DISTRIBUTION OF GROUND-LAYER PLANT SPECIES IN A FRAGMENTED LANDSCAPE IN THE COROZAL DISTRICT, BELIZE, CENTRAL AMERICA

A thesis submitted in partial fulfillment of the requirements for the degree of Master in Science

By

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Divan Catzim ENTITLED Distribution of ground-layer plant species in a fragmented landscape in the Corozal district, Belize BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Masters of Science.

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ABSTRACT

Catzim, Divan. M.S., Department of Biological sciences, Wright State University, 2006. Distribution of ground-layer plant species in a fragmented landscape in the Corozal district, Belize.

In this study, I specifically looked at three major issues regarding 36 target plant species in a fragmented landscape in the Corozal district, Belize:

1) Determine woodlot characteristics that tend to favor the target species.

2) Determine plant characteristics that tend to favor the target species.

3) Determine whether age and size of a woodlot favors the presence of the target species.

The study area was divided into three areas and each area had woodlots varying in sizes and ages. 36 plant species were sampled in all woodlots upon which woodlot characteristics and species characteristics were associated with the number and frequency of these plants. Data was analyzed using Correlation techniques, Stepwise Regression analysis and Detrended Correspondence analysis.

Woodlot and species characteristics seem to be confounding. Woodlot characteristics that yielded greater species richness for the correlation and regression techniques are older, larger, closer to Shipstern Nature Reserve, farther from sugar cane fields and farther away from papaya fields. Woodlots that are older, closer to Shipstern Nature reserve and farther away from papaya fields had higher Axis 1 values for DECORANA.
Species were more widespread when they were insect pollinated for the correlations and regression analysis. Species had higher Axis 1 values if they were insect pollinated and higher Axis 2 values if they are perennials. Over all, our data suggest that the Copper Bank area is more species rich because the woodlot and species variables accounted seem to favor the presence of more of the target species in this area, whereas these properties of woodlots are lacking in the other two areas namely San Narciso and Santa Elena.
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“BELIEVE IN ANGELS, THEN RETURN THE FAVOUR”.
I. INTRODUCTION

We live in an era of high levels of species extinction; perhaps the sixth major extinction event in recorded history (Honnay et al. 2004). Most of the world’s forests are being diminished in quantity and quality with forest cover being lost at higher rates in the tropics than any other place in the world (Corrales 2000; Laurance 2004). Without a doubt, there is a biodiversity crisis because we are losing numerous species of amphibians, mammals and other organisms (McKinney 1999). Furthermore, only a small portion of living organisms are being studied resulting in limited understanding of the complex ecological relationships that arise due to anthropogenically derived land uses, changing climatic conditions, and other factors that may or may not be induced by human activities. In the neo-tropics and sub-tropics, very little is known about the interactions among these disturbances and relationships. This limitation hinders our understanding of why certain plants exist where they exist, and why certain plants are absent where they could survive (Tremlova and Munzergova 2007). Presumably most species do not have similar dispersal capacities and most species do not have the same probability of reaching a target community (MacArthur & Wilson 1967).

Agriculturally dominated landscapes in the sub-tropics often include fragmented woodlots surrounded by human-dominated agricultural spaces (Mayfield et al. 2006; Laurance 2004). Habitat fragmentation and land use change are processes that are known to be major threats to species diversity (Lindborg 2007) because agricultural spaces tend...
to be unfavorable to the survival of most species of plants (Kupfer et al. 2004). It has been argued that the conversion of forests into agricultural lands is a leading cause of species loss because it separates forest habitats isolating species within only a certain area, which is a major topic in ecology when the ideas created by MacArthur and Wilson (1967) in their famous theory of island biogeography was applied to mainland systems. Furthermore, others argue that the conversion of agricultural lands into urban sprawl further reduces biodiversity (Main et al. 1999). As a result, tropical and sub-tropical forests are no longer large continuous tracts that tend to have a similar composition and mixture of plant species. Rather they are a diverse mixture of species, distributed within small-scale patchy landscapes.

Forest fragmentation is a landscape-level phenomenon in which humans have extensively modified natural continuous forests, forcing species to conform to an area that has been reduced in size. As such, many species have been extensively isolated, establishing novel ecological boundaries between and within fragments. This modification creates implications for individual organisms because species differ and vary in life history strategies (Ewers and Didham 2005). Even though we recognize the importance of landscape structure, very little is known about the effects of alteration of landscape structure on life-history traits and species composition (Lindborg 2007). Furthermore, we associate fragmentation with the idea that forested areas are usually inhabited, and non-forested areas are uninhabitable for most plant species (Kupfer et al. 2006; Tremlova and Munzbergova 2007). This perspective about fragmented landscapes often relates to the erroneous conclusion that agricultural matrices could not serve as habitats for most plant species. Some studies indicate that plant spread into arable land is
limited (Devlaeminck et al. 2005). However, plants do inhabit the agricultural matrix and can persist there in the absence of further perturbations such as the application of herbicides and continuous plowing (personal observation).

Some studies, e.g. Tremlova and Munzbergova, (2007) tried to answer questions pertaining to the movement of plant species into fragments followed by their successful colonization of new woodlots. Some of these results suggest that species richness in fragmented landscapes can be supported due to spacing among plants. As such, distance and density dependent seed and seedling mortality are some of the larger factors in the persistence of species in fragmented landscapes (Ghazoul 2005). Also, some results show that limitations of some plant traits (e.g. pollination, life history strategy etc.) can lead to unsuccessful establishment and spread of plant species in fragmented spaces (Tremlova and Munzbergova 2007).

Forest fragmentation alters some important processes such as dispersal of seeds and pollination of flowers leading to successful colonization of some plants but not others, thus changing major constituents of the ecosystems. But the question has always been how can the removal of forest cover create all of these disturbances? Some authors, e.g. Kufper et al. (2006), reviewed some of the major effects of forest fragmentation on human-dominated landscapes and noted three distinct changes: reduced forest area, increased isolation of resulting remnants, and the creation of edges. Because reduction of habitat types is usually correlated to fewer species, and loss of resources is correlated to smaller populations, scientists argue that the end result is a decline in species. Furthermore, isolation of remnants adversely affects colonization patterns and movement patterns of animals thus reducing movement of genes. When few successful colonization
events occur, the chances of species persistence within woodlots are significantly reduced. And lastly, forest remnants under fragmentation are susceptible to edge effects; that is, we expect changes in the microclimate of the forest remnant, leading to changes in the biotic composition and ecological function, thus changing the structure of the forest (Kupfer 2006). Existing ecological research clearly shows that forest fragmentation causes major changes to biodiversity. This study will focus on the nature and extent of these elements as they currently operate in the Belizean forests and woodlots.

Agriculture has been the main reason for the creation of forest fragments. The interior of fragments is very restricted for the colonization of species because fragmentation creates changes in the ecological and biogeochemical properties of the landscape. For example, abiotic factors such as topography, soil composition, light penetration, wind and rainfall are changed due to changes in vegetation. Within a forest, topographic relief has been shown to be a major determinant of canopy and ground-layer species composition because it affects both water and nutrient pools (DeMars and Runkle 1992; Florinsky and Kuryakova 1995). Furthermore, microsite characteristics, such as the amount of decaying matter in tree fall gaps, affect community composition by altering dispersal patterns, germination rates, recruitment rates and growth rates among other functions (Rankin and Tramer 2002; Meerman 2007; Personal Communication). For instance, decaying matter enhances nutrients on the ground. Tree fall gaps create opportunities for greater light penetration leading to conditions favorable for a number of species. Tree fall gaps also lead to greater availability of water leading to greater nutrient uptake by ground-layer species. It has also been suggested that replacing the vegetation cover of an area with a perennial crop, such as sugar cane, alters the temperature regimes,
which leads to major changes in the evapo-transpiration rates, followed by decreases in rainfall (Harding et al. 2006). The net result is that species composition is considerably altered in fragmented forests.

Fragmentation has implications for individual plant species and their ability to colonize the interior of the woodlot as, for most woodlots, a large portion of ground-layer species are edge species. This is a result of the structural composition of the edges that are created due to fragmentation. Usually in the early stages of development, these edges are structurally open and more exposed to light penetration. Water availability increases as a result of more shedding of leaves trapping moisture in the surface of the ground. This activity in turn increases the rate of decomposition. But this effect does not last for long periods of time, for there is the closing of these gaps as trees continue growing. Studies such as Laurance et al. (2006) indicate that a potentially critical consequence of habitat fragmentation is an increase in disturbance in early successional trees. While there is a great diversity of plant species on the edge (Devlaeminck 2005) and fewer in the interior, there are greater mortalities of successional trees near the edges than in the interior of woodlots (Laurance et al. 2006). As a result of agriculture, additional disturbances such as logging and surface fires further increase tree mortalities on forest edges. Other issues, such as successful colonization of plant species in both interior and edges of a woodlot, are described by other studies (Sizer and Tanner 1999; Laurance et al. 2006; Gonzales et al. 2006).

Isolated fragments are generally the outcome of extensive agricultural practices. Small habitat spaces can support only small populations. Isolated habitat spaces do not receive or send migrants to other fragments, thus increasing their chances of extinction.
(Laurance et al. 2001; Honnay et al. 2004). Because species richness is positively related to fragment size, smaller fragments usually have fewer species per unit area than intact forests (Laurence et al. 2006). Furthermore, fragments closer to a main continuous forest tend to have more species than those farther away. In many parts of the neo-tropics, including Belize, fragments tend not to be so isolated. For small isolated fragments cannot sustain pollinator communities or are too isolated to attract a large diversity of pollinators (Steffan-Dewenter & Tscharntke 1999). Furthermore, smaller areas cannot sustain large mammals, primates, understory birds, ants, bees, termites and butterfly species because those animals are highly sensitive to fragment area (Laurance et al. 2006). Thus chances of successful seed dispersal events are reduced.

Some plants can survive the effects of habitat fragmentation because the matrix has a major influence on fragment connectivity and functioning, thus providing opportunities for plant species to move across the agricultural matrix into another woodlot. Therefore, instead of assuming that characteristics within the woodlot result in the distribution of plant species within the woodlot, we need to consider the ability of agricultural lands to sustain plants or the ability of the plant to persist in the agricultural space followed by the colonization of seedlings into the nearby woodlot.

