

THE IMPACT OF HUMAN PRACTICES ON FOREST REMNANTS:
PEOPLE AND CONSERVATION IN A SMALL NATURE RESERVE
IN WESTERN NICARAGUA

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THE IMPACT OF HUMAN PRACTICES ON FOREST REMNANTS:
PEOPLE AND CONSERVATION IN A SMALL NATURE RESERVE
IN WESTERN NICARAGUA

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Given the practical difficulties to manage large protected areas in poor countries, the present study addresses the possibility of preserving small forest remnants by involving local actors in their management. The study area embodies the highlands of the volcanic complex “Chonco-San Cristóbal-Casitas” in western Nicaragua, where a Nature Reserve was established in 1983 with the aim of protecting the remaining patches of deciduous dry forest. The methodology included aerial photography interpretation to evaluate changes in forest cover during the past four decades, interviews of the forest holders to how they value and manage the forest, and forest samples on their properties to assess the state of species diversity. The findings revealed a clear trend of forest reduction and fragmentation over the past decades, and a significant alteration of tree species composition in the remaining forest stands due to human-caused fires and selective logging. When these disturbances are moderate and infrequent, they prevent the best competitors from dominating the other tree species, thereby enhancing species diversity in the forests. A careful exploitation of woods might hence contribute to their preservation. A series of recommendations are put forward to motivate

peasants and coffee farmers to manage species diversity, since they are the two main forest owners in the Nature Reserve.

Dedication

To the peasants buried by Hurricane Mitch's landslide
in the flanks of the Casitas volcano.

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Introduction

The establishment of large protected areas where human presence is minimized has been considered the main means to protect biological diversity from the rapid rate of habitat destruction and species extinction caused by human beings (Brandon 1995, Green and Paine 1997). However, the attempt to set aside natural areas excluding people from access to natural resources has brought about many practical problems. In Central American countries, where poverty and social inequalities foster pressure on natural resources, the enforcement of the protection of large Biosphere Reserves has been very difficult. Various human groups “invade” the protected areas to exploit the lands and make their living. Governments lack the force, the resources, and even the interest to remove these people from the reserves and guarantee forest conservation. Protected areas thus become “paper parks” (Utting 1993, Barraclough and Ghimire 1995).

On the other hand, little attention has been paid to the conservation potential of small forest fragments mixed within intensely humanized landscapes. The management of forest patches could contribute to complementing and expanding the conservation activities implemented in larger areas (Turner and Corlett 1996), and to involve and motivate the people in the sustainable management of forest habitats. Local populations may realize that they can improve their livelihoods by preserving wider forest diversity, thus feeling more engaged in forest conservation (Wood 1995, Badola 1998).

This research aims to find out why and how various farmers and local actors manage the forest patches on their lands, and to understand the implications of their management practices for forest diversity conservation in a small Nature Reserve in western Nicaragua. Based on the knowledge of their current forest management practices, this study assesses how to improve and modify their forest systems to achieve the goal of biodiversity conservation and improve the livelihoods of forest owners at the same time.

The protected area chosen for the study embodies the highlands of the volcanic complex “Chonco-San Cristóbal-Casitas,” where two main type of forests are found: a) the *broadleaf deciduous forest* characteristic of the fertile and relatively moist lands in the Pacific region, and b) the *pine forest* more typical of the acidic soils of the mountains in the northern region of the country. The research is limited to the study of the richer broadleaf forest. I analyzed how the different forest holders in the reserve (coffee farmers, peasants, and a local government) use and transform the forest extent and composition. The methodology included gathering and processing geographic information to evaluate changes in forest cover during the past four decades, interviews of forest holders to find out how they use and value the forest, and forest samples on their properties to assess the state of species diversity.

By investigating the link between forest use and forest conservation, I hope to make a modest contribution to achieve the stated goal of the protected area, which is conserving the forest through its sustainable management.

I. Conservation of forests in a humanized landscape: a review of the literature

1. The problems regarding the management of large reserves

According to the classical equilibrium theory of island biogeography developed by McArthur and Wilson in the late 1960's, forest patches scattered in the middle of a deforested landscape can be compared to oceanic islands surrounded by seawaters that limit the species dispersal from the "mainland" source (the large non-fragmented forest) to the islands. In this model, the rate of species extinction and colonization is associated with two main factors: the size of the forest "island" and the distance separating the island from the mainland source. The larger the island, the lower the rate of species extinction, since there is a larger area for the species population to persist and wider variety of habitats to which they can adapt. The closer the forest patch to large masses of compact forest, the higher the rate of species colonization, since it is easier for the species to "jump" across a short gap of hostile environment than to undertake a long trip across an unfriendly landscape (MacArthur and Wilson 1967).

The practical application of this theory for the design of protected areas pursuing biological conservation is the need to establish the largest and best-interconnected reserves possible, in order to preserve the greatest species diversity. Human intervention should be avoided, thus preventing the fragmentation and deterioration of the last large "untamed" forests remaining. This idea has inspired

the design of large protected areas with minimal human presence around the world, as the cornerstone to save biodiversity (Brandon 1995, Green and Paine 1997). In the International Union for the Conservation of Nature (IUCN) classification system, these large and most restrictive protected areas are embodied in categories number I and II¹, which account for 44% of the total extent of world's protected lands (Table 1).

Table 1. Global protected areas network classified by IUCN management category

IUCN management category	Number	%	Extent (km ²)	%	Mean size (km ²)	% of total land area
Ia: Strict Nature Reserve	4,389	14%	978,698	7%	223	0.65%
Ib: Wilderness Area	809	3%	940,360	7%	1,162	0.63%
II: National Park	3,384	11%	4,001,605	30%	1,183	2.67%
III: Natural Monument	2,122	7%	193,021	1%	91	0.13%
IV: Habitat / Species Management Area	11,171	37%	2,459,703	19%	220	1.64%
V: Protected Landscape / Seascape	5,578	18%	1,057,448	8%	190	0.71%
VI: Managed Resource Protected Area	2,897	10%	3,601,440	27%	1,243	2.40%
TOTAL	30,350	100%	13,232,275	100%	4,312	8.83%

Source: Green and Paine 1997.

¹ In the IUCN classification system, categories with lower numbers represent protected areas where the use is most restrictive, while the higher numbers correspond to management categories with greater human influence. In addition, each category has been established for specific purposes, indicated in their names (Wilderness Area, National Monument, etc).

In Central America as well as in other underdeveloped regions, the significance of large restrictive protected areas is also remarkable. Several Biosphere Reserves and other types of large protected areas were set up during the 1980's and the early 1990's along the seven countries that conform the Central American isthmus. The most important Biosphere Reserves are the Maya reserve in Guatemala (15,000 km² in extent), Sierