research, and recognizing that different farmers have different objectives related to their systems is equally important (Dagang & Nair 2003). Identifying valuable multipurpose tree species for silvopastoral use is a necessary step in appropriate conservation planning.

Despite the availability of information on the conservation value of silvopastoral systems, and the associated production benefits, few researchers have studied individual tree species to recommend for use in silvopastoral systems. Although each of the previously mentioned studies suggests the necessity for conservation-minded management in agricultural landscapes, most of the studies have generically assessed the value of remnant trees without identifying the effect of individual species. Few researchers have studied specific tree species and their effect on pasture productivity as well, and correlated those same tree species to the conservation of biodiversity. The diversity of tree species is high in already established silvopastoral systems (Harvey & Haber 1999); however, identification of specific trees that may contribute to biological conservation would greatly enhance the planning of future conservation efforts.

Research Objectives

Completed research on silvopastoral systems suggests that agroecosystems have the potential to mimic a natural environment and provide habitat and corridors among forest fragments for native fauna. However, limited research has been conducted on the effect of individual tree species on biodiversity and ecosystem productivity. This thesis addresses the aforementioned issues by evaluating the effect of three native tree species on the growth of common pasture grasses during the dry season, as well as their effect on the diversity and productivity of arthropods. Generally, this thesis addresses the following research objectives as they relate to silvopastoral systems in Matiguás, Nicaragua:

1. How do specific tree functional characteristics relate to grass productivity and arthropod communities?
2. How does pasture productivity differ below different tree species, as compared to each other and as compared to the open pasture?
3. How do arthropod communities differ below different tree species, as compared to each other and as compared to the open pasture?

Study Area

I collected data in Matiguás in the Department of Matagalpa in central Nicaragua between January and May of 2008. The area is located at 12°50' north latitude, 85°27' west longitude, with complex topography varying from 300 to 500 meters above sea level, and is in a transition zone from tropical dry forest to tropical humid forest (Harvey et al. 2005; Pagiola et al. 2007). With an average annual temperature of 25° Celsius, the region receives approximately 1700-2500 millimeters of rainfall annually with a seasonal dry period during the months of January and May during which farmers are often concerned with the availability of forage (Harvey et al. 2005; Yamamoto et al. 2007).

Very little forest remains in the region, with less than 10% of the landscape under canopy cover (Harvey et al. 2005). Matiguás is one of the prominent cattle producing areas in central Nicaragua and farmers produce both dairy and beef cattle, with pastures accounting for approximately 68% of the current land use (Harvey et al. 2005). Due to the minimal amount of remaining forest, as well as the widespread distribution of cattle pastures in the region, Matiguás provides ideal conditions for assessing the environmental effects of individual tree species on pasture productivity and arthropod communities.

Site Selection

In early January 2008, I selected 5 study farms in the Limas Arriba and Limas Central regions of Matiguás from approximately 20 that I visited, according to a specific set of criteria. First and foremost, it was necessary that farmers were willing to participate in the study. In order to standardize the data among farms, and thus limit cattle consumption of the grass below trees and trampling by cattle on the arthropod pitfall traps, it was necessary to enclose a representative area with barbwire below each tree and within the open pasture in order to limit access by cattle (see Methods for Tree Characteristics for further discussion). Many farmers were resistant to this idea, due to the impending limitations of fodder during the dry season. Farmers that were willing to allow the construction of such enclosures, and farms where the soil conditions and topography would allow for construction of such enclosures, were considered for collaboration. Many of the farms in the region are landlocked, with access only through other farms, so I also limited the study farms to those that were accessible by an ATV (All Terrain Vehicle) with less than a 2 kilometer walk from the primary dirt road.

On each farm, I limited study pastures to those containing *Brachiaria brizantha* or *Pennisetum purpureum* grasses. These grasses were chosen for their abundance within the agricultural matrix of Matiguás, and the likelihood that farmers in similar areas, who may potentially implement silvopastoral systems in the future, will also have pastures planted with these two species (Peters et al. 2001; Yamamoto et al. 2007; Andrade et al. 2008). I also looked for pastures with apparent homogeneity on the farm as well as among farms, meaning the pastures appeared similar based on observation in regards to density of pasture grasses as well as density of plant species other than the pasture grasses.

Once I identified pastures according to the presence of *B. brizantha* and *P. purpureum*, I selected potential study pastures which contained multiple species of dispersed pasture trees. I identified prospective trees which were large enough to study, with a diameter at breast height greater than 10 centimeters, and at a distance of at least 10 meters from the nearest tree to avoid any effect of the neighboring trees (Heitz 2005; Perfecto et al. 1997). Three tree species—*Alibizia saman*, *Enterolobium cyclocarpum*, and *Guazuma ulmifolia*—were then selected for the study based on the representation of each species across the farms, the appropriate size of each tree, and independence from neighbors of each of the trees. Further, the range in structural characteristics of these three tree species indicated they may differ ecologically in their function, and thus provide an interesting set of comparisons in regards to pasture productivity and arthropod communities.

Tree Characteristics

Research Objectives

A wealth of information exists regarding the conservation value of remnant pasture trees, however, knowledge regarding specific tree characteristics that may affect ecosystem productivity as it relates to both pasture grass productivity and arthropod communities remains limited. In order to assess the role of different tree species, this thesis relates the following tree characteristics measured in the field to pasture productivity and arthropod communities:

1. Tree height
2. Branching height
3. Number of stems at breast height
4. Canopy area
5. Trunk size (diameter at breast height)
6. Relative coverage of branches by epiphytes

Further, site characteristics such as number of trees at each study farm, are correlated to environmental conservation at the landscape level, and information obtained from a literature review regarding leaf structure and phenology flower structure and phenology and various other tree characteristics are also discussed in this thesis as they relate to arthropod communities.

Methods

Study Design

For the purpose of this study, a study plot is considered one fenced enclosure containing either a tree or an open pasture area. In order to exclude cattle from each plot, field assistants at each farm built enclosures (Figure 1) using locally obtained fence posts and barbwire I purchased in Matiguás and transported to each farm. Each enclosure featured three fence posts on each side, with three strings of barbwire along the circumference of the plot. Where no tree was present to mark the center of the plot, field assistants placed a pole in the center in order to construct plots that matched those in size of the tree plots.

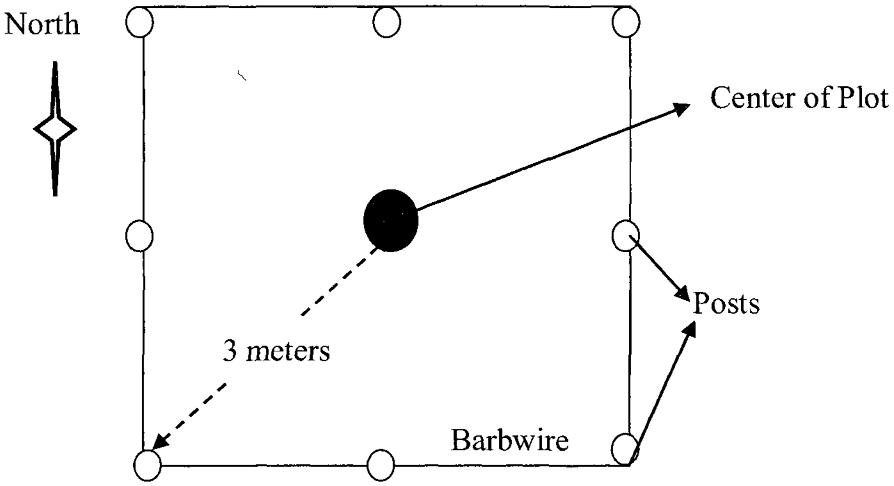


Figure 1. Plot enclosure (not to scale).

To obtain the tree plots, I used every tree of the three species—*A. saman*, *E. cyclocarpum*, and *G. ulmifolia*—meeting size and independence criteria (greater than 10 cm diameter at breast height and no less than 10 meters away from adjacent trees) on the five study farms (Table 1). Open pasture plots were selected according to the number of tree plots of any species within each study pasture, with one plot placed in pastures with less than 4 study trees, and two plots selected in pastures containing 4 or more tree plots, yielding well interspersed plots among the farms (Table 1). Selection of the open pasture plots also required that no shade was present anywhere within the plot; plot construction was feasible according to topography and soil conditions; and in the case of larger pastures, the plot was no further than 30 meters from at least one of the tree plots.

Table 1. Number of plots at each farm.

		Plot			
Producer	**Number of Pastures**	***A. saman***	***E. cyclocarpum***	***G. ulmifolia***	**Open Pasture**
Juan Jose Jarquin Jarquin	3	2	1	5	3
Tomas Soza Morales	3	4	0	2	4
Juan Jose Jarquin Robles	2	3	2	2	2
Isidro de Jesus Leon Jarquin	5	3	6	5	6
Trinidad Lanzas Flores	2	1	3	0	2
Total		13	12	14	17

Data Collection

In the field, I collected data on height, canopy area, diameter at breast height (DBH), and branching height using a Forestry Suppliers© diameter tape and a Suunto© clinometer, and I counted the number of stems with a DBH greater than 10 centimeters for each tree. I used the Domin-Krajina scale (Barbour et al. 1999), selected for the precision in classes as compared to similar coverage scales, to assess the number of epiphytes present in each tree. The tree branches served as the plot area, and with a visual assessment I determined the percentage of branch area within each tree covered in epiphytes and assigned the corresponding coverage class. Slope and aspect were also recorded for each plot using the clinometer, and I collected basic information regarding farm size and farmer opinion regarding dispersed pasture trees from each producer. Every tree species (with no limitations on DBH) within each study pasture were also identified and counted. I conducted a literature review in order to obtain information for each tree on nitrogen taxonomic group (legume or non-legume) and leaf and flowering structure of each of the trees.

Data Analysis

All data were managed in a Microsoft Excel© spreadsheet. Mean and standard error of the arithmetic mean (SE) were calculated using SYSTAT© 12 analytical software for tree height, branching height, number of stems at breast height, canopy area, and DBH. To compare epiphyte coverage, I used SYSTAT© 12 to identify the median Domin-Krajina coverage value for each tree species, with the interquartile range (IQR) calculated in Microsoft Excel© (Wheater et al. 2000).

Limitations

The selection of tree specimens for this study was based on the availability of specimens within *B. brizantha* and *P. purpureum* pastures, and on the availability of specimens isolated from nearby neighbors to determine a single tree effect. Thus, the selection of the trees is not random, and the characteristics identified are not representative of the species, but of the trees I measured.

A number of other tree characteristics, which I did not measure for this study, are known to significantly affect the functional role of different tree species, not limited to light penetration through the canopy, bark thickness, and nectar and fruit production (Petit et al. 1999; Hernández-Daumás & Russell 2001; Nieder et al. 2001). The effect of any given tree characteristic is purely correlational however, and could vary drastically in time based on any number of factors, such as changes in wind, temperature, and humidity. Further, the mechanism of how each individual tree characteristic relates to other aspects of the environment is also equally as significant (for example, organic matter decomposition provides both additional plant nutrients as well as potential food sources for arthropods) as the tree characteristics themselves. Thus, to measure every tree characteristic that could potentially influence environmental productivity and the mechanisms associated with its environmental effect would be next to impossible. Several tree characteristics considered significant to grass productivity and arthropod communities have been chosen for this study, and any related results are important in identifying significant trends and objectives for future research.

Although I collected information regarding overall tree diversity at each farm, these values should not be taken as a systematic comparison, as the areas of each farm and of each pasture vary drastically and were not selected according to a formal methodology. This information is simply provided in order to note the drastic differences among on-farm diversity at the landscape level.

Results

A total of 98 *A. saman*, 257 *E. cyclocarpum*, and 284 *G. ulmifolia* trees were found on the five farms, including trees not meeting study criteria (Figure 2). The farm of Isidro de Jesus Leon Jarquin contained the greatest number of study trees, as well as trees of other species, as compared to the other farms (Figure 2; Table 2).

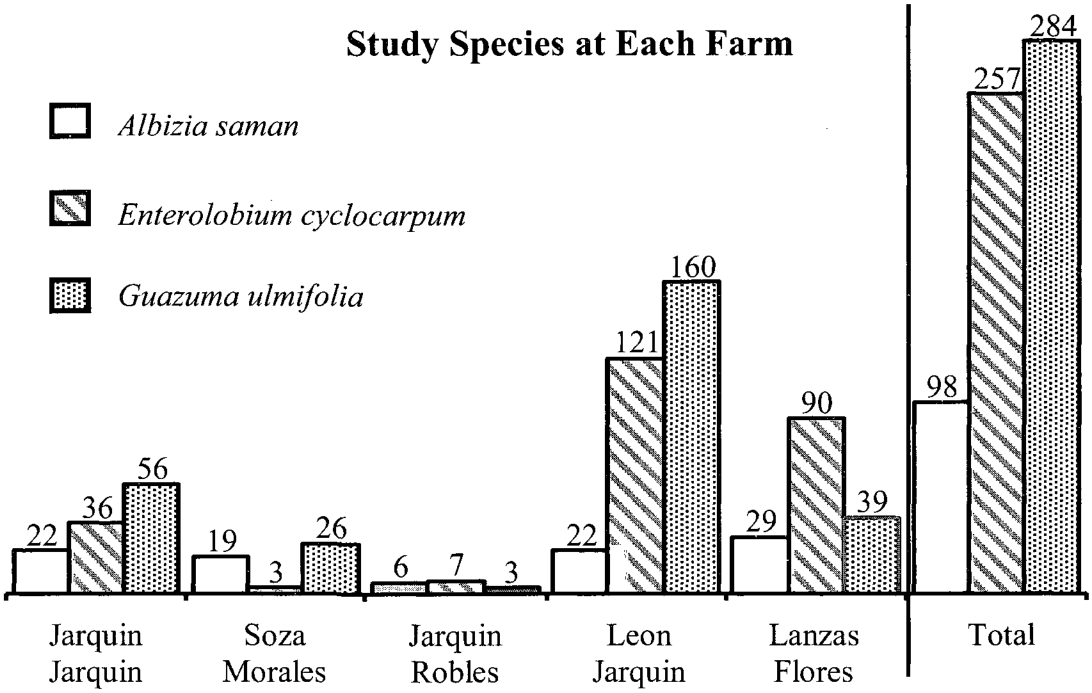


Figure 2. Total number of *A. saman*, *E. cyclocarpum*, and *G. ulmifolia* within study pastures at each farm and for all farms combined, including trees not meeting study criteria.

Table 2. Description of Study Farms.

Producer	Trinidad Lanzas Flores	Isidro de Jesus Leon Jarquin	Juan Jose Jarquin Robles	Tomas Soza Morales	Juan Jose Jarquin Jarquin
Region	Limas Arriba	Limas Arriba	Limas Central	Limas Central	Limas Central
Farm Size (ha)	126.0	17.5	42.0	58.1	56.0
Pasture Grass	*B. brizantha*	*B. brizantha*	*B. brizantha*	*B. brizantha* and *P. purpureum*	*B. brizantha*
Number of Pastures	2	5	2	3	3
Pasture Area (ha)	9.8	7.4	3.5	5.3	6.3
Trees per Farm (study pastures only)	678	1,103	147	128	784
Tree Density/Pasture	339.0	220.6	73.5	42.7	261.3
Tree Density/ha (tree/ha)	69.17	150.05	41.99	24.38	124.43
Tree Species/Pasture (#)	45	39	16	20	38
Producer Opinion on Pasture Trees	Only *Cojoba arborea* negatively affects pasture, unless trees are closely spaced	*G. ulmifolia* and *E. cyclocarpum* both have a lot of foliage, limiting penetration by the sun	Under any shade, pasture does not grow well	All trees that generate a lot of shade prevent growth of pasture grass	The pasture quality is poor where there is a lot of shade from trees

Accounting for the different numbers of study pastures at each farm, Leon Jarquin also has the greatest density per hectare of trees on his farm, but not the greatest density of trees per pasture (Table 2). The farm of Trinidad Lanzas Flores has the greatest diversity of tree species, but he also has the largest area of study pastures (Table 2). Similarly, the farm with the lowest area of the study pastures, that of Juan Jose Jarquin Robles, also has the fewest number of tree species, but not the fewest number of trees overall (Table 2). Although the farms varied greatly in their characteristics, every farmer had the same basic opinion regarding trees within their pastures; pasture is less abundant and of poor quality when grown in shade (Table 2).

Each of the trees is semi-deciduous and drops its leaves for a short period during the dry season (Table 3). *A. saman* and *E. cyclocarpum* are both legumes with binpinnate leaves, although the leaves of *A. saman* are more rounded than those of *E. cyclocarpum* (Table 3). All three of the trees flower during the dry season as well, with different varieties of flowers. *A. saman* flowers are pink and white, those of *E. cyclocarpum* are white, and *G. ulmifolia* features small yellow flowers. The fruits of all three trees are edible by livestock, as are the leaves of *A. saman* and *G. ulmifolia* (Table 3).

In terms of tree characteristics, *A. saman* and *E. cyclocarpum* were very similar in terms of height, branching height, number of stems at breast height, canopy area and DBH (Table 4; Figure 3). However, *A. saman* had higher median epiphyte coverage as compared to *E. cyclocarpum,* with greater variability in the values as well (Table 4).

G. ulmifolia on the other hand was much shorter, with a lower branching height, a greater number of stems at breast height, a much smaller canopy area, and a reduced trunk size compared to the other two species (Table 4; Figure 3). This tree is essentially smaller and more structurally diverse than the other two trees. The median Domin-Krajina coverage class for *G. ulmifolia* is the same as that of *A. saman*, however, the variability of epiphyte coverage is less on *G. ulmifolia* than *A. saman* (Table 4).

Table 3. Nitrogen functional group, leaf and flowering characteristics, and edible plant parts of study species, obtained from a literature review.

	Tree		
	A. saman	***E. cyclocarpum***	***G. ulmifolia***
Nitrogen Group	Legume (Durr 2001)	Legume (Francis 1988)	Non-Legume (Francis 1991)
Leaf Structure	Bipinnate, up to 30 cm in length with 2-6 pairs of pinnae. Each pinnae contains 2-8 pairs of semi-round leaflets (Durr 2001)	Bipinnate leaves, up to 22 cm in length, with long, semi-rectangular leaflets (Francis 1988)	Alternate, ovate to lance shaped leaves, up to 7cm long and up to 5 cm wide (Powell 1997)
Leaf Drop	February – March (Durr 2001)	February – April (Francis 1988)	March – April (Francis 1991)
Flower Structure	Inflorescence with 15-22 pink and white flowers (Durr 2001)	Small white flowers in clusters at base of leaves (Francis 1988)	Clusters of small, fragrant yellow flowers, at the base of the leaves (Francis 1991)
Flowering Period	March – May (Durr 2001)	March – April (Francis 1988)	March – April (Francis 1991)
Plant Parts Edible by Cattle	Leaves and Fruit (Morrison 1996)	Fruit (Francis 1988)	Leaves and Fruit (Francis 1991)

Table 4. Mean (SE) and median (IQR) values for height, branching height, number of stems at breast height, DBH, the Domin-Krajina Class for epiphyte coverage for the study specimens only.

	Tree		
	A. saman	*E. cyclocarpum*	*G. ulmifolia*
Height (m)	11.04 (0.917)	12.90 (1.014)	9.48 (0.493)
Branching Height (m)	1.94 (0.150)	2.13 (0.273)	1.52 (0.132)
Number of Stems at Breast Height	1.17 (0.104)	1.40 (0.260)	2.00 (0.286)
Canopy Area (m^2)	171.87 (33.943)	128.97 (21.615)	87.00 (8.810)
DBH (cm)	42.13 (4.569)	38.28 (2.739)	35.36 (2.301)
Domin-Krajina Class for Epiphytes	4.00 (Median) 5.50 (IQR)	1.00 (Median) 4.00 (IQR)	4.00 (Median) 2.00 (IQR)

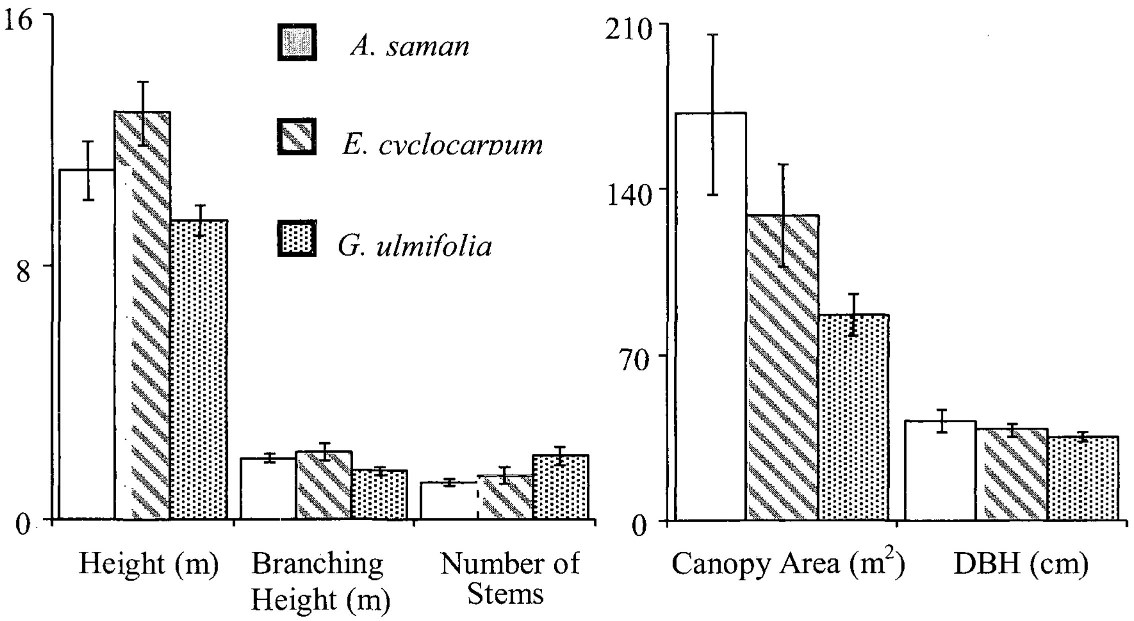


Figure 3. Mean (and SE) of height, branching height, number of stems at breast height, canopy area, and DBH of the study trees only.

Grass Productivity

Research Objectives

One of the primary objectives of this thesis is to identify different tree species for incorporation into silvopastoral systems that will minimally impact pasture grass productivity during the dry season. To do so, I compared pasture grass productivity, as measured by grass wet weights and grass heights, below three different tree species and compared the tree species to each other as well as to open pasture areas. The associated null hypothesis states:

H_0: Pasture grass productivity will not differ significantly below the tree species, as compared to each other and as compared to the open pasture, during the forage limited dry season.

A. Total pasture grass biomass will not differ among plots.

B. Heights of the pasture grasses will not differ among plots.

Methods

Study Design

All data collection for grass productivity was conducted within the enclosures described in the methods for tree characteristics, during the months of February and May of 2008. I used a random number generator to select four subplots (0.5 meter x 0.5 meter) north, east, south, and west of the center of the main plot (Figure 4). This method was selected in order to ensure that differences in grass productivity could be related to the whole tree as opposed to outlying effects such as differences in tree structure on one side of the tree as compared to another, movement in sun, differences in topography below the tree, and other similarly uncontrollable effects. Each subplot was marked for use throughout the data collection period.

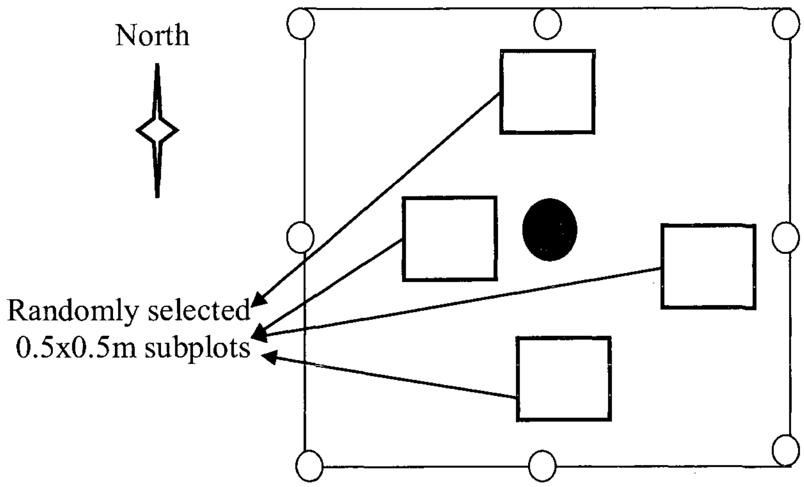


Figure 4. Plot enclosure with subplots for collection of grass data (not to scale).

Data Collection

Samples for grass biomass were collected three times during the dry season—in the early season, in the mid-dry season, and in the late dry season—approximately six weeks apart. Data collection spanned a week's time in each case, with samples collected from one farm per day due to the distances between each farm. Within each of the four subplots, we used basic hedge shears to cut and collect all pasture grass at 12 centimeters above ground level. This is the average height above which cattle browse, and the point at which pasture grass grows in minimally grazed areas (as is the case during the period of study for this thesis) thus this height was selected to determine plant biomass (‘t Mannetje 2000; Demirbağ et al. 2008). The grass was bagged in the field and weighed immediately upon return to the field station on an Ohaus© Triple Beam Balance. Grass height of the tallest plant within each subplot was measured from the base of the plant to the tip of the longest leaf prior to each cutting and at three week intervals throughout the dry season using a standard metric yardstick.

Data Analysis

The values for the four subsamples for grass height and grass weight were averaged for each series of measurements in Microsoft Excel© to obtain a total plot value for use throughout analysis. Basic statistics were calculated in SYSTAT© 12 in order to determine the appropriate set of analyses.

The following comparisons were tested for grass weight and height separately for each sample period during the dry season:

1. Open pasture as compared to all tree plots combined (All Trees Combined)
2. Open pasture as compared to the legumes (*A. saman* and *E. cyclocarpum*) and *G. ulmifolia* (Legumes)
3. Open pasture as compared to each tree species individually (Tree Species)

Grass heights and weights were log transformed in Excel© and analyzed using a General Linear Model (GLM) in SYSTAT© 12. For each GLM, I used Tukey’s Honestly-Significant-Difference Test to conduct a post hoc comparison in SYSTAT© 12.

Since transformations of the values for grass weights did not alter the skewness of the data, I used a Wilcoxon signed-rank test to determine trends in wet grass weights.

Limitations

Due to a variety of unforeseen field conditions, conducting standard procedure for grass biomass, including determining dry weights of samples, was not possible for this study. Grass wet weights were thus used to assess differences in plant biomass among plots. Further, the first cutting, in the early dry season, is more a reflection of the wet season effect of the tree than any initial conditions of drought. A preliminary cutting among all plots to standardize the grasses prior to actual data collection would have proven valuable (Durr & Rangel 2002), as would data collection for multiple dry seasons. Despite these limitations however, the results provided by this study still provide worthwhile information regarding potential trends in the effect of different tree species on pasture productivity.

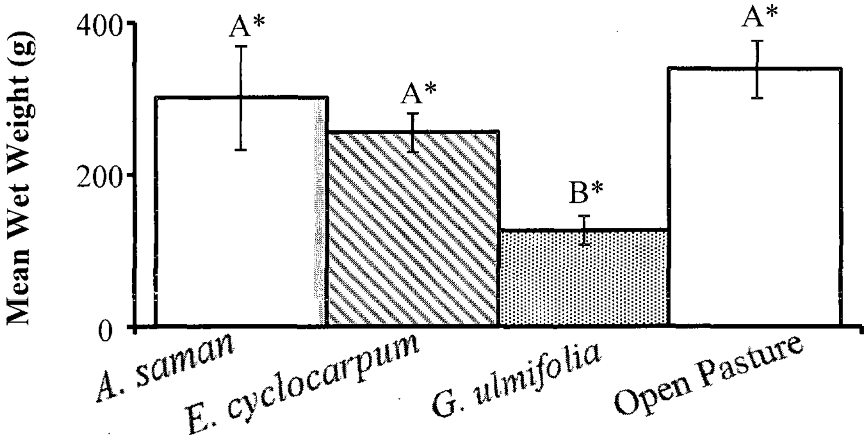
Results

In the early dry season, grass wet weights under the legumes (*A. saman* and *E. cyclocarpum*) were comparable to each other and the open pasture (Table 5; Figure 5). Wet weights of pasture grass under *G. ulmifolia* were significantly different from the weights in the open pasture, as well as the wet weights of the combined legumes, and the legumes individually (Table 5). Tree plots were not significantly different from each other or the open pasture in the middle of the dry season (Table 5; Figure 5).

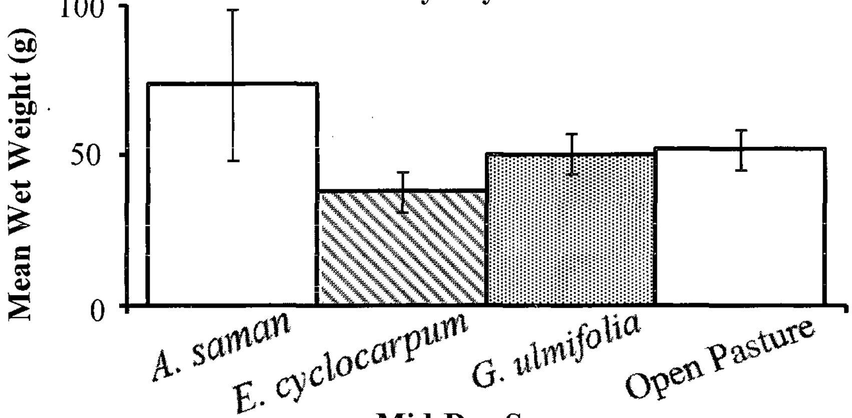
By the late dry season, the grass wet weights below all three trees are higher than the wet weights within the open pasture (Figure 5). The difference is significant when the trees are combined and compared to the open pasture, and when the legumes are analyzed together as compared to the open pasture (Table 5; Figure 5).

Table 5. Comparisons of grass wet weights throughout the dry season, between Plot 1 as compared to Plot 2 (*p is significant at <0.05).

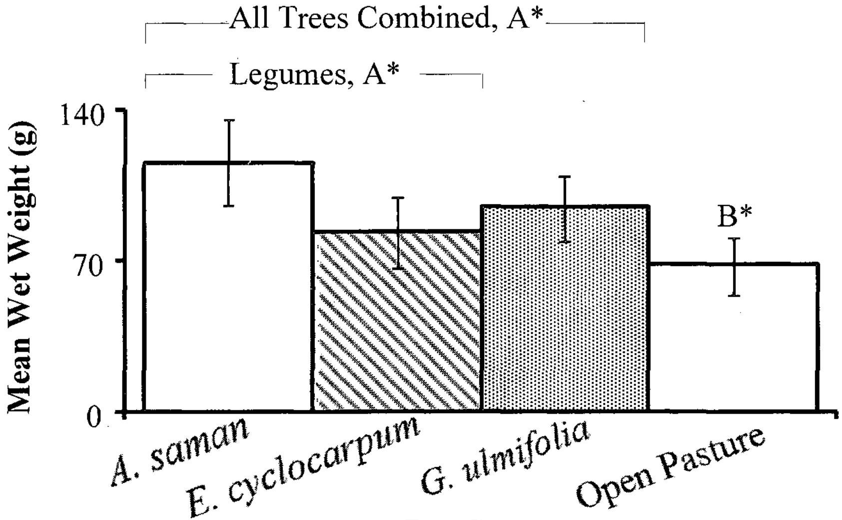
Compared Plots		Time Period (p-value)		
Plot 1	**Plot 2**	**Early**	**Mid**	**Late**
All Trees Combined	Open Pasture	0.113	0.758	**0.039***
Legumes	Open Pasture	0.193	0.586	**0.049***
	G. ulmifolia	**0.026***	0.140	0.363
A. saman	*E. cyclocarpum*	0.937	0.583	0.099
	G. ulmifolia	**0.033***	0.101	0.311
	Open pasture	0.382	0.807	0.196
E. cyclocarpum	*G. ulmifolia*	**0.028***	0.182	0.695
	Open pasture	0.239	0.530	0.530
G. ulmifolia	Open pasture	**0.001***	0.158	0.683



Early Dry Season



Mid-Dry Season



Late Dry Season

Figure 5. Mean (and SE) for grass wet weights in each plot throughout the dry season (*A is signficantly different from B at <0.05).

Grass heights performed similarly to the wet weights. Early in the dry season, the heights of the legumes were comparable to the open pasture plots, but significantly different from *G. ulmifolia* (Tables 6, 7; Figure 6), with the difference driven by the substantial disparity between *E. cyclocarpum* and *G. ulmifolia* (Figures 6, 7). The grass heights below *E. cyclocarpum* were on average higher than within all other plots (Figure 7). G. *ulmifolia* and the open pasture trend towards a level of significance in the complete GLM model (Table 7). When separately compared excluding *A. saman* and *E. cyclocarpum*, the difference is significant (F(1,31)=5.037, p=0.033).

By the middle of the dry season, there is no significant difference between any of the plots when compared by GLM (Table 6); however, between the early dry season and the middle of the dry season, the growth patterns of the grasses are different (Figure 7). The grasses below *A. saman* are typically taller than the others, and between the fifth week of the study and the middle dry season cutting (week 8), the growth rates of the grasses below both *A. saman* and *E. cyclocarpum* are much higher than that of *G. ulmifolia* or the open pasture plots (Figure 7). The heights below *G. ulmifolia* start to level off around the fifth week as compared to the other plots, while the grasses within the open pasture maintain a relatively constant change in height (Figure 7).

By the end of the dry season, differences in grass heights are significant in all comparisons (Table 6), as a function of the increased grass heights below *A. saman* (Table 7; Figure 6). Interestingly, the grasses performed very similar below *E. cyclocarpum* and *G. ulmifolia* (Table 7; Figure 6). The growth rate between week 11 of the study and the late dry season cutting (week 14), is similar below all three trees, but the grasses seem to grow less within the open pasture (Figure 7).

To summarize, in the early dry season, the grass productivity below the leguminous tree species was comparable to the open pasture. By the middle of the dry season, the differences among the plots have faded, but by the end of the dry season, grass productivity is significantly higher below the trees than within the open pasture, with this difference primarily due to higher grass productivity below *A. saman*.

Table 6. Comparisons among plots of grass heights throughout the dry season (*p is significant at <0.05).

Season	Model Name	n	df	F-ratio	p-value
Early Dry	All Trees Combined	56	1	1.346	0.251
	Legumes	56	2	3.717	**0.031***
	Trees	56	3	3.442	**0.023***
Mid-Dry	All Trees Combined	55	1	0.000	0.991
	Legumes	55	2	1.519	0.229
	Tree Species	55	3	1.815	0.156
Late Dry	All Trees Combined	55	1	9.718	**0.003***
	Legumes	55	2	5.105	**0.009***
	Tree Species	55	3	3.984	**0.013***

Table 7. Comparisons of grass heights throughout the dry season, between Plot 1 as compared to Plot 2 (*p is significant at <0.05).

Compared Plots		**Time Period (p-value)**		
Plot 1	**Plot 2**	**Early**	**Mid**	**Late**
All Trees Combined	Open Pasture	0.251	0.991	**0.003***
Legumes	Open Pasture	0.980	0.800	**0.007***
	G. ulmifolia	**0.047***	0.199	0.732
A. saman	*E. cyclocarpum*	0.371	0.429	0.584
	G. ulmifolia	0.545	0.115	0.571
	Open pasture	0.741	0.538	**0.007***
E. cyclocarpum	*G. ulmifolia*	**0.023***	0.891	1.000
	Open pasture	0.881	0.990	0.212
G. ulmifolia	Open pasture	0.078	0.699	0.170

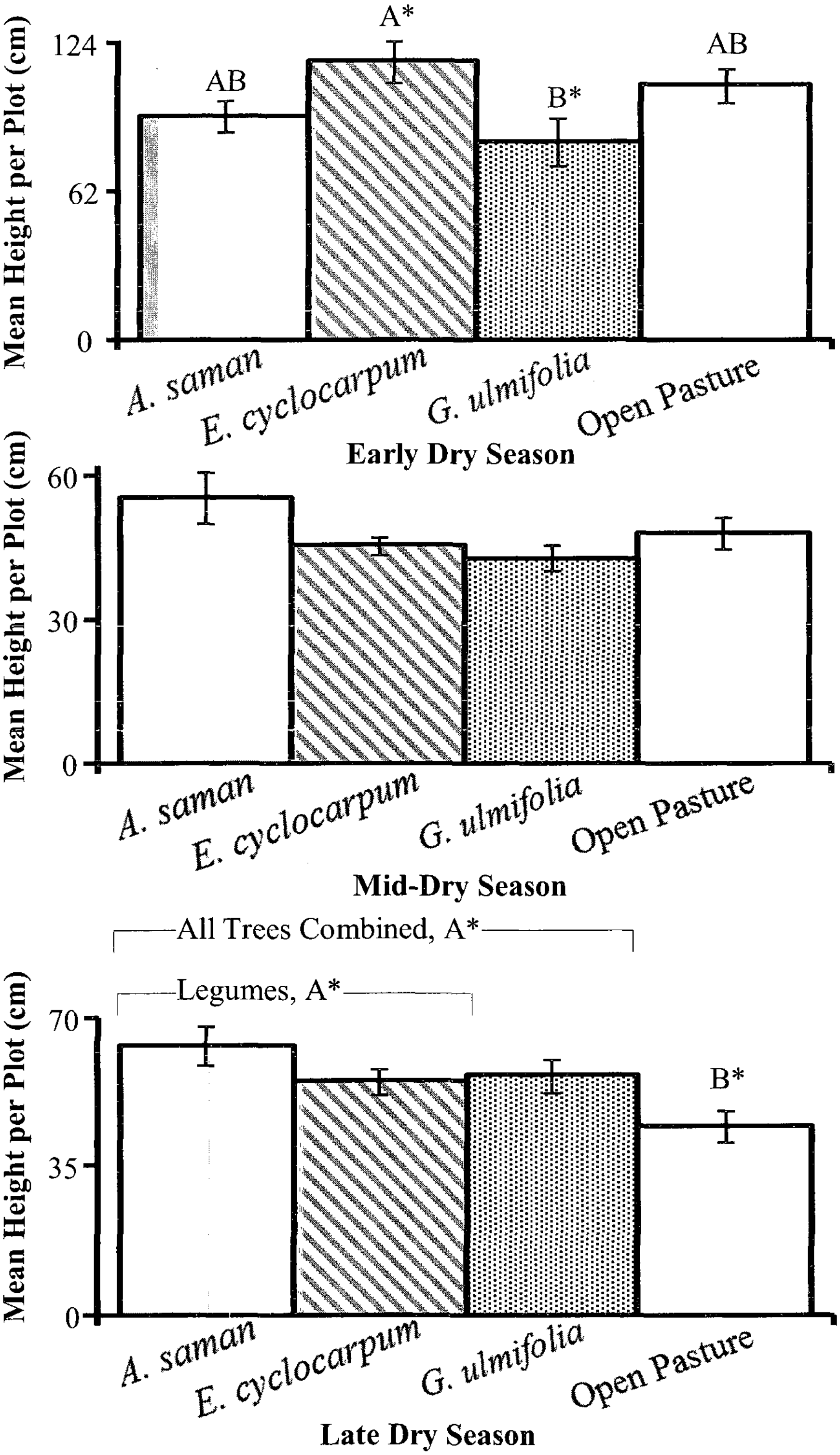


Figure 6. Mean (and SE) grass heights in each plot for all measurements prior to pasture cutting (bars marked with different letters are significantly different at p<0.05).

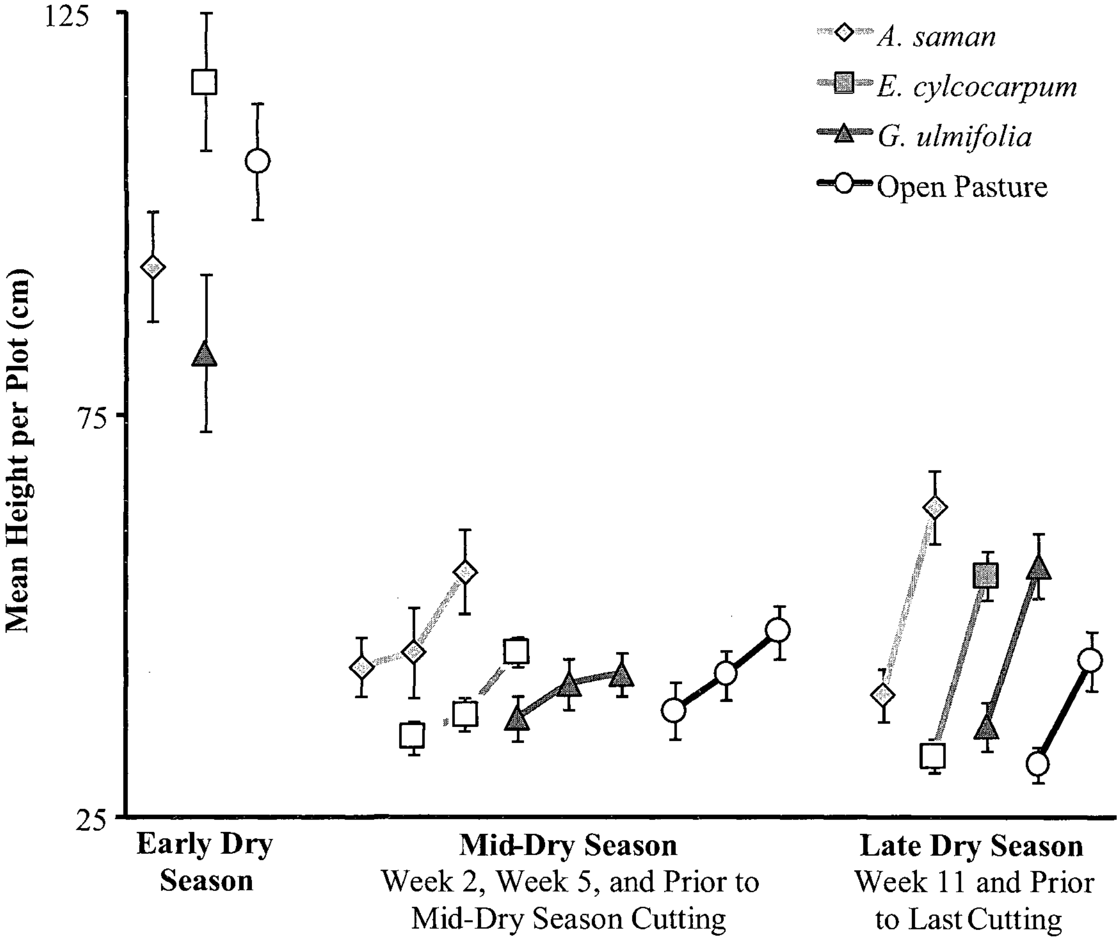


Figure 7. Mean (and SE) grass heights for each plot throughout the dry season, measurements taken initially in early dry season, then at week 2, week 5, prior to the mid-dry season cut (week 8), week 11, and prior to the late dry season cut (week 14).

Arthropod Communities

Research Objectives

The conservation value of remnant pasture trees is increasingly important as deforestation continues throughout Central America. Agroecosystems are playing a greater role in preserving biodiversity, and arthropods are an adequate indicator to determine the conservation value of different tree species. In order to address this issue, I collected arthropods below three different tree species and compared the diversity and abundance of the specimens to open pasture plots. The null hypothesis states:

H_0: Arthropod communities will not differ significantly below the different tree species as compared to each other and the open pasture.

A. Total arthropod diversity, as measured by number of morphospecies, will not differ among plots.

B. Arthropod diversity within each taxonomic group, as measured by number of morphospecies, will not differ among plots.

C. Overall arthropod abundance, as measured by total number of specimens, will not differ among plots.

D. Arthropod abundance within each taxonomic group, as measured by number of specimens, will not differ among plots.

Methods

Study Design

I collected arthropod samples using pitfall traps once in late February 2008.

Pitfall traps function best under relatively dry conditions, as rains can disrupt the trapping process, and trapping began as soon as the dry season was firmly established. Pitfall traps were selected as the appropriate method as they allow for a simultaneous collection of samples among all plots and permit trapping for a relatively extensive time period as compared to other methods (Duelli et al. 1999). Specimens with varying degrees of activity throughout the day could thus be trapped, as could a greater abundance of specimens as compared to other non-invasive methods.

In order to determine the length of time for sampling, I collected preliminary data from below a randomly selected specimen of *A. saman* outside the boundaries of any sample plots so as not to disrupt the actual plot areas. Forty-eight hours proved sufficient to collect at least 20 arthropod specimens per tree without decomposition while still in the field. Similar to the procedure for collection of grass samples, four points were randomly selected within each plot, outside of the grass subplots, for the traps (Figure 8).

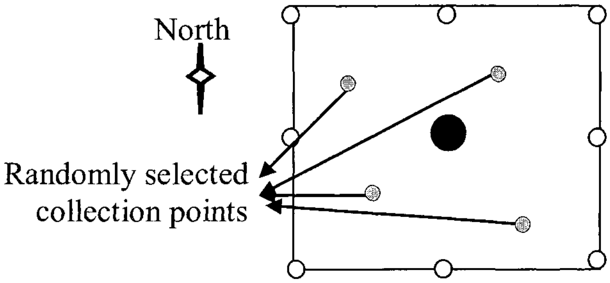


Figure 8. Plot enclosure with subplots for collection of arthropod samples (not to scale).

Data Collection

Three white, plastic, 230 milliliter cups were placed in holes dug in the ground for each pitfall trap, with the level of the uppermost cup even with the ground. I pre-

prepared the trapping solution of tap water saturated with table salt, which acts as a preservative, combined with a small amount of locally purchased dish washing liquid to break the surface tension in the traps. My field assistant and I transported the solution to the field on February 27, 2008, and each person filled half of the sample cups at each farm throughout the day. The researchers returned on February 29, 2008 to collect the samples at the same time as the cups were filled two days prior. Each subsample, represented by one pitfall trap, was transported to the field station in plastic bags and immediately transferred to 20 milliliter glass scintillation vials containing pure medicinal alcohol ordered from the local pharmacy.

Data Analysis

For each subsample of arthropods (those collected in one pitfall trap), I used a Brock Magiscope® field microscope to examine every specimen. Individuals were compared based on characteristics, and those that differed from all others were classified as a distinct morphospecies. A representative of each new morphospecies was photographed and assigned a generic name according to taxonomic group (e.g., Araneae #1), added to a database tracking all morphospecies in Microsoft Excel©, and preserved in medicinal alcohol in a 20 mL glass scintillation vial.

Within each subsample, once I identified every specimen to morphospecies, I counted the total number of individuals within each morphospecies. From this value, I used Microsoft Excel© to count the total number of morphospecies and number of morphospecies within each taxonomic group. I also used this value to obtain total abundance by summing the number of specimens within each subsample, and abundance within each taxonomic group by summing the number of specimens within each morphospecies (e.g., number of Araneae #1 + number of Araneae #2, etc). Subsample values were averaged in Microsoft Excel© to obtain a mean trap value per tree and then log transformed.

Overall total number of morphospecies and total number of arthropods were contrasted using GLM in SYSTAT© 12 according to plot. Although 16 Orders were represented throughout the study plots, only Araneae, Coleoptera, Diptera, Hemiptera, Homoptera, Hymenoptera, and Orthoptera were analyzed individually due to the abundance of specimens within each of these Orders. To represent the differences of the individuals within the Order Hymenoptera, the Order was divided further to Family and contrasted by non-Formicid Hymenoptera (parasitic wasps) and Formicidae (ants). Total values for all non-Formicid Orders were also combined and contrasted due to the overall abundance of insects collected within the Family Formicidae and the social structure of these particular insects. Number of individuals and numbers of morphospecies were contrasted for most of the Orders by GLM, and a post hoc comparison of means was conducted by a Tukey's Honestly-Significant-Difference Test for each GLM.

Limitations

Arthropods occupy a range of habitats, and thus a range of trapping methods at various times throughout the year could greatly enhance the availability of knowledge related to the effect of different tree species on arthropod communities. Similarly, the functional role of insects in the environment is extensive, and information regarding such arthropod interactions (e.g., the edible fraction of arthropods that support insectivorous bird and bat communities) would also greatly enhance the study of biodiversity conservation in silvopastoral systems. The collection method used for this study, pitfall traps, was selected as a passive technique, as it allows for standardization and simultaneous collection among plots (Duelli et al. 1999). Although other forms of traps, such as malaise traps, and multiple collection time periods, would have been incredibly valuable to this study, identification of insects is known to be a lengthy process (Duelli et al. 1999), and thus any available information regarding diversity and abundance, especially within different taxonomic groups of insects, is incredibly valuable.

Results

A total of 21,795 specimens were collected in 237 morphospecies. Diptera, Formicidae and Homoptera were found in every plot, with Araneae, Coleoptera, Hemiptera, non-Formicid Hymenoptera, and Orthoptera found in the majority of the plots. Most of the specimens collected, 72.7%, were Formicidae, with the other dominant taxonomic groups comprising an additional 18.4% of the specimens.

Diversity, as measured by number of morphospecies within each taxonomic group, differed between plots (Table 8). Comparisons of the means showed a difference between the open pasture and *A. saman* plots (Table 9), with no significant difference between *E. cyclocarpum* and any of the other plots or *G. ulmifolia* and any of the other plots (Table 9; Figure 9).

Comparative analysis of diversity within each taxonomic group among plots revealed significant differences only in Formicidae and Homoptera (Table 8). In both cases, the only distinguishable differences are between *A. saman* and the open pasture plots (Table 9; Figure 9).

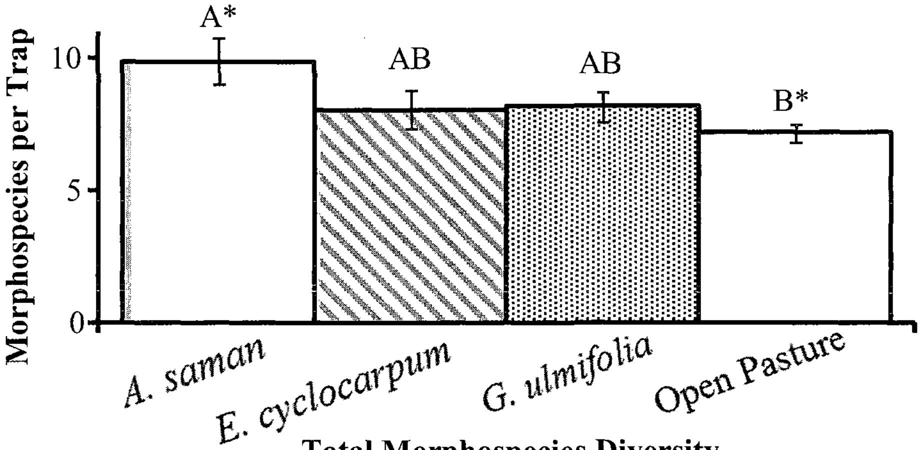
In the case of Homoptera and overall number of morphospecies, the number of morphospecies collected below *E. cyclocarpum* and *G. ulmifolia* were relatively similar (Table 9; Figure 9). For Formicidae, the number of morphospecies collected under *G. ulmifolia* is trending towards a significant difference as compared to the open pasture (Table 9). When the two plots are contrasted separately, excluding *A. saman* and *E. cyclocarpum*, the number of Formicid morphospecies below *G. ulmifolia* is significantly different from the number within the open pasture plots (F(1,31)=6.562, p=0.016).

Table 8. Comparisons among plots for number of morphospecies within each taxonomic group (*p is significant at <0.05).

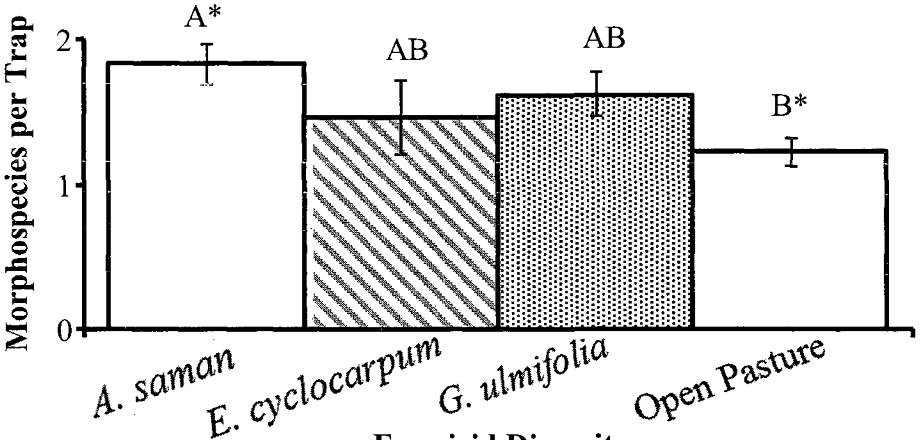
Taxonomic Group	n	df	F-ratio	p-value
Total Number of Morphospecies	**56**	**3**	**3.233**	**0.030***
Total Non-Formicid Morphospecies	56	3	2.224	0.096
Araneae	56	3	0.751	0.527
Coleoptera	51	3	1.763	0.167
Diptera	56	3	0.760	0.522
Formicidae	**56**	**3**	**3.789**	**0.016***
Hemiptera	36	3	1.488	0.237
Homoptera	**56**	**3**	**3.020**	**0.038***
Non-Formicid Hymenoptera	55	3	1.873	0.146
Orthoptera	45	3	1.212	0.318

Table 9. Comparisons between Plot 1 as compared to Plot 2 for number of morphospecies in groups with significant differences (*p is significant at <0.05).

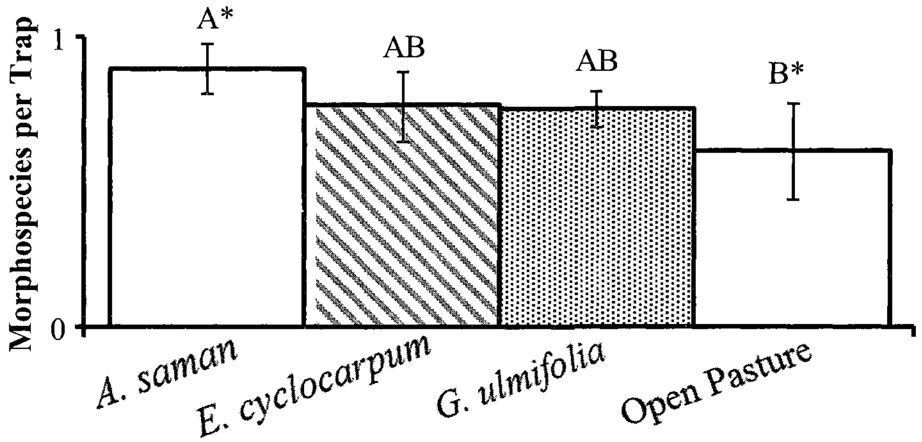
Plot 1	Plot 2	All Morphospecies p-value	Formicidae p-value	Homoptera p-value
A. saman	*E. cyclocarpum*	0.281	0.369	0.691
	G. ulmifolia	0.281	0.793	0.593
	Open Pasture	**0.016***	**0.012***	**0.024***
E. cyclocarpum	*G. ulmifolia*	1.000	0.872	0.999
	Open Pasture	0.682	0.499	0.325
G. ulmifolia	Open Pasture	0.604	0.111	0.349



Total Morphospecies Diversity



Formicid Diversity



Homoptera Diversity

Figure 9. Mean (and SE) total morphospecies richness and mean (and SE) Formicidae and Homoptera morphospecies per trap (bars with different letters are significantly different at p<0.05).

Analysis for abundance of arthropod specimens also yielded significant differences (Table 10). Total abundance was not significant; however, with the exclusion of the Formicid specimens, abundance of the remaining taxonomic groups combined is (Table 10). Differences between *A. saman* and the open pasture were significant, as were differences between *A. saman* and *E. cyclocarpum* (Table 11; Figure 10), and the abundance of non-Formicid arthropods below *G. ulmifolia* is highly variable (Figure 10).

The differences in Araneae abundance among plots were not significantly different (Table 10), but specific comparisons between plots indicated that *A. saman* was significantly different from the open pasture plots (Table 11; Figure 11).

Similarly, in terms of non-Formicid Hymenoptera (parasitic Wasps), there was a significant difference among plots (Table 10), again driven by *A. saman* (Table 11). In this case, however, the difference was between *A. saman* and *E. cyclocarpum*, with an increased number of specimens collected below *A. saman*, with high variability among the *A. saman* plots (Figure 11).

The number of specimens collected within Coleoptera also differed significantly among plots (Table 10), with the significance again between *A. saman* and one other plot (Table 11). Although the number of Coleoptera collected within *A. saman* plots were highly variable (Figure 11), more insects were collected below this tree than below *E. cyclocarpum*, with no discernible differences among any of the remaining plots. Similarly, in the case of Homoptera abundance, significant differences among plots were again driven by *A. saman*, but for this taxonomic group, *G. ulmifolia* performed poorly in comparison to *A. saman* with no evident variation among the other plots (Tables 10, 11;

Figure 11).

To summarize the results for arthropod communities, the open pasture was consistently less diverse than under the trees, and this difference was significant with respect to *A. saman* (Table 9; Figure 9). Arthropod abundances performed similarly in that *A. saman* featured a higher abundance of several arthropod taxonomic groups (Araneae, parasitic Wasps, Coleoptera and Homoptera), however, in terms of insects, the differences were among the tree plots (Table 11; Figure 9). Only in the case of Araneae and total abundance excluding Formicidae did the open pasture significantly produce fewer individuals than any of the tree species (Table 11).

Table 10. Comparisons among plots of arthropod abundance within each taxonomic group (*p is significant at <0.05).

Taxonomic Group	n	df	F-ratio	p-value
Total Abundance	56	3	1.378	0.260
Total Non-Formicid Abundance	**56**	**3**	**4.188**	**0.010***
Araneae	**54**	**3**	**2.539**	**0.067**
Coleoptera	**51**	**3**	**3.759**	**0.017***
Diptera	56	3	1.666	0.186
Formicidae	56	3	0.744	0.531
Hemiptera	35	3	1.341	0.279
Homoptera	**56**	**3**	**3.480**	**0.022***
Non-Formicid Hymenoptera	**55**	**3**	**3.343**	**0.026***
Orthoptera	45	3	0.382	0.767

Table 11. **P-values for comparisons between Plot 1 as compared to Plot 2 for arthropod abundance within groups with significant differences (*p is significant at <0.05).**

Plot 1	**Plot 2**	**Overall Abundance (excluding Formicidae)**	**Araneae**
A. saman	*E. cyclocarpum*	**0.021***	0.238
	G. ulmifolia	0.102	0.310
	Open Pasture	**0.014***	**0.048***
E. cyclocarpum	*G. ulmifolia*	0.872	0.996
	Open Pasture	1.000	0.951
G. ulmifolia	Open Pasture	0.885	0.847

Plot 1	**Plot 2**	**Coleoptera**	**Homoptera**	**Hymenoptera (excluding Formicidae)**
A. saman	*E. cyclocarpum*	**0.010***	0.962	**0.024***
	G. ulmifolia	0.129	**0.030***	0.189
	Open Pasture	0.213	0.180	0.073
E. cyclocarpum	*G. ulmifolia*	0.624	0.110	0.774
	Open Pasture	0.382	0.446	0.900
G. ulmifolia	Open Pasture	0.981	0.780	0.988

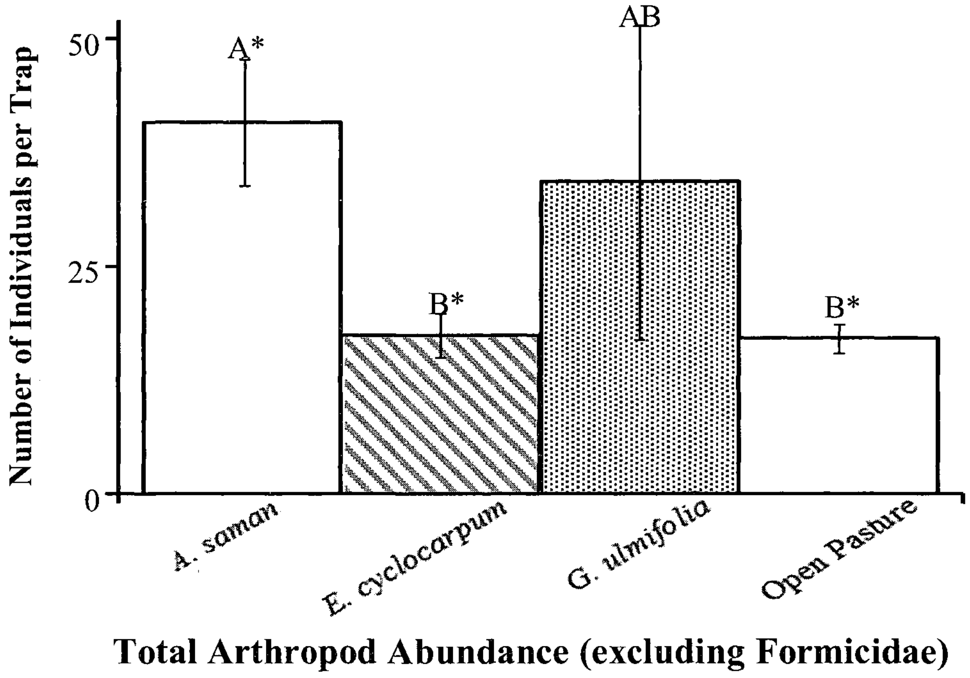
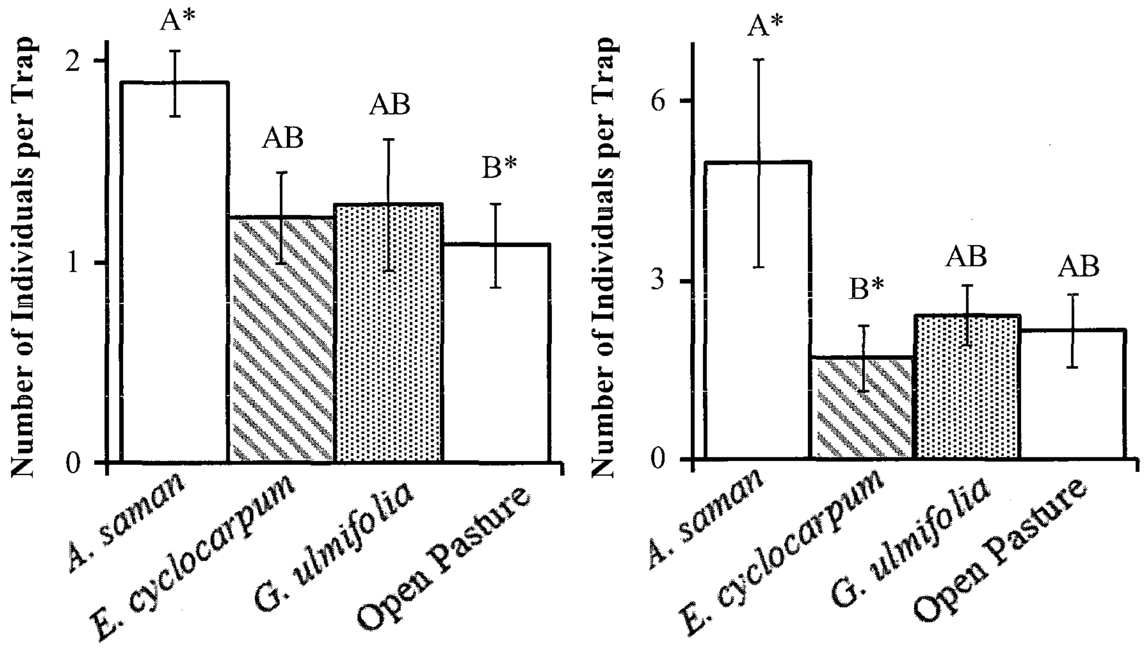
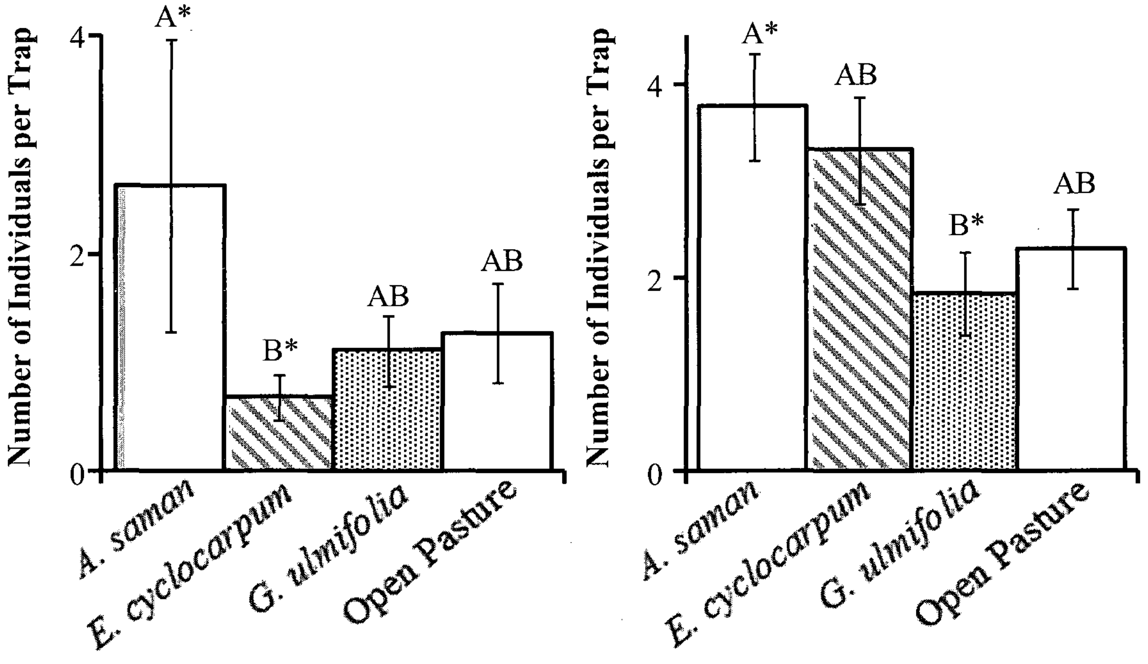


Figure 10. Total mean (and SE) arthropod abundance per trap, excluding Formicidae (bars marked with different letters are significantly different at p<0.05).



Araneae Abundance

Hymenoptera Abundance (excluding Formicidae)



Coleoptera Abundance

Homoptera Abundance

Figure 11. Mean (and SE) of arthropod abundance within the significantly different taxonomic groups (bars marked with different letters are significantly different at $p<0.05$).

Discussion

The conservation value of remnant trees is especially important, as is conserving the actual trees themselves. Within the farms used for this study, the diversity of tree species varied, but so did the overall size of the study pastures. Thus it is difficult to determine if the differences in tree species diversity are related to the actual farms, or if it is simply a function of the methods. Similarly, abundance of trees varied within the farms as well. Of the three trees studied for this thesis, I found fewer *A. saman* specimens than the other two species, with the highest number of *G. ulmifolia.*

G. ulmifolia has been cited as a pioneer species and due to its ability to easily propagate from cuttings it has also been called invasive in cattle pastures (Francis 1991; Craven et al. 2007). Craven et al. (2007) also suggest that *E. cyclocarpum* is especially tolerant of adverse site conditions such as limited availability of water. The increased numbers of these two species within the study pastures could be a factor of such characteristics; however it also indicates that they may be appropriate for silvopastoral use due to the limited need to pay special care to their growth. *A. saman* on the other hand is less frequent at the landscape level, and should be considered for future conservation efforts. Durr (2001) states that there is a need for a wider range of tree species in silvopastoral systems, and similarly supports *A. saman* for use within cattle pastures.

Each of the trees is edible by livestock, and can provide supplemental fodder during the dry season. Morrison et al. (1996) found that farmers in Jamaica believe their cows actually perform better and look healthier after eating the fruits of *A. saman.* A study in Colombia quantified the suggestions by Jamaican farmers, in that cows fed the fruits of *A. saman* during the dry season produced greater quantities of higher quality milk than those that were not (Zamora et al. 2001). Similarly, Sandoval-Castro et al. (2005) found that in a study of five tree species, cattle preferred to consume the available fodder of *G. ulmifolia* over three others. The seeds of all three trees are easily dispersed by cattle after consumption of fruits, creating a seed bank for future regeneration within pastures as well (Durr 2001; Griscom et al. 2005; Miceli-Méndez et al. 2007).

This study showed that grass productivity under the three study species, *A. saman, E. cyclocarpum,* and *G. ulmifolia*, did not differ substantially from the grass productivity within open pastures during the dry season. Researchers have previously acknowledged the positive effects of trees on pasture grasses in silvopastoral systems, especially in regards to *A. saman*, which not only increased pasture grass productivity within the study pastures in Matiguás, but has done so in earlier research trials as well (Durr 2001). Farmers have previously cited a fear of pasture-tree competition within improved pastures (Morrison 1991), and the farmers with whom I worked for this study all stated that shade negatively influences pasture growth (Table 2). However, the results of this study indicate that perhaps the observations of the farmers are not pertinent to the actual grass productivity during the dry season. Fisher and Kerridge (1996) similarly concluded that the perceptions of farmers in regards to the drought tolerance of different improved grasses were not always accurate.

Many researchers have suggested a variety of reasons that trees actually augment pasture grass productivity, and have arrived at the conclusion that soils below trees generally feature increased nutrient levels and enhanced soil physical and structural properties (Hernández-Daumás et al. 2001; Durr 2001; Durr & Rangel 2002). The source of the nutrients is still in question (Durr & Rangel 2002); however in this case, two of the study tree species were legumes, *A. saman* and *E. cyclocarpum*, and it is likely that the nitrogen contributed by these two tree species positively influenced the pasture grasses. This effect can be seen in the changes in heights of the grasses below the two legumes from week 5 to week 8 of the study, while during the same time period the grasses below *G. ulmifolia* did not perform as well (Figure 7). The nutrient contributions by leguminous species are commonly cited as one of the predominant reasons grasses perform better below trees in silvopastoral systems (Durr 2001; Sierra & Nygren 2006).

Researchers have suggested that increased levels of phosphorous, potassium, and carbon can also be found below trees in similar agroecosystems (Morrison 1991; Dagang & Nair 2003). Although the source of these nutrients are again less defined, some of the primary reasons researchers suggest for the increased levels of overall nutrient cycling below trees involve the increased organic matter input through leaf drop, root sloughing, and droppings from animals using the trees as migratory stopover points (Belsky et al. 1993; Morrison et al. 1996; Durr 2001). Nair et al. (2007) concluded that in the coarse soils of Florida, silvopastoral systems were better able to retain phosphorous and the combined tree-grass root systems were better able to absorb nutrients than grasses in treeless systems.

Further, researchers have indicated that the more expansive root systems of trees as compared to grasses allows the trees to extract water and nutrients from areas inaccessible to the grass roots, thereby reducing the competitive interaction for resources (Belsky et al. 1993; Hernández-Daumás & Russell 2001; Dulormne et al. 2004). The *A. saman* specimens I measured were typically larger in terms of trunk size and canopy area than the other two study trees (Figure 3). This could be an indication of an overall larger root system with access to greater soil depths than the other trees, with an enhanced ability to extract nutrients from various areas within the soil profile. An expansive root area as well as a large canopy area as compared to the other two trees could potentially allow *A. saman* to contribute more to soil organic matter and productivity beneath its canopy, though these hypotheses remain to be tested and are traits of the individual tree rather than the traits of the species per se.

Water is a limiting factor for production during the dry season, and shading of the grasses by trees has been cited as a means to limit evaporative losses during the dry season (Harvey & Haber 1999). Combined with the increased access to soil water by expansive tree roots (Dulormne et al. 2004), trees could significantly increase availability of water to the pasture grasses during the dry season while limiting desiccation by shading. This is again important in relation to *A. saman* as it is the tree with the largest trunk size and canopy area within this study. Although all three trees drop their leaves for some period during the dry season (Francis 1988, 1991; Durr 2001), the structure of the trees could still contribute to shading of the pasture grasses when the leaves are not present, especially in the case of *A. saman* and *G. ulmifolia*, both of which were covered in an increased number of epiphytes (providing further contributions to shade). Of the *G. ulmifolia* trees that I measured, the branching height was lower, as was the number of stems at breast height, both of which could be an indication of a more diverse structure within the tree. As the shortest tree, closest to the ground, *G. ulmifolia* could also contribute to a greater amelioration of the microclimate below the tree, and reduction in wind below trees is also cited as a means for reducing grass desiccation (Dulormne et al. 2004). Although it did not contribute to increased pasture grass productivity as compared to the open pasture, *G. ulmifolia* did not negatively affect it either. The period of leaf drop ends towards the end of the dry season for all three trees (Francis 1988, 1991; Durr 2001), possibly contributing to the increased grass productivity below the trees as compared to the open pasture for the last period of cutting.