During the last century, land use practices changed drastically (Lindborg 2007) leaving fragmented woodlots surrounded by remnants of different agricultural matrices. This is ecologically important because of their inter-connectedness and relationships with forest woodlots (Harvey et al. 2006). Therefore, the maintenance of biodiversity depends heavily on community interactions within and between woodlots and agricultural spaces. As such, the species composition in agricultural spaces should also be well understood in
order to determine changes that could be dictated in forest remnants. The conservation of biodiversity in forest fragments will depend not only on the establishment of protected areas and Reserves, but also on the management of agricultural spaces. These changes might be very hard to determine as very little data have been collected in the neo-tropics comparing the diversity of multiple animal taxa on agricultural landscape with different types of forest cover. Furthermore, there are not many studies of how plant-pollinator relationships, plant-dispersal relationships and other mechanisms are influenced by changes in vegetation cover (Harvey et al. 2006). These kinds of relationships are important because the movement of genes and resources from one fragment to the next determines the ability of species to colonize other forest patches (Sekercioglu 2006).

Studies of habitat fragmentation have investigated the following topics: reduction of area, isolation within fragments, and various agricultural matrices as unsuitable for supporting most plant species and eventually the loss of diversity to human disturbances. But fragmentation of the landscape can result from natural events such as hurricanes and tornadoes (Watson 2002). The effects of hurricanes on community dynamics have recently been studied by ecologists but very little is known of their effects on herbaceous species (Melendez-Ackerman 2003). Studies such as Melendez-Ackerman (2003) suggest that mortalities of herbs were low and were caused mainly by fallen trees. However, open canopies due to fallen trees create suitable habitats for seedling establishment, a positive result. Air pollution, changes in climate patterns, plant invasions, overabundant herbivores, etc., all contribute to biodiversity loss. Managing ecosystems (Rooney et al. 2004) requires that we understand how these factors act together to simplify communities. Yates et al. (2003) argues that plant invasions are the second most
important reason for biodiversity loss worldwide. But many introduced species do not become invasive because some aspects of the new environment are unfavorable. Which species become invasive is, therefore, determined by the conditions of the new ecosystem and will vary from place to place. Some introduced species do persist, become invasive and may overcome a whole community of other plant species to become dominant in these fragments (Yates et al, 2003). For some forests that have developed on former agricultural land, as much as 80% of the forest cover is from invasive plant species (Flinn and Vellend 2005). The interactions developed between the plants that persist after such invasion further the loss of biodiversity.

Another relationship that further enhances biodiversity is plant/herbivore interactions (Coley 1998). These interactions are more important in the sub-tropics and tropics than in temperate regions for three major reasons. (1) There is a greater abundance of herbivores. (2) Herbivores have a specialized diet. (3) Some plants tend to be better defended both physically and chemically (Coley 1998, Saunders et al. 1991). For instance, ants are very efficient herbivores of only certain plants that do not produce toxins. Not producing toxins may provide the plant with an advantage because these ants could potentially move seeds from one woodlot to the next. Large mammals that are herbivores play a similar role in the tropics, simultaneously eating and dispersing plants. Forest fragmentation impacts all these relationships and they all seem to play a role in determining the structural composition of communities and the distribution patterns of plant species, even though it is hard to determine the relative significance of each variable.
Modification of landscapes and creation of new habitats and landscapes by humans have created profound changes in our environment. Understanding human modification of landscapes provides insight to understanding virtually all biomes (Mayfield et al. 2006). Yet, there are many uncertainties that need to be investigated such as: Which species are still present? What mechanisms allow them to persist in such habitats? How are these elements of the biota functionally similar to, and different from, the wild communities they replace? Similar studies have been carried mostly in temperate regions with little applications to sub-tropical countries.

Recent studies of landscapes that have been altered by humans reveal a consistent pattern of species diversity (Mayfield et al. 2006). Mayfield et al. (2006) compared specific plant functional traits of importance for the long-term sustainability and function of these communities. In the present study, I involve pollination and seed dispersal modes for all plants as possible dictators of variances in species present in most woodlots. Also, I included life span such as perennials and annuals, and growth form such as woodiness, as possible dictators of species survival in most woodlots. This study advances or extends former studies by testing woodlot characteristics such as proximity to sugar cane, papaya, pasture lands and distance to ocean as possible parameters for changes in species presence, absence and abundance in the woodlots studied.

Because many habitats remain largely unexplored, early studies in places like Belize present many uncertainties. In developing countries within the neo-tropics, land is not cultivated all at once; instead, some sites are allowed to recover providing an opportunity to study the long-term effects of human disturbances (Singleton et al. 2001; Honnay et al, 2004). The woodlots in this particular study are still not described because
people have failed to study biological diversity in most areas of the northern part of Belize (Meerman, Personal Communication, 2007; Herrera, Personal Communication 2007). Some dynamics of mammal species, insects and other organisms within the nearby Shipstern Nature Reserve have been studied (Meerman 1989). However, it is not clear why certain species found in woodlots of the region are present. This leads us to ask: What characteristics found in the woodlots or what characteristics of species lead to successful establishment?

Understanding the forest dynamics in Belize is very important to the region’s ecology and conservation of its natural resources. Forest dynamics and successional distribution patterns of plants have been studied more in the southern and western areas of Belize, but very little research exists for the northern areas (Meerman Personal Communication 2007). This study proposes to help fill that void.

In order to understand forest fragment dynamics created by agricultural practices in the north, I developed an index of 36 target species of herbaceous plants, woody plants and vines. Using simple tally I established the presence/absence of each species in 19 woodlots of different ages and sizes. I associated woodlot traits (age, sizes, distance to sugar cane fields, distance to papaya fields, presence of stream, distance to Shipstern Nature Reserve) to their species frequency and species traits (edge vs. interior species, lifespan, flower pollinators, fruit dispersal, life forms, and whether the target species was present in the agricultural matrix) to their frequency in woodlots. These data help explain why certain plants within the target species index exist in some woodlots and not in others. The 36 target species are the plants that are most commonly known by Belizean ecologists and botanists as well as by native people of the Corozal district. Because most
of these plants are medicinal plants, native people will be especially motivated to conserve these species. The goals of this study are four:

1) Determine the distribution of 36 target species within woodlots of three size categories (<5 ha, 5-10 ha and >10 ha) and three age categories (5-15 yrs, 16-30 yrs and >30 yrs).

2) Determine whether size and age are important components in describing the distribution patterns of plants species.

3) Determine the woodlot characteristics that tend to favor certain target species.

4) Determine plant characteristics that tend to favor certain target species.

Because woodlots vary in age and size, I predict that persistence of target species is variable, but predictable. Only a few woodlots under study are older than 100 years and some scientists argue that the colonization of most plant species into new areas takes at least 100 years (Honnay et al. 2004). Thus, I expect to find greater plant diversity in the older forest fragments.

Woodlots surrounded by agriculturally dominated matrices lead to isolation of forest fragments. Thus, I expect to find fewer target species in woodlots that have the greatest isolation. In this case, isolation of a fragment is the distance measured from a main continuous forest fragment and also the presence of other woodlots surrounding the site of interest. Other studies of species diversity show that there is a positive relationship between diversity and distance to a main continuous forest fragment: closer fragments are more diverse, regardless of age and size.
In the Corozal district of Belize, the agricultural practices required to support the production of sugar cane, papaya and pastureland consume much of the total landscape. Sugar cane farming has been, and still is, the major cause of fragmentation in the Corozal district. Devoting such a large amount of the landscape to cane, not to mention papaya and pasture, has led to a major decrease in species richness. Giving more land over to the cultivation of sugar cane continues to this day. As such all these activities negatively affect the relationship between the number of species thus decreasing the number of species the closer agricultural lands are from the woodlot.

I predict that perennial plants are present in most woodlots, regardless of the degree of isolation, because long-lived perennials form remnant populations that are less susceptible to habitat fragmentation (Honnay et al. 2004). Perennial plants are able to survive other anthropogenically-derived stresses such as fires, occasional logging, and tourism. I predict that mammals are more efficient seed dispersal agents than under-story birds, primates, etc. Lastly, I predict that insects are the main agents of pollination for these 36 target species and thus expect to find that insects are more responsible for pollination than any other form.
II. METHODS

Study Area:

Belize is in the northeastern part of Central America, bordered by Mexico in the north, by Guatemala on the west and south, and by the Caribbean on the east. Belize’s geographic coordinates are within 15°53’ to 18°30’ North Latitude and 87°15’ to 89°15’ West Longitude (Meerman and Moomsma 1993). Belize’s geology is largely based on limestone except for the Maya Mountains. The northern half of the country consists of heterogeneous sediments deposited on the Yucatan platform containing limestone, chalk, marl, and other sedimentary layers (Rosado 1999). According to the Geology department in Belmopan, Belize, the study sites are within the Orange Walk group: marls, corals, and coquinal limestone deposits composed mostly of clay and sand. These sites are at elevations not greater than 20 meters above sea level according to a map found in the geology department and data collected in the field (Appendix 1).

The northern latitudes given for Belize indicate that it lies in the outer tropics or subtropical geographic belt and that it has higher extreme and mean temperatures than the tropical latitudes (Rosado 1999). According to the Meteorological department of the Phillip Goldson International airport, the annual average rainfall from 1992-2002 in the Libertad weather station (Libertad is approximately 6 km from the areas of study) is 1428.4 millimeters. The highest recorded monthly rainfall within this period occurs in September with 226.3 millimeters and the lowest reading occurs in February with 29.9
millimeters. The months with highest rainfall occur from June to October, which is known as the wet season, whereas from November to May is known as the dry season. Similar rainfall patterns are observed at the Consejo weather station, which is closer to the Santa Elena location (Figure 1). The minimum temperature occurs in January with 16.9° C and the highest recorded temperature from 1992-2002 at the Libertad weather station occurs in April and July (33.1° C) (Figure 2) (Meteorological department 2006).

The northern part of Belize is well known for the cultivation of sugar cane and its association with deforestation. As such much of the biodiversity has been disturbed, many habitats degraded and only small patches of forest exist. The remaining parcels of forested land in the neo-tropics, Belize in particular, are generally small (<100 ha) and isolated fragments (Turner and Corlett 1997). In northern Belize most fragments are less than 12 ha with many being converted to the cultivation of papaya or pasture lands.

Sugar accounts for 60% of Belize’s agricultural exports. Introduced into the Corozal district in 1848 from Yucatan, sugar cane thrived in the 19th century, declined in the early 20th century, and increased again after construction of the Libertad factory in 1935. After 1951, the area under sugar cultivation began to expand rapidly. At that time, some 800 ha (2000 acres) of sugar cane were harvested. Today an estimated 16,000 ha (40 000 acres) in the northern lowlands are reaped annually. But in the last two decades sugar production occurred only at one factory operated by Belize Sugar Industries, Ltd with the closing of the Libertad factory. More than 4000 farmers supply sugar cane to the Belize Sugar Industries Limited (Naturalight Productions 2007).

Fragmentation significantly impacts biodiversity. Many years ago, the normal agricultural practice used by the Mayas to clear land was mainly slash and burn: trees and
saplings were cut and left to dry, followed by burning of the dry material. Planting was done manually and very little or no fertilizers were used. The “Mestizos”, a group of people that is a mixture of Mayans and Spaniards, created lots of negative effects within their environment. However, the current intensified modes of slash and burn, the repetitive cultivation of crops without a fallow period, and the cultivation of monoculture crops has led to severely degraded and almost sterile soils (Saqui, 2007 unpublished thesis).

In the early days, farmers cleared only what was necessary to produce enough plant material for one family. The average crop yields were normally corn, yams, beans, watermelons etc. The population was very small; consequently, the demand for tillable soil was also small. Some trees were cleared, but animals were able to shift to forested areas yet untouched. The environment was able to recover from minor transgressions and many species of animals were commonly seen. Today some animals are rarely seen and some animals are endangered. The disappearance of animals and plants paralleled the increase in farming. As population increases there is a corresponding demand for agricultural space, cash crops such as sugar cane and papaya, and for housing.

Fragmented forests in the Corozal area of northern Belize can be described as semi-deciduous with some trees shedding their leaves in the dry season while others keep their green leaves all year long (Meerman 2007, Personal communication). These woodlots are also heterogeneous in terms of size and age. Many of them are not bigger than 4 ha (10 acres), very few are up to 8 ha (20 acres) and even fewer are up to 40 ha (100 acres).
Selection of sites:

In this study, I sampled 19 fragments (n=19), which were of different sizes and ages (Appendix 1). Clusters of forest fragments were chosen in three different locations in the Corozal district, Belize. See Figure 3 for sites sampled in the Corozal district and also look at Appendix 1 showing the distribution of woodlots according to age, size and location in the map of the Corozal district: Santa Elena (6 sites), San Narciso (6 sites) and Copper Bank (7 sites). In terms of size, three ranges were used: 1) smaller woodlots <2.5 ha, 2) medium-sized woodlots 2.5-10 ha, and 3) bigger woodlots > 30 ha. I obtained sizes of the woodlots by looking at Land Plans for the Corozal District at the Corozal Lands Department. Mr. Adolfo Rodriguez measured some of these woodlots using the GPS at the Corozal Lands Department.

Unfortunately, recorded history is silent about these 19 woodlots. However, elder native landowners were very important in estimating the age and past land use of all woodlots. During the site selections, I talked to Mr. Alejandro Avilez (72 yrs old), Mr. Orlando Olivera (Chairman of Chunox), Mr. Geronimo Catzim (58 yrs old), and others to help determine approximate ages of the chosen woodlots. I used three age categories: younger (0-15 yrs), medium-aged (15-25) and older (>30 years). Because not many older forests (>50 years) are left in the area, woodlots that are 30 years and older on average are considered older for this study (Refer to Appendix 1 for further detail). I tried to find sites with a set of woodlots that contained all possible pairings of variables (age and size). For instance, location 1, the Santa Elena area, has two woodlots greater than or equal to 8 ha (20 acres). One woodlot is classified as older and the other younger. This pairing, then, can test the relationship between age, fragment size and species distribution in
woodlots. In the Santa Elena and San Narciso locations there are not many older
woodlots. Thus, some comparisons are missing. Importantly, sites (13-19) occupying the
third location (Copper Bank) have been impacted to a lesser extent by habitat
fragmentation because less natural vegetation cover has been cleared for agricultural
purposes. The reason why more remains is still not completely understood. I offer three
possibilities: 1) most men from Copper Bank are fishermen; 2) sugar cane has not been
very successful because the soils along the river tend to get saturated during the rainy
season, which is detrimental to cane growth; and 3) transporting sugar cane to the Belize
Sugar factory is costly because of distance and poor road conditions. Comparing the
Copper Bank sites to the other two locations should yield some interesting findings
because wide agricultural matrices surround the other two locations (Santa Elena and San
Narciso).

Woodlot structure:

I estimated woodlot structure for four woodlots of different ages by placing
transects and measuring tree dbh. Six plots (10 m X 10 m each), were placed along two
transects in each of the four woodlots sampled. The transects were 20 m apart running
parallel to each other. I measured dbh for trees >3cm but < 10 cm in the 4 m that is on the
center of the plot. The number of trees > 10 cm were recorded in the whole plot. The
woodlots used were woodlot 1 (medium-aged), woodlot 7 (older), woodlot 11 (younger),
and woodlot 13 (older) representing different categories in terms of age.

I varied the placement of each transect. Plots were randomly placed on transects
such that adjacent plots were no farther than 1/3 the length of the whole woodlot. To
avoid the effects of edges, I placed plots further than 20 m away from the edge of the woodlot. The distribution of stems within the woodlots sampled can be viewed in Figure 4.

Selection of species:

I collected species on site 13, which served as a reference site because it is large (125 ha). A complete list of species can be found in Appendix 2. It has been a Reserve since 1896 and essentially has been undisturbed by human interventions. These two facts lead me to believe that this Reserve represents a community of plant species that have been less impacted by fragmentation. I included species of each type, herbaceous, shrubs and vines, favoring species that are more abundant and the ones better known by local people. I chose exactly thirty-six plant species from the edge and interior of woodlot 13.

Species were identified using Standley et al. (1946-77) and Arvigo and Balick (1993). Nomenclature follows that of Balick et al. (2000). I deposited voucher specimens from site 13 in the Laboratory of Dr. James Runkle, Wright State University.

Data collection for species distributions:

After the 36 target species were identified at the reference site, I started collecting data from woodlots. I sampled targeted species twice: once in the month of June during the rainy season and once in the month of December during the dry season. In the month of June I recorded presence and absence of each species in each woodlot (Appendix 3) and in the month of December I divided sightings into three categories: 0 observations = absent; less than 10 observations = present; 10 or more observations = common
(Appendix 3). These comparisons were made to analyze the vegetation variation that occurs within these woodlots. This rank-abundance procedure was used in the ordinations section of the analyses, which is discussed later.

Soil collection and analysis:

Soils were collected in 8 woodlots; 4 woodlots in the San Narciso area, 2 woodlots in the Santa Elena area and 2 woodlots in the Copper Bank area (Table 1). Zip-loc bags were used to collect, transport and store soils prior to analyses. On the ground, the leaf litter and partially decayed leaf litter (organic horizons) were removed from the surface. By using a digging apparatus (machete and shovel), at least 250 g of soil were collected at a depth of 10 cm and approximately 4 cm wide. Two samples were taken from each of these 8 sites.

The A & L Southern Agricultural Laboratories, Inc in Pampano Beach, Florida performed the initial soil analysis. Their tests included three sites, one from each woodlot: site 6 from the Santa Elena location, site 12 from the San Narciso location and site 13 from the Copper Bank location. These tests included measurements of nutrients such as aluminum and sulfur and other important measurements such as pH and percent base saturation (Table 1).

The second part of the soil analysis tests was done in the laboratory of Dr. Thomas Rooney at Wright State University in the Department of Biological Sciences. Organic matter and ash content analyses using the dry-ash method were done for three sites: 1, 7 and 13. Organic matter and ash content was done by first sieving approximately 3.0 g of soil air-dried at 105 C for 24 h of which 2.0 g of this oven-dried material was placed in oven-dried crucibles. These were weighed. The crucibles were
placed in a muffle furnace for 1 hr at 375 °C. After this, the ash content was measured by placing the samples at 600 °C for 6 h after which the oven was allowed to cool to 150 °C. The warm crucibles were placed in desiccators filled with desiccant. After cooling, the crucible and ash were weighed.

Determination of soil texture was done for sites 1, 6, 7, 10, 11, 12, 13 and 18 (table 1). Soil texture determination was done using sodium-hexametaphosphate (Na-Hex) solution to store the soil samples. 50 g of the chemical was added to 1 liter of distilled water and 100 ml of the Na-Hex is further mixed to make a liter solution. A hydrometer was placed in the solution after it is allowed to stand for 30 minutes. 40 g of air-dried soil, 100 ml Na-Hex solution and 300 ml distilled water were mixed to produce a solution, which was allowed to stand overnight. The Na-Hex treated sample was blended for 5 minutes after which the suspension was made into a liter solution. This solution was shaken for several minutes after which the hydrometer was lowered and read after 40 seconds. This is called 40s. After 7 hours, the same procedure was carried and this was called R7h (Table 1 for results).

Analytical methods:

The statistical component is divided into three sections to answer the following questions:

1) **Which woodlot characteristics predict the presence/absence of our 36 target species?**

I selected a set of variables that could influence species distributions according to woodlot characteristics. The variables are woodlot size, woodlot age, distance to closest
fragment, distance to Shipstern Nature Reserve, distance to ocean, distance to sugar cane, distance to a papaya farm, distance to pasture land and whether a stream is present or not. Distance to closest fragment relates to the idea that woodlots that are closer together have greater diversity due to better chances of dispersal and colonization events by migrating species. Some distances were estimated due to lack of time or other boundaries/constraints.