A wide variety of tree characteristics are likely related to an increase in pasture grass productivity below the different trees. Although I measured some characteristics of the three species that might positively affect pasture grasses, many tree characteristics which I did not measure could also significantly contribute to augmenting grass productivity. Soil structure and texture below the trees, organic matter contributions and their effect on the grasses, and root structure of both the grasses and the trees (although this will vary from tree to tree) all play a significant ecological role. The results of this study indicated a positive correlation between the trees and the grasses during the dry season of 2008, indicating a need for further exploration of the mechanisms driving the enhanced pasture productivity.

This study provides evidence that increasing canopy cover within cattle pastures could easily contribute to the conservation of invertebrate biodiversity as well. Although the overall conservation impacts of silvopastoral systems are widely known (Harvey &

Haber 1999; Lumsden & Bennett 2005), the results for multiple arthropod taxonomic groups provided by this study are quite valuable. Clearly, dispersed pasture trees are not a replacement for forest, but as the results of this study indicate, with the implementation of dispersed trees into cattle pastures, arthropod communities could benefit as compared to pastures left without any level of added complexity contributed by the trees.

Of the characteristics measured for this study, it is likely that the different levels of epiphyte coverage within the trees played a significant role in affecting arthropod communities. Increased epiphyte abundance is important not only in diversifying the structure and resources available to arthropods, but also in the conservation of epiphytes themselves. A wide variety of factors drive the abundance of epiphytes on trees, such as distance to forest fragment, fragmentation pattern at the landscape level and locations within the tree for propagation (Heitz-Seifert et al. 1996). I found a high variability within the epiphyte coverage on the *A. saman* trees I studied, indicating that not every tree is the same from the epiphyte perspective. In terms of size characteristics, *A. saman* and *E. cyclocarpum* are fairly similar; however, the abundance of epiphytes differed drastically. Although the median coverage value of epiphytes did not differ between *A. saman* and *G. ulmifolia*, the range in classes did. Whereas every *G. ulmifolia* specimen had at least one epiphyte within its branches, some *A. saman* specimens had none. However, it was frequent that the *A. saman* trees that did contain epiphytes featured far more than any of the other tree species. Thus the differences in arthropod communities could be driven by the *A. saman* specimens with very intense epiphyte coverage, or some other characteristic of this tree that I did not measure, such as availability of nectar or the presence of volatile chemicals in the case of *G. ulmifolia* (Strobel et al. 2007).

As compared to the open pasture plots, *A. saman* supported an increased level of overall arthropod diversity, as well as diversity in the taxonomic groups Formicidae (ants) and Homoptera (Table 9). Researchers have presented similar results in regards to ant diversity; with higher species richness discovered below isolated pasture trees in Mexico (Gove & Majer 2006), and below isolated trees in crop systems in Ghana (Dunn 2000) as compared to open areas. Although researchers have suggested similar findings, that isolated trees do impact ant diversity, the conclusions of this study indicate that not only are isolated trees important to conservation of ant diversity, but so is the actual tree species. Any number of factors could contribute to the differences among the diversity within the taxonomic groups. Ants, for instance, occupy a wide range of habitats and consume a wide diversity of foods (Borror et al. 2004). Diversity in vegetational structure would thus increase the diversity of ants in theory, and the *A. saman* trees I measured not only featured a larger canopy area as compared to the other two species, but greater abundance in epiphytes. These two factors could contribute to the increased diversity of the ants. Similarly, many Homoptera feed on plants (Borror et al. 2004), and with the greater productivity of pasture below *A. saman*, perhaps there is a greater availability of food for these omnivores as compared to the other plots.

The importance of individual tree species extends to arthropod abundances as well. In every case where arthropod abundance was significantly different among plots, more specimens were collected below *A. saman* as compared to at least one other plot (Figures 10, 11); however, only in the case of total abundance (excluding ants) and in the case of Araneae abundance were more specimens collected below *A. saman* than within the open pasture. Within the other taxonomic groups, individuals preferred *A. saman* as well, but over the other tree species, and not over the open pasture. This again indicates that the identity of the individual tree species may be very important to conservation of biodiversity if the assumption is that where we find greater abundances of specific taxonomic groups, such as Coleoptera and Homoptera which act as food for higher trophic guilds, we would also find higher diversity of those trophic guilds (Lumsden & Bennett 2005).

The predominant distinction in arthropod abundance is not between the open pasture and the tree species, but between *A. saman* and the other two trees. However, this should not negate the value of the results indicating that dispersed pasture trees significantly contribute to biodiversity conservation. *A. saman* plays an important role to arthropod communities, but the mechanisms as to why are not necessarily identified by this study. For example, parasitoid wasps (Order Hymenoptera) are especially sensitive to fragmentation of the landscape due to habitat specialization (Fraser et al. 2008). Hymenoptera is one of the most beneficial insect Orders, as they contain many parasites and predators of insect pests, as well as bees which play a significant role in pollinating many plants (Borror et al. 2005). For the purposes of this study, *A. saman* contributed to supporting the abundance of this Order more so than the other two tree species. The attractive pink and white flowers of *A. saman* (Durr 2001) may contribute to the distinction between the tree species, and Hymenoptera are often attracted to such showy displays, but this is one example of the many factors that could drive the differences between the tree species.

Spiders and known to favor structurally complex systems, and are particularly sensitive to changes in habitat type and wind and temperature exposure, contributing to a unique set of habitat requirements, and like Hymenoptera, are ecologically significant predators (Borror et al. 2004; Pinkus-Rendón et al. 2006). *A. saman* supported a greater abundance of spiders than any of the other plots, most likely as a result of this species being more structurally diverse than both *E. cyclocarpum* and the open pasture, based on the number of epiphytes within the tree. Similarly, omnivorous Coleoptera occupy a range of habitats, and like spiders, may prefer *A. saman* due to the diversity of resources associated with the tree. An increased epiphyte load, a larger canopy, greater grass productivity below the tree, a greater availability of other arthropods to eat, as well as any number of other aspects, could all factor into the increased diversity and abundances of arthropods below *A. saman.*

Amelioration of the microclimate is important to arthropods as well (Perfecto et al. 1997); however this is obviously not the determining factor as to why the arthropods are more frequent below *A. saman.* Regardless of overall structure, any tree will contribute to minimizing wind and solar radiation under its canopy (Dulormne et al. 2004), however, the significant differences in arthropod abundance and diversity identified by this thesis are not related to decreased wind and solar radiation apparently. As previously mentioned, it is likely that *G. ulmifolia* would have the biggest affect on the microclimate below its canopy, considering it is much closer to the ground and more branched than the other two trees, however, *G. ulmifolia* did not perform comparably to

A. saman in respect to arthropod communities. The abundances below *G. ulmifolia* were highly variable however, especially in the case of total abundance excluding ants, thus the fact that there were not significant differences between this tree and any other, or at least between *G. ulmifolia* and the open pasture, may be a function of the methods.

Based on the observation of this study *A. saman* is similar in characteristics to both *E. cyclocarpum* and *G. ulmifolia*, for example all three are flowering at the same time, *A. saman* and *E. cyclocarpum* feature similar leaf patterns, and *A. saman* and *G. ulmifolia* both support higher levels of epiphytes. Thus it is likely that something outside of the scope of this study is driving the relationship between *A. saman* and the arthropods. Flower structure, nectar production, palatability, and many other factors not measured for this study are likely driving the relationship between *A. saman* and the arthropods.

Recommendations

Researchers have already suggested the importance of increasing conservation of biodiversity in agroecosystems, and remnant trees are known to support increased biodiversity in the agricultural matrix (Guevara et al. 1998; Vandermeer & Perfecto 2007). Increasing canopy cover, regardless of tree species, is essential at the landscape scale to promote connectivity in fragmented regions. This study has shown that during one dry season, specific trees did not inhibit pasture production and contributed to increased diversity and abundance in arthropods. Specifically, increased productivity of both pasture grasses and arthropod communities were identified below *A. saman* as compared to the open pasture during the study period.

Farmers have suggested that remnant trees could inhibit the productivity of pasture grasses. Identifying appropriate extension outlets to discuss the implications of silvopastoral research with farmers, and working with them to retain *A. saman* could greatly contribute to the conservation of biodiversity as well as enhanced pasture production. The decreased numbers of *A. saman* in the pastures studied for this thesis indicates that, as compared the other two study species, this tree is in need of protection. With its potential to augment grass productivity, as well as the increased value to arthropod communities as compared to all other plots, *A. saman* is a very promising tree for silvopastoral systems.

As this study indicates, individual tree species can impact the environment differently. However, I studied only three tree species during a very short duration of the year, and collected arthropods only one time. Future research should incorporate the study of other remnant tree species and include more than one dry season. Methods should also include dry weight and nutrient analyses of the pasture grasses in order to assess the quality of forage below different tree species. Additional research should be conducted on the mechanisms which could lead to increased grass productivity during the dry season, such as shading of the grasses to prevent desiccation, the movement of water within the soil profile due to the deeper root systems of the trees, impacts on nutrient cycling, and impacts on soil physical properties. It is also typical that within any pasture, the pasture grasses are accompanied by a wide variety of other vegetation. Studying the complex relationship between the pasture grass, the other non-pasture plant species and the trees would also be very valuable and likely contribute to planning more appropriate silvopastoral systems as well. It is important, however, to address each of these research issues while minimally disrupting the livelihoods of the producers.

To increase the knowledge base surrounding the impact of different tree species on arthropod communities, further research should expand the methods of this study to include various trapping methods and to collect insects at various intervals throughout the year. Research should focus specifically on multiple taxa within these production systems in order to determine different preferences within the arthropod community. Correlating arthropod abundance in this agroecosystem to various insectivorous species, such as birds and bats, could also contribute to a greater understanding of macrofaunal relationships to specific tree species as well. Further, the specific reasons for why arthropods are choosing *A. saman* cannot be determined from the data collected for this study, and this should be addressed in future research.

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