Shipstern Nature Reserve is one of the few protected areas that are located in the northern part of Belize. It is a Reserve (22,000 acres) comprised of different systems including saline lagoon systems and mangrove shorelines. It is the only protected area in Belize that includes the more seasonal northern hardwood forests. Some researchers (e.g. Meerman and Herrera) say it was disturbed by hurricane Janet in 1955 and is in a state of recovery. It is one of Belize’s richest areas having ecologically diverse tropical rainforests (Naturalight Productions 2007). This Reserve may be very important in supplying seeds, pollen etc. to other fragmented woodlots. I performed a cross-reference check of the 36 target species using the “Occasional papers of the Belize Natural History Society” (1993) and a personal encounter with Dr. Jan Meerman, who had been a research activist in the Reserve and had compiled checklists of both flora and fauna of the area. During a visit to the sites, I recorded coordinates of all woodlots under my study. I then chose a reference point within the Reserve and measured the distances from all woodlots to that reference point in the Reserve. I used these data to test the claim that woodlots closer to a main continuous area will have higher species richness than woodlots farther away.
Hurricanes seem to have impacted woodlots in the past (Meerman 2007, personal communication). Strong sea winds as well as hurricanes can change the structure of woodlots. I took the distance from each woodlot to the closest seashore as a measure of wind disturbance assuming that the closer the woodlot is to the shore, the heavier the impacts from wind and the consequent lowering of species richness. Using the coordinates I obtained for all woodlots and using coordinates from a Google earth map, I obtained the distances and then recorded them in kilometers.

Distances from the woodlots to any agricultural land, whether pasture, sugar cane or papaya were all estimated on site. In many cases, woodlots were as close as 2 or 3 meters or even closer to agricultural land: in these cases estimating was both accurate and easy. The presence of a stream within a woodlot alters the vectors for dispersing seeds by encouraging mammals, birds and insects to visit or inhabit the woodlot. Thus, the presence of a stream probably increases species richness within woodlots. For the statistical analysis, I used numerical codes to represent each of these variables. For example; the presence of a stream was represented as 1 and absence as the number 2 (to see the codes used for each category of variables refer to appendix 4). These were the variables related to the dependent variable, which is the number of species present per woodlot, in order to answer what characteristics present in the woodlots make them more or less species rich.

Analyses were made using the SAS (Statistical Analyses System) statistical package 9.1. The data were normally distributed and therefore no mathematical transformation was required.
Pearson and Spearman Correlation coefficients were used to analyze the relationships among the number of species present in each woodlot to all those independent variables described above. Spearman Correlation coefficient is a nonparametric rank statistic for measuring the strength of the association between two variables: Spearman Correlation coefficient is less influenced by unusual values than is the Pearson Correlation coefficient. A stepwise regression procedure, using the maximum R2 improvement technique, was used to determine which variables were most important in influencing species richness within these woodlots.

2) **Which species characteristics make them more or less widespread?**

To determine which species characteristics make species more or less widespread, I analyzed the number of woodlots in which a species occurred to a set of independent variables. I analyzed the relationship between the number of species and the following independent variables: interior vs. edge species, lifespan, pollination agent, fruit type, seed dispersal, and plant type (growth form).

Because studies have found that shade-tolerant species increases with area (Hill and Curran 2001) and that forest edges enhance the colonization of pioneer species, in the determination of the species index, I tried to find as many interior species as possible so as to minimize the impacts of forest edges on the distribution of plant species. For the statistical analyses, the category edge was assigned the number 1 and interior species was assigned the number 2. Life span of certain species may determine the persistence of species within woodlots. Plants are commonly grouped by expected life span: annuals, biennials, and perennials. For the statistical analyses, I assigned 1 to annuals, 2 to biennials and 3 to perennials. Woodiness and herbaceousness were two parameters also
considered. But some plants were vines and 1 species was a cycad. They are also number
for statistical purposes in the following way; Herbaceous 1, woody shrub 2, vine 3, Liana
4 and cycad 5.

The two parameters that were investigated in more detail were pollination and
seed dispersal. The information on seed dispersal of all these plants was obtained in a
personal encounter with Dr. Jan Meerman, Director of Biodiversity and Environmental
Resource Data System of Belize. He previously worked in the Shipstern Nature Reserve
compiling checklists of mammals, fishes, plants and invertebrates. Because it is still
uncertain which types of animals specifically pollinate these plants, there were only two
categories. They were either pollinated by animals or by wind. For statistical purposes, I
used the number 1 to represent animal-pollinated and 2 for wind-pollinated. For dispersal
of seeds, there are three categories. They are animal dispersed represented by the number
1, wind-dispersed represented by the number 2 and self-dispersed represented by the
number 3. Refer to Appendix 5 for a series of codes used for each category under each
variable.

The statistical analyses were similar to the first part of the analyses.

3) How is species composition related to woodlot and species characteristics? The
third part of the analyses, I looked at vegetation variation within woodlots using
Detrended Correspondence Analysis (DCA), which is an eigenanalysis ordination
technique. DCA is used mainly to analyze ecological data sets creating ordinates for both
species and samples simultaneously. DCA was performed with a modified version of
DECORANA using PC-ORD 4. Axis scores for woodlots were related to the woodlot
characteristics given above using correlations and stepwise regressions. Axis scores for species were related to species characteristics in the same way.
III. RESULTS

Diameter breast height distributions:

Diameter distributions for the four woodlots varied with woodlot age. In woodlot 1, 48.5% of the stems were larger than 6.5 cm but less than 20 cm. There was a large number of smaller trees (< 6.5 cm) and some trees larger than 50 cm. This woodlot was older than 15 years but not older than 30 years. Woodlot 7, which is characterized as an older fragment (>30 years), had a majority of stems less than 20 cm as a result of firewood harvesting within two of its plots. However, two trees were larger than 100 cm; one tree was 160 cm. Woodlot 11 is classified as a younger forest (less than 15 years old). Most stems were smaller than 50 cm with very few over 60 cm. The reference site (woodlot 13) is dominated by stems between 3 cm and 20 cm in diameter with some of the larger stems present (Figure 4).

The Kolmogorov-Smirnov test revealed that all woodlots significantly differed in terms of the distribution of stems (Table 2) when compared to each other.

Soils analyses:

No statistical analysis was performed for soils sampled because the samples were too small in number to yield significant findings. The soils’ pH of the three woodlots (1 woodlot per location) tested was nearly the same value for each. The percentage of organic matter varied. San Narciso was the lowest and the other two locations had nearly
the same percentage of organic matter. Location 3 (Copper Bank) had at least 15% less clay than the other two study locations. There was a corresponding increase, of approximately 15%, in sand. Both nutrient content and silt, at the 10cm depth, varied only slightly between the three locations (Table 1).

Woodlot characteristics:

The correlation procedure showed that woodlots were overall more species rich for the older woodlots (Pearson r = 0.05, p = 0.0277; Spearman r = 0.58, P = 0.0083) (Figure 5 and 6), larger woodlots (Pearson r = 0.73, p = 0.0004; Spearman r = 0.50, p = 0.0286) (Figure 6), and closer to Shipstern Nature Reserve (Pearson r = -0.71, p = 0.006, Spearman r = -0.76, p = 0.001) (Figure 7), farther from sugar cane fields (Pearson r = 0.51, p = 0.025; Spearman correlation was not significant) (Figure 8), farther from papaya fields (Pearson r = 0.61, p = 0.0053; Spearman r = 0.59, p = 0.0066) (Figure 9), and closer to each other ( Spearman r = -0.83, p = <0.0001, Pearson was not significant) (Figure 10).

Stepwise regression analysis for the actual number of species and other variables found woodlots to be more species rich when woodlots were closer to Shipstern Nature Reserve: the number of species = 44.9 - 0.83 Distance to Shipstern Nature Reserve (R² = 0.52, P = 0.007).

The 1-variable model was significant when the number of species was associated with the ranks of the other variables: number of species = 25.9 - 0.81 Rfragment (R² = 0.47, p = 0.0012), where Rfragment = ranked distance to nearest fragment. This result shows that woodlots are more species rich when they are closer to each other.
The best 4-variable model shows that woodlots are more species rich when they are older (P= 0.007), when woodlots are closer to each other (P=0.017), closer to Shipstern Nature Reserve (P=0.025), and closer to the ocean (P=0.013). The rank number of species= 10.05 + 2.48 Age – 0.47 Distance to fragment – 0.52 distance to Shipstern Nature Reserve + 0.43 Distance to Ocean (R² =0.8492, p= <0.0001). This stepwise procedure related the Rank number of species to the ranks of the other variables.

Species characteristics:

The Correlation procedure shows that plant species would be more widespread if they were insect pollinated (Pearson r = 0.39396, p= 0.0174; Spearman r = 0.38859, p= 0.0192). Insect pollination was the only significant variable for Stepwise regression: Frequency = 2.67 + 8.19 InsectP (R²=0.23, p= 0.0062) where freq= number of woodlots each targeted species was found in and InsectP= 1 if the species is insect pollinated. Thus, species that were insect pollinated were found in more woodlots than species pollinated only by wind, birds or bats. Species that were not pollinated by insects were present on average in 2.7 woodlots and species that were insect pollinated were present on average in 10 woodlots.

Relationships among other plant species variables:

Woodlot characteristics

The analysis indicated that some variables are related to each other. For example, older woodlots were found closer to the Shipstern Nature Reserve (Pearson r = -0.47929,
p = 0.0379; Spearman r = -0.47065, p = 0.0420) and fragments were closer to other fragments when they were closer to Shipstern Nature Reserve (Pearson r = 0.44956, p = 0.0535; Spearman r = 0.79225, p = < 0.0001). Furthermore woodlots that were older are closer to the Caribbean Sea (Pearson r = -0.57731, p = 0.0096; Spearman r = -0.49723, p = 0.0303). Being closer to Shipstern Nature Reserve also brought them closer to the Caribbean Sea (Pearson r = 0.6444, p = 0.0029; Spearman r = 0.68627, p = 0.0012). The distance between papaya fields and Shipstern Nature Reserve was found to be significant because papaya fields were not found in the Copper Bank area and as such is farther from Shipstern Nature Reserve (Pearson r = -0.86917, p = <0.0001; Spearman r = -0.72178, p = 0.0005).

Species characteristics
Most species found in the edge of forests were also found in the agricultural matrix (Spearman r = -0.44728, p = 0.0062). This result suggests that agricultural matrices potentially can be successful habitats for many of these species.

Ordinations:
Woodlot characteristics
Differences in species composition among the three regions are apparent, with Copper Bank (woodlots 13-19) concentrated at high values of Axis 1, Santa Elena at low values of both axes and San Narciso at low values at Axis 1 and high values at Axis 2 (Figure 11). High values of the first axis are significantly associated with older woodlots (Pearson r = 0.45633, p = 0.0495; Spearman r = 0.53701, p = 0.0177), proximity to Shipstern Nature Reserve (Pearson r = -0.75031, p = 0.0002; Spearman r =-0.79017,
<0.0001) and distance to papaya plantations (Pearson r = 0.71261, p= 0.0006; Spearman r = 0.65936, p= 0.0021).

The Stepwise Procedure shows high Axis 1 values for woodlots close to Shipstern: Axis 1 value= 352.78 - 17.58 Dshipstern (R²= 0.5630, p =0.0002). High Axis 1 values also are associated with woodlots farther from papaya fields and closer to Shipstern Nature Reserve: Axis 1 value = -849.6 + 39.5 Dshipstern + 0.03 Dpapaya (R² = 0.40, p = 0.0159).

Woodlot characteristics were not significantly related to Axis 2 values.

Species characteristics
For Axis 1, insect pollination is the only significant variable (Pearson r = -0.38745, p= 0.0196; Spearman r = -0.36279, p= 0.0296) (Figure 12). The three plants that were not insect pollinated were found mostly in the Copper Bank area. The Stepwise Regression Procedure (values plotted on Axis 1) shows that insect pollination across these target species is the only significant variable so that Axis 1 score= 150.33-106.01 InsectP (R²= 0.30, p=0.0014).

Our 36 target species have higher Axis 2 scores for perennials (Pearson r = 0.39432, p= 0.0173; r = 0.43282, p= 0.0084). The Stepwise procedure shows that Axis 2 score= 25.6 + 23.2 Lifespan – BirdP (R²= 0.31, p= 0.0051) (Figure 15).
IV. DISCUSSION

As a result of clearing and cultivation activities, the Corozal district contains numerous forest patches of different ages and sizes. Overall the data suggest that the patterns of targeted species are related to the nature of agricultural lands, characteristics of woodlots such as age and size, proximity of the woodlot to a main continuous Reserve, and certain plant species characteristics which mostly act together shaping the structure and composition of targeted species within the woodlots under study.

Diameter breast height

The Kolmogorov-Smirnov test shows that the diameter distributions of the four woodlots varied with woodlot age (Table 2). Because farming has been more extensive in the San Narciso area, fewer older woodlots were found there and larger stems were uncharacteristic. The woodlot in the Copper Bank area is characterized by more of the larger stems. These results suggest that the recovery process is just starting in the San Narciso woodlot whereas in the Copper Bank area, the woodlot has not been cleared completely. Diameter breast height measurements have been used in other places, such as southeastern Madagascar, where the process was used to determine community structure. They have used this method to explain species composition contrary to what I did. They found out some problems with using this method. They agreed that the major constraints of using this method are in the use of proper experimental design and in sampling
methods (Cadotte et al. 2001). In my case the lack of time was a major drawback due to the fact that it would have been convenient to do the same procedures for all woodlots because certainly this procedure can aid in understanding the dynamics of fragmented woodlots in the Corozal district, Belize.

Size and age of woodlot:

I found that size and age of woodlots is related to plant species richness. Generally, younger and smaller woodlots yielded fewer species. The number of species present increased with the age of the woodlots (Pearson r =0.05, p= 0.0277; Spearman r = 0.58, P= 0.0083) (Figure 5 & 6). In a study done by Hill and Curran (2001), the species-area curves shows that larger woodlots contained a greater diversity of trees and, most importantly, the proportion of rare trees increases directly with woodlot size. This relationship underscores how important it is to conserve the larger forested areas.

The relationship with size is visible. Younger and smaller woodlots had fewer of the targeted species than medium-aged and medium-sized woodlots; the latter category also had fewer of the targeted species than older and larger woodlots (Figure 5 & 6). The result obtained here where larger woodlots were more species rich (Pearson r = 0.73, p= 0.0004; Spearman r =0.50, p =0.0286) is equivalent to the result obtained by Jacquemyn et al. (2001), Kolb and Diekmann (2004) and Lindborg (2007). They found that species richness significantly increased with age and age was significantly interrelated with area. Therefore, neither of these predictors of plants species richness can be assessed independently, at least in this study. It has been argued that the relationship between size and species richness could be attributed to sampling effects. In this study, I believe that
sampling bias must be ruled out due to the presence/absence method of sampling that I
used. I was acutely aware of the absolute necessity to treat each woodlot similarly, giving
the same degree of critical attention to counting, measuring and recording within each
plot. In a similar presence/absence study the researchers (Hill and Curran 2001)
maintained that the sampling effect could not account for the variation of species
richness.

Other studies, such as Nickolson and Monk (1974), talk about succession. I did
not include succession as part of this study for the following reasons: A standard for
succession was not available within the region, primarily because there was no
identifiable standard in the Corozal area. Even the reference site has been disturbed due
to natural activities and, most likely, even agricultural activities. Furthermore, in this
study a small size of plants was sampled.

Microsite characteristics

Other studies have attempted to explain the variations of vegetation diversity by
relating it to variables such as altitude and precipitation (Pysek, Kucera and Jarosiks
2002) that make significant contributions to changes in species richness. In this study
altitude was not a major factor affecting the distribution of targeted species. (Statistical
analyses were not done because there were only slight changes in elevation between sites
Appendix 1). The area encompassed by this study is known as the “Northern Flatlands”
of Belize.

The interval from June to October is known as the rainy season in the Corozal
district. On average 225 cm of rainfall occurs during this rainy period (average computed from 1992-2002 shown in Figure 1). Because farmers struggle to clear, plant or cultivate their fields during the rainy season, plants have the opportunity to mature and multiply. During the dry season farmers are able to clear most of the species that are present in the agricultural matrix (personal observation). I propose that because farmers struggle to clean their farms in the rainy season and because many targeted species are present in the agricultural matrices, targeted species are likely to become more widespread during the rainy season.

Farmers report that some species are very hard to remove because they keep coming back because the application of chemicals is expensive and the price of sugar cane has decreased making it less feasible to purchase chemicals. Thus, the farmers have been unable to keep their fields as clean as they have in the past. More than once, farmers mentioned that most of the target species used in this study are the first ones returning to areas where disturbances such as fires and plowing have occurred. Although I did not look at these disturbances specifically (plowed and burned plots as independent variables) I propose that the seed bank of most of these species are enriched within plowed and burned areas, accelerating the colonization of at least half of the target species into neighboring woodlots. Kupfer et al. (2004) found that high mortalities of plants occurred due to weeding and burning and that recovery was due to the arrivals of propagules changing the proximity of seed sources. Because the seeds of most of the target species are still common in the burned and plowed agricultural fields, plants have an opportunity to colonize neighboring woodlots because of their high endurance and persistence within the agricultural matrix. This is true and is beneficial because even in
the absence of animal seed dispersal vectors, which seem to be the most common seed dispersal agents in the neo-tropics (Wunderle 1997), plants have good chances of survival as long as the seed bank is not completely destroyed.

Soil analysis:

Due to the limited numbers of soils tests done, statistical analyses of soils were not carried out. However, the tests that were performed suggest that only two of the locations proved different from the others: San Narciso (lower organic matter content and slightly higher pH Table 1); and Copper Bank (soil types, percent composition of each).

As pointed out by Flinn and Vellend (2005), lower organic matter and higher pH clearly indicate a recovery stage from prior agricultural practices. I personally know that the San Narciso area has been under more intense and longer agricultural practices than the other two areas. The organic matter content of the woodlot in San Narciso is 5.1%, Santa Elena is 7.7% and Copper Bank is 7.2%. The reason for a lower percentage of organic matter in the San Narciso woodlot is uncertain but I predict that because more sugar cane production exists in this area, there are more frequent fires that spread into these woodlots burning the detritus.

Saqui (2007) suggests that soils that have higher organic matter content are healthier soils and that healthier soils provide better recourses for plant growth. This study seems to imply that the San Narciso woodlots would be less hospitable to our target species than the other two locations perhaps partly due to lower organic content in the soil. That is, indeed, the finding: the San Narciso woodlots showed the fewest target species. Also, woodlots that are recovering from prior agricultural practices have been shown to contain
fewer species than woodlots that were not formerly plowed, for example pasturelands (Marcano et al. 2002, Wulf 2004). At least 5 woodlots in the San Narciso location apparently have a history of agriculture, including being plowed. Sugar cane farming is widespread and intense in the San Narciso location, less so for the other two locations. In the San Narciso location, where organic matter content was lower and pH slightly higher species richness was found to be lower.

Soil tests showed that nutrients in the soils, except for organic matter, did not differ significantly among the three locations studied. Kupfer et al. (2004) suggests that soil nutrient level is instrumental to the recovery of abandoned agricultural lands because nutrient-poor plots do not encourage a large number of species. But the amounts of nutrients such as magnesium, calcium, and copper etc. remained almost the same. Thus I believe that the similarity in levels of these nutrients across the three locations leads one to conclude that no inferences are possible.

Woodlot Characteristics

Woodlots are more species rich when the woodlots are bigger, older, closer to each other, closer to Shipstern Nature Reserve, and further from papaya and sugar cane fields.

Woodlots were more species rich when they were closer to each other. This pattern can be observed in Figure 10. Furthermore, I found that woodlots were more species rich when they were close to an older woodlot. Butaye et al. (2002), Singleton et al. (2001) and Wulf (2004) found that younger woodlots had almost similar composition of flora to an older woodlot especially when they were closer to one. For instance Butaye
et al. (2002) found that at least 91% of the species in older woodlots was found in younger woodlots closer to the older woodlot but that this fraction decreased the farther away the woodlots were from the older woodlot. Mainly, species richness decreases the more isolated they become, not because the area cannot sustain more diverse plant communities, but because there is a need for a pool of both seed and pollen. Thus, the closer the pool of sources, the more species rich the woodlots should be. However, in order to preserve species richness, it may be just as important to conserve forest heterogeneity (Honnay et al. 1999), as it is to conserve habitat quality.

In fact the data I collected suggest that the species composition, which was heterogeneous in younger woodlots is not a random sample of what has always existed there; instead, the composition of the younger woodlots appears to be determined by the spatial configuration and the species composition of nearby older woodlots. For instance, the two older woodlots (site 13 and 18) contained more of the target species, 36 and 33 species respectively and I proposed that it was because woodlots were closer to each other and younger woodlots were closer to the older woodlots that the area was, in general, more species rich. I drew this conclusion from the ordination procedure that yielded the following statistical result: fragments were closer to each other when they were closer to Shipstern Nature Reserve so that woodlots that were closer to each other were also close to a cluster of older forests which encompass the Shipstern Nature Reserve.

Copper Bank’s woodlots are closest to Shipstern Nature Reserve and the most species rich when compared to the other two areas. On the other hand, in the San Narciso area, there are fewer of the older woodlots and the woodlots are more widely separated leading
to a corresponding decrease in species richness. I strongly believe, therefore, that species richness is dictated by the presence of older woodlots in the area. In other words the species richness within these woodlots was not by chance as predicted in other studies, Hill and Curran (2001), for example. Another study by Chinea and Helmer (2003) found that increasing the distance to an older fragment had some negative impact on species richness but no effect on community composition or species diversity. In this study, the distances to older woodlots proved to be a significant variable in the determination of species richness. My general conclusion is that the distance between woodlots, especially older woodlots significantly influences species richness in the following way: woodlots closer to other woodlots (small or large) and closer to an older woodlot (especially) were found, as expected, to be more species rich than those woodlots with greater separation (Figure 10).

However, it is important to mention at this point that it is very hard to distinguish which variables are more significant than the other but rather that all these variables act together to dictate the species composition in these woodlots. These factors as seen in the ordinations results is similar to those in other studies in that to some extent they are mutually correlated, which makes it difficult in assessing the role of each in determining species richness (Pysek, Kucera and Jarosiks 2002). For example, the best 4-variable model shows that the 4 variables, older, closer to each other, closer to Shipstern Nature Reserve and distance to ocean are correlated but despite this finding, the four variables have an independent influence to species richness to some degree acting separately but most of time seem to be acting together.
Of the three areas in this study, Copper Bank’s woodlots are closest to each other (p=0.017). San Narciso’s woodlots have the widest separation among the three study areas and the fewest plants among the targeted species. Again, the San Narciso area, in general, has been farmed widely leading to smaller and younger woodlots with greater separation. It is important to note that in the San Narciso area, two older woodlots (woodlot 7 and woodlot 8) were separated only by the Northern Highway and in contrast to our other results where closer woodlots and older woodlots are consistently more species rich, these two woodlots were less species rich (Number of species = 14). These two woodlots were not farmed because of topographic relief (two get flooded during heavy rains; personal communication); and, likely as a result of frequent flooding, these two woodlots (7 & 8) show low species richness in comparison to other woodlots. Furthermore, local people have physically disturbed these woodlots by cutting trees for firewood (Alejandro Avilez, personal communication).

Woodlots closer to the Shipstern Nature Reserve are more species rich than others more distant. This reserve, which is close to 22,000 acres, was disturbed by hurricane Janet in 1955 and subsequent fires and is described as a second-growth mature forest. This Reserve is comprised of many ecosystems: saline lagoon systems, coastal mangrove shorelines and hardwood forests. In many studies, for example Pysek et al. (2002), the idea that a nature Reserve area with abundant habitat diversity contribute significantly to higher species richness in surrounding areas is obvious and certainly worth noting. In particular this Shipstern Nature Reserve supports a great variety of both fauna and flora of the Corozal district. Furthermore, the northeastern part of the Corozal district has been less fragmented than the western and northern part of the district and as such gives an
opportunity for the dispersal of plant species. However, a question still lingers: “How close to a larger wooded area does a woodlot need to be in order to eventually contain most of the species in the larger and older woodlot such as the Shipstern Nature Reserve?” It seems apparent that there is no simple answer to it. As we have already seen, the effects of habitat fragmentation and landscape configuration combine in such a way as to confound the most careful and skillful researcher.

Nature Reserves such as Shipstern, represent remnants of natural vegetation in the landscape and centers of species diversity (Pysek et al. 2002). Because humans have had only small impact on reserves, reserves reflect a more or less “natural” distribution pattern of plant species. The 36 target species found in the reference site were cross-referenced with the checklist of Shipstern Nature Reserve’s flora and all of the target species are listed on the Reserve’s checklist. This discovery may serve as an indication that these species are part of the natural vegetation of the area and that at one time both fragments were connected at some point. Also, the fact that both the reserve and the reference site have been less impacted by human activities may partially explain why they share similar patterns of plant composition. It is, therefore, crucial to understand that the ecology of the Corozal district is largely determined by human activities such as agricultural practices. This conclusion is based on data in this study and others that confirm the following result: the presence of older and larger woodlots, especially Reserve woodlots, relates positively species richness.

Agriculture has been the major reason for the present state of ecology in Belize. Advancing agricultural pursuits has been the major cause of forest clearance and the creation of physical boundaries within fragments (William 2004, Mayfield et al. 2006).
In this study, I found that species richness declines the closer the woodlot is to a sugar cane field (Figure 8) and closer to a papaya plantation (Figure 9). Sugar cane production has been the major industry in Belize since the beginning of the 20th century and has been cultivated on a large-scale during the latter half of the 20th century. Papaya, on the other hand, has not been active that long in Belize. Papaya farming has taken hold only during the last 15 years. Also, this industry is not completely dependent on clearing forest fragments that remain uncleared. Instead, papaya growers tend to rent former sugar cane fields for growing papayas. Although the impact on the Belizean ecology is lessened, by occupying a space papaya culture impedes forest recovery.

The effects of sugar cane production are vast, especially in the northern part of Belize. I will discuss, in turn, three of the most far-reaching effects that clearing woodlands has had on the ecology of Belize. First, the clearing of forest in the beginning was necessary to decrease forest cover in most of the northern part of Belize contributing largely to a decrease not only in habitat diversity, but also in species composition and species richness (Meerman and others Personal communication). Most farmers and local people could not foresee the eventual impact of deforestation and tended either not to understand the information that was forthcoming, or tended to disregard or not believe the information. Today, however, most farmers are aware of the consequences of forest fragmentation; they have actually seen the changes that have occurred. For example, elder people told me that large mammal population such as deer, tigers or even birds have decreased especially in the northern part of Belize. Local Bushmen have encountered situations where the local plant remedies for certain diseases are now rare in most woodlots in the Corozal district. It has been apparent that Belizeans have learned to rely
on already manufactured medicine and have stopped relying on our local plant remedies. Have Belizeans become too dependent on agriculture for their economic support? Do they now rely too much on pharmacies for healing to the neglect of their own culture, including the use of plants, found locally with medicinal properties, for healing the sick and afflicted and for preserving health? Is it possible that one or more of these plants that may be eradicated by agricultural practices holds the key to curing a major illnesses? This is not too difficult to imagine since many of the drugs now in existence owe their origin to a plant of some kind. Information is one of the keys to initiating action to change entrenched practices. My hope is that this study may, in some small way, help to reverse the increasing neglect of the environment that I have personally observed in Belize.

Second most sugar cane fields are uninhabitable for most species of plants because they are destroyed or controlled, either chemically or physically. In order to maximize sugar yield, the cane fields need to be clean during the early development of the crop. If they are destroyed, then the agricultural matrices are not adequate spaces for the dispersal of species. If they are controlled instead of destroyed, during the closing of the canopy of sugar cane as it grows, plant species are at a disadvantage due to sunlight limitations. Nevertheless, not all fields are made clean and it is during this time that plants can take advantage of the agricultural matrices, which does happen more often today (personal observation).

And third, on a smaller scale, sugarcane production has caused the fires that escape into nearby woodlots destroying the ground cover. In many places such as the Amazon, where forests are larger than the woodlots used in this study, fires tend to
penetrate deeper into the woodlot because the edges are so dry during the dry season of the year (Cochrane and Laurance 2002). Because the woodlots used in this study are relatively small, the edge to interior ratio of spaces is higher, thus increasing the overall susceptibility of these smaller spaces to the effects of runaway fires.

In the Corozal district, both sugar cane and papaya fields account for nearly the entire matrix that separates small patches of forest. To truly understand species response to fragmentation, we need to understand virtually all the components of the landscape including the matrix. Previous studies conclude that matrices do not necessarily act as a barrier to all organisms; rather, they act as a filter for the movement of organisms across the landscape. Those organisms that tend to ignore the matrix are expected to increase their vulnerability to extinction (Gascon et al. 1999). This rule seems to apply almost everywhere. It seems that when species try to exploit the agricultural matrix, they are affected adversely and cannot successfully complete the process of transition from one woodlot to the next using the agricultural matrix. A very important result was thus obtained. Most species that I found in the edge of the woodlots, I also found within the agricultural matrix, which was either a cane field or papaya field. Thus I can conclude that certainly the agricultural matrix can be a transitional space for some target species that are trying to colonize new woodlots. I attribute the presence of these target species to the fact that farmers have been finding it harder to clean their fields providing even greater opportunity for these target species, as well as others, to move across the landscape.

Contrary to what I expected, the presence of pasturelands near targeted woodlots was not a significant variable in the determination of species richness. Flinn and Vellend
(2005) suggested that species respond variously to different forms of agriculture; and Wulf (2004) states that former pasturelands generally have similar species composition to older forests mainly because the lack of plowing gives an opportunity for most of the species to recover and that constant plowing favored the presence of mostly annual species. There was not a direct effect of pasturelands in this study mainly because there are scarcely any pasturelands found around the sampled woodlots. Furthermore, no precise history exists for most of these woodlots so I can make no assertion as to a woodlot’s prior use, as pasture or otherwise.

Species Characteristics

Perennials exist nearly everywhere whereas annuals are short-lived in most landscapes. Kolb and Diekmann (2004) suggest that certain plants may have the ability to persist and survive even in highly fragmented forests, which is supported by the fact that they are long-lived. In this study 30 out of 36 target plants are perennials, which may be a predictor of a wide distribution of species among woodlots. In some other studies area however, not only lifespan but also habitat quality are associated with plant persistence and plant species richness (Lindborg 2007) whereas annuals are highly interrelated with the spatial configuration of the landscape; that is, annuals require the presence of a greater number of woodlots and woodlots closer to each other. In certain places (for example, areas with frequent fires, the presence of pests and other natural disturbances) perennial species can be more tolerant and therefore more widespread than annuals. On the other hand, annual species seem to be affected more drastically even by small runaway fires and even more vastly in the presence of larger fires.
Pollination interactions are altered by forest fragmentation. It has been found that a decrease in both population density and population size of plants, which is normally caused by fragmentation, can have profound effects on ecological interactions and population dynamics (Mustajärvi et al. 2001; Feldman 2006). The mutual interaction between plants and pollinators will be disrupted in small and isolated populations. Pollinator abundance decreases with decreasing habitat, which reduces the movement of genetic material from one woodlot to the next (Lundberg and Moberg 2003). Recent studies have concluded that in small isolated populations, there is insufficient transfer of pollen, eventually leading to lower seed set. Some other studies show that higher plant diversity is positively correlated with the visitation rates of both hummingbirds and insect pollinators (Mustajärvi et al. 2001).

In this study, the only significant species characteristic that increases plant species richness is insect pollination because insect-pollinated plants are more widespread than those that are not pollinated by insects or than any other form of pollination. There have been arguments on pollinator visits by animals to plants in patches of different sizes. Patch size has been found to either: increase, not affect or decrease plant reproduction (Feldman 2006). In this study, I assume that insects are more diverse than other pollination agents and thus visit more plants more often. Also because these forest fragments are not so isolated, they tend to be successful in pollination. Other studies have shown the importance of distance in pollination, but the question is: “How far can insects travel?” Studies like Townsend and Levey (2005) show that when the forest is continuous, insects can generally travel 1000 m but can only travel approximately 100 m into the matrix and into the nearby woodlot, thus showing a direct and inevitable effects
of forest fragmentation on insect pollination. This study area, however, is generally described as not being very isolated; most of the woodlots are not separated by more than 1000 m, which may explain why insect pollination has been very important in maintaining and spreading species.

On the other hand, pollination by birds or bats seems to be very limited, a possible outcome of low bird diversity as noted by locals. Furthermore, matrix composition and connectivity have been found to influence the dispersal, diversity, abundance and persistence of a variety of taxa including insects, birds and mammals (Anderson et al. 2007). But in this study, thirty-three (33 out of 36) of the target species were insect pollinated, reflecting the diversity and importance of insects in this area. It would be interesting to investigate the local reaction of insects to different anthropogenic processes such as the use of insecticides in the area.

Ordinations
Woodlot Characteristics

It is apparent that species composition is different in the three locations. For the Copper Bank area, species richness in the woodlots was determined by three variables: 1) older, 2) closer to Shipstern Nature Reserve and 3) farther away from papaya fields. The Stepwise regression shows that distance to Shipstern and distance to papaya are the most significant variables explaining the patterns of target species seen here. For this area, it is important that most men are fishermen. Furthermore, sugar cane is harder to cultivate and so the people of this area have allowed their forest stands to grow; thus they are older without significant anthropogenic disturbances. Furthermore, the papaya industry found
that this area is not feasible for the cultivation of papaya and as such it does not have
effects from such activity. These variables however, were opposite in the San Narciso
area. Woodlots were generally younger, farther from Shipstern and there are more papaya
fields in the area.

Species Characteristics
The most significant variable that determined the patterns of species richness within
the area is that most of the target species were insect pollinated. The only three plants
that were not insect pollinated were found in the Copper Bank area suggesting the wider
availability of pollinators, which have decreased in the other two areas. Thus, the overall
patterns suggest the importance of protecting the populations of insects. Plants were more
widely distributed when they were perennials and not bird pollinated for Axis 2. Insects
seem to have been present over the whole area and have been significantly important in
pollinating target species maintaining and making these species persist within woodlots.
V. CONCLUSION AND RECOMMENDATIONS

Conclusion:

In this study, the species composition varied according to location because of different landscape characteristics. The area with highest species richness was the Copper Bank location. The variables that accounted for this result were the strong correlations among woodlot age, size, proximity to older woodlots and closeness to Shipstern Nature Reserve. Woodlots in the Copper bank location were thus older, larger, and closer to Shipstern Nature Reserve thus making woodlots in the whole area closer to each other especially where woodlots were normally closer to older woodlots. This data suggests that there is a wider diversity of pollinators in this area in comparison to the other two locations. This spatial configuration and diversity of pollinator accounted for the most number of species present in woodlots in this study. Interestingly the agent for dispersal of seeds was not significant in this study.

On the other hand, the species composition of targeted plants in the San Narciso location was determined by the presence of younger woodlots recovering from former agricultural lands. The woodlots are separated more because agricultural practices as in the case of sugar cane and papaya cultivation has been occurring at a larger scale in this area. The cluster of woodlots is further away from Shipstern Nature Reserve, which could
potentially be a rich source of seeds and pollen. This area was highly characterized by having all plants that are insect pollinated suggesting the lack of other forms of pollination. In the Santa Elena area, the species richness increased in comparison to the San Narciso location and it is because woodlots were not as widely separated, there were more older forests in the area and agricultural practices was not as widely practiced. All these results suggest the importance of conservation and the lack of conservation interest within the Corozal district.

Economics of the Corozal District

Belize is a developing country where the socio-economic conditions play a central role in spreading, halting or slowing fragmentation. Increasing the population requires expansion of the residential and agricultural areas, which leads to a decrease in forest cover (Butler et al. 2004). In 1993, the population estimation for the country of Belize was 203,957 (Belize Gifts 2006) whereas in the July estimate 2007, the population is 294,385, a 45% increase. Especially in the northern part of Belize, farmers require more land for the cultivation of sugar cane. Moreover, the people of Corozal have relied on three industries lately: fisheries for most men in the eastern part along the coast of Corozal, sugar cane and papaya for the remaining majority population of the Corozal district. Belize is almost completely dependent on the production of sugar and papaya for its economic existence. Obviously, there is a need to establish an alternative industry for Belize, one that is not so dependent on intensive use of an agriculture space. The two leading industries, sugar cane and papaya production, require clearing more woodlots to
meet the increasing demand. Lands formerly used to grow can are planted in papaya, leaving no opportunity for the spaces to recover.

Belize is well-known for setting aside protected areas and which at least 41% of its territory is under protection, which is a clear indication of the presence of pristine and untouched ecosystems, containing spectacular natural wonders and beauty. Belize’s natural treasures can serve as an alternative source of income for Belize. In the northern part of Belize, there is a wide array of sources. Tourism and cultural history can generate income for the locals as well as the government. For instance, the past cultural history for the northern part of Belize, including the Mayan ruins, can generate income to improve the living standards of most people, whereas agriculture alone can no longer do it. I heard many complaints on behalf of farmers who, themselves, told me that the sugar harvest is not enough to keep the process of production going because the price of the product is lower and the cost of production has been going higher. And if the previous statement is true, Belize’s leaders need to look for alternative industries.

Success stories attest to the potential that Reserves hold for improving the economic well being of Belizeans. For example in the Shipstern Nature Reserve, people of the village of Sarteneja, which is just a couple of kilometers away, sell artifacts and locally produced craft items to tourists. The designation of protected areas can, therefore, serve Belize in two important ways: 1) protecting the natural environment and 2) helping communities generate family income. Belize’s continued heavy dependence on farming has serious implications for further degrading its biodiversity. Any effort to shift the economy toward tourism and other industries that are not dependent on agriculture should be encouraged.
It has been shown that the dynamics within forest areas in the Corozal district have been disrupted by nearby agricultural practices. This study has explored the dynamics of forest cover, agricultural spaces, and forest fragments in the Corozal district of Belize. Many of the results are inconclusive, suggesting the need for further investigation, especially of those vectors that are interrelated, of which there are many.

Constraints

Ecological history of the woodlots was lacking or did not exist. I obtained some of the history by speaking directly with the landowners, lessees and neighbors. It is still uncertain how and when these woodlots were originally formed and, most importantly, what kind of species composition they had decades ago. “Historical ecology” is a view that shows ecosystems as open systems to human inputs, not only spatially, but also historically (Lunt and Spooner 2005). Understanding past activities in the landscape can provide insight into patterns we now see in the landscape. However, reconstructing the history of the study areas was, and will continue to be, extremely challenging. For example, I could not find a map of the study area showing the percentage of forest cover for any period of time in the 20th century.

Time allowed for this study was a limiting influence. Due to limited time, I selected only 36 target plants and 19 woodlots. I was unable to fully explore the distribution of small patches. Hopefully, the patterns observed for the study sites are predictive of patterns of species richness and distribution within the Corozal district. The patterns I observed, however, may be capable of being extended to the whole
configuration of woodlots because there seems to be little variation within the study area in physical characteristics: age, size, elevation and temperature.

Furthermore, there are few experts who have done research in this part of the country, analyzing the distribution of species within fragmented woodlots. I commend Dr. Jan Meerman for his dedication to understanding and explaining the dynamics of the forests in the Corozal district. And, most importantly, I encourage other Belizeans to follow his example. It is and will be very important to understand forest dynamics in the Corozal district, in particular the role that we play in structuring habitats as we convert new land for agricultural use.
Table 1: Results of soil analyses obtained from two sources: a commercial laboratory in Florida and Dr. Thomas Rooney laboratory. Only site 11 (San Narciso location) had lower organic matter and slightly higher pH. Site 13 (Copper Bank location) soils had lower clay content and higher sand content.

<table>
<thead>
<tr>
<th>Site 1</th>
<th>Site 6</th>
<th>Site 7</th>
<th>Site 10</th>
<th>Site 11</th>
<th>Site 12</th>
<th>Site 13</th>
<th>Site 18</th>
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<tr>
<td>Organic Matter %</td>
<td>7.7</td>
<td>5.1</td>
<td>7.2</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>P1 Weak Bray ppm</td>
<td>3 VL</td>
<td>4 VL</td>
<td>4 VL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P2 Strong Bray ppm</td>
<td>9 VL</td>
<td>19 L</td>
<td>5 VL</td>
<td></td>
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<td>110 VL</td>
<td>140 L</td>
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<tr>
<td>Magnesium</td>
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<td>260 M</td>
<td>390 H</td>
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<td>Calcium ppm</td>
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<td>5880 VH</td>
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<td><strong>Percent Base Saturation</strong></td>
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<td>% Mg</td>
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<tr>
<td>% H</td>
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<td>Sulfur ppm</td>
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<td>993 H</td>
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<td>Zinc ppm</td>
<td>11.2 VH</td>
<td>1.4 L</td>
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<td>Manganese ppm</td>
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<td>Iron ppm</td>
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<td>Copper ppm</td>
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</table>

**Code to Rating**

- Very Low (VL)
- Low (L)
- Medium (M)
- Very High (VH)

Soil Analyses tests for woodlots 6, 11, 13. The soils were analyzed at the A & L Southern Agricultural Laboratories, Inc in Pompano Beach, FL on the 11th of August 2006.

Soil type %

| Clay % | 76.25 | 78.75 | 76.25 | 78.75 | 60 | 62.5 | 42.5 | 45 |
| Sand % | 10 | 10 | 10 | 10 | 23.75 | 21 | 45 | 41.25 |
| Silt % | 13.75 | 11.25 | 13.75 | 11.25 | 16.25 | 16.5 | 12.5 | 13.75 |

Ash Content %

- 92.3
- 94.9
- 92.8

Analyses done in Dr. Thomas Rooney Laboratory, Associate Professor, Biological Sciences, Wright State University.
Table 2: Kolmogorov-Smirnov test comparing the stems at DBH of all four woodlots to each and other. All woodlots are significantly different from each other at 0.05 significance level.

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<th>n2</th>
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<td>256</td>
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<td>0.117</td>
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<td>1,13</td>
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<td>7,11</td>
<td>0.167</td>
<td>0.122</td>
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<td>7,13</td>
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<td>0.127</td>
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<tr>
<td>11,13</td>
<td>0.171</td>
<td>0.129</td>
<td>243</td>
<td>206</td>
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Figure 1: Monthly Average rainfall for Consejo and Libertad Weather Stations, Corozal District for the period 1992-2003.
Figure 2: Monthly Average temperature for the Corozal district, Belize for the period 1992-2002.
Figure 3: The country of Belize. The red square shows the study area in the Corozal district.
Figure 3: Map of Belize showing project/research sites in the Corozal District. Taken by Google Earth on 2007 and plotted by David Rankin using coordinates obtained on site.
Figure 4: Distribution of stems at diameter breast height (DBH) for the four woodlots. Note that for woodlot 7, even though, it is an older woodlot, the number of stems <3 cm is high. That is because local people seeking firewood had disturbed 2 plots within this woodlot.
Figure 5: Species richness for woodlots of different age classes (Mean + SE) for each region and overall.
Figure 6: Species richness in relation to size and age of woodlots.
Figure 7: Species richness per woodlot and the distance of the woodlot to Shipstern Nature Reserve.

\[ y = 858.62x^{-1.3168} \]

\[ R^2 = 0.6019 \]
Figure 8: species richness and distance to sugar cane fields.

\[ y = 15.157x^{0.0423} \]
\[ R^2 = 0.1059 \]
Figure 9: Species richness and distance to papaya fields.

$y = 12.353x^{0.0463}$

$R^2 = 0.1545$
Figure 10: species richness and woodlot’s proximity to each other woodlots.

\[ y = 24.231x^{-0.1347} \]

\[ R^2 = 0.4559 \]

\[ \text{Number of Species} \]

\[ \text{Distance to closer fragment} \]
Figure 11: Species composition within the three locations is apparent. Copper Bank (W13-19) has high Axis 1 values. Axis 1 values are associated with older woodlots and woodlots closer to Shipstern Nature Reserve. Santa Elena (W1-W6) had low values on Axis 1 but high values on Axis 2. San Narciso had low values for both Axes. Axis 2 was not related to any variable.
Figure 12: Ordination graph showing the number of species pollinated and not pollinated by insects. Note that the three species that were not insect pollinated have high Axis 1 values. These high values are associated with the Copper Bank area, thus these plant species not pollinated by insects are found in the Copper Bank area.
Figure 13: Ordination graph showing the distribution of plant species according to lifespan and pollination agent. Targeted species had higher Axis 2 values when they were perennials and were not bird pollinated.
Appendix 1: chart shows the distribution of sizes, ages, elevation and location of the 19 woodlots. Note that in the statistical analyses, the description of woodlot age and size were coded in the following way: Younger and smaller = 1, Medium-aged and Medium-sized = 2, Older and Larger = 3.

<table>
<thead>
<tr>
<th>Woodlot # and location</th>
<th>Woodlot age description</th>
<th>Approximate age</th>
<th>Woodlot size description</th>
<th>Size (ha)</th>
<th>Elevation</th>
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</tr>
<tr>
<td>1</td>
<td>Medium-aged</td>
<td>25-30 years</td>
<td>Medium-size</td>
<td>8</td>
<td>15.8</td>
</tr>
<tr>
<td>2</td>
<td>Younger</td>
<td>10-15 years</td>
<td>Smaller</td>
<td>2</td>
<td>10.9</td>
</tr>
<tr>
<td>3</td>
<td>Older</td>
<td>&gt;40 years</td>
<td>Larger</td>
<td>20</td>
<td>10.8</td>
</tr>
<tr>
<td>4</td>
<td>Older</td>
<td>&gt;30 years</td>
<td>Smaller</td>
<td>2</td>
<td>14.9</td>
</tr>
<tr>
<td>5</td>
<td>Medium-aged</td>
<td>15-20 years</td>
<td>Smaller</td>
<td>4</td>
<td>18.9</td>
</tr>
<tr>
<td>6</td>
<td>Medium-aged</td>
<td>15-20 years</td>
<td>Smaller</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>San Narciso</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Older</td>
<td>&gt;30 years</td>
<td>Medium-sized</td>
<td>7.4</td>
<td>9.1</td>
</tr>
<tr>
<td>8</td>
<td>Older</td>
<td>&gt;30 years</td>
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<td>4.6</td>
<td>14</td>
</tr>
<tr>
<td>9</td>
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<td>Smaller</td>
<td>2.7</td>
<td>7.9</td>
</tr>
<tr>
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<td>10-15 years</td>
<td>Smaller</td>
<td>4.4</td>
<td>10</td>
</tr>
<tr>
<td>11</td>
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<td>5-10 years</td>
<td>Larger</td>
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<td>15.8</td>
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<tr>
<td>15</td>
<td>Older</td>
<td>&gt;100 years</td>
<td>Larger</td>
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<td>Smaller</td>
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<td>13.1</td>
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<td>Larger</td>
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<td>20 years</td>
<td>Medium-sized</td>
<td>5.12</td>
<td>10.9</td>
</tr>
</tbody>
</table>
Appendix 2: Scientific names and family names for the 36 target species used in this research.

**Agavaceae**
*Agave americana L.*

**Apocynaceae**
*Stemmadenia donnell-smithii (Rose) Woodson*

**Asteraceae**
*Artemisa mexicana* Willd. Ex Spreng.
*Chromolaena odorata* (L.) R.M. King & H Rob
*Neurolaena lobata* (L.) R. BR. Trans. Linn. Soc
*Syngonium podophyllum* Schott
*Thevetia ahouai* (L.) A. DC. Juss. Ex Aubl.Pl.
*Wedelia trilobata* (L.) Hitchc.

**Boraginaceae**
*Heliotropium indicum* L.

**Caesalpiniaaceae**
*Caesalpinia pulcherima* (L.) Schwartz

**Caricaceae**
*Carica papaya* L.

**Cucurbitaceae**
*Momordica charantia* L.

**Euphorbiaceae**
*Acalypha arvensis* Poepp. & Endl.
*Cnidoscolus souzae* Mc Vaugh, Bull
*Euphorbia pulcherrima* Willd. Ex Klotzsch
*Ricinus communis* L.

**Fabaceae**
*Desmodium adscendens*
*Mimosa pudica* L.

**Lamiaceae**
*Hyptis suaveolens* (L.)
*Urera baccifera* (L.) baccifera
Loganiaceae

Lygodiaceae
_Lygodium venustrum_ Sw. J. Bot (Shrader)

_Malvaceae_
_Sida rhombifolia_ L.

Piperaceae
_Piper aduncum_ (L).
_Piper amalago_ (L.)
_Piper peltatum_ (L.)

_Rosaceae_
_Rubus fagifolius_ Schltdl & Cham.

_Rubiaceae_
_Hamelia patens_ Jacq. var. patens
_Morinda royoc_ (L.)

_Smilacaceae_
_Smilax munda_ Killip and Morton

_Solanaceae_
_Acnistus arborescens_

_Verbenaceae_
Lantana camara L.
_Priva lappendaceae_ (L.) Pers.
_Stachytarpheta cayennensis_ (L. Rich)

_Zamiaceae_
_Zamia polymorpha_ D.W. Stev., A. Moretti & L. Gaudio
Appendix 3: Table showing raw data collected for the number of species ranked into three categories in June of 2006. The numbers assigned is as follows: 0= absent, 1= present, 2= common and 3= abundant.

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<tr>
<td>Ricinus communis</td>
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</tr>
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<tr>
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<td>Acalypha arvensis</td>
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</table>
Appendix 4: Raw data used for the statistical analyses. Note that these numbers were also ranked for the other part of analyses where the ranks of these variables were associated with the species frequency and among other variables.

<table>
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<tr>
<th>Woodlot No.</th>
<th>Woodlot age</th>
<th>No. of species</th>
<th>Distance to closest fragment (m)</th>
<th>Distance to shipstern nature reserve (miles)</th>
<th>Distance to ocean (miles)</th>
<th>Proximity to Papaya farm</th>
<th>Proximity to Pasture (m)</th>
<th>Presence of Stream</th>
</tr>
</thead>
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<tr>
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.= absent  1= absent  2= present
Appendix 5: Codes used for statistical analyses. This information was also ranked for statistical analyses. Note that 0 = absent and 1 = present for the other variables. A period (.) means that information is still unknown.

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<th>Life Form</th>
<th>WindP</th>
<th>BirdP</th>
<th>InsectP</th>
<th>BatP</th>
<th>Present in matrix</th>
<th>Berry/Drupe</th>
<th>Other Fruit</th>
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1 = edge, 2 = interior, 3 = perennial, 1 = annual, 2 = biennial, 3 = self, 0 = absent, 1 = present, 0 = unknown.
Appendix 5 (continued): Codes used for statistical analyses. This information was also ranked for statistical analyses. Note that 0= absent and 1= present for the other variables. A period (.) means that information is still unknown.

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<th>Freq</th>
<th>Life</th>
<th>Seed Displ.</th>
<th>Life Form</th>
<th>WindP</th>
<th>BirdP</th>
<th>InsectP</th>
<th>BatP</th>
<th>Present in matrix</th>
<th>Berry/ Drupe</th>
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1=edge 1=annual 1=animal 1=herb 0=absent 0=absent 2=interior 2=biennial 2=wind 2=shrub 1=present 1=present 3=perennial 3=self 3=vine .unknown .unknown
Literature cited:


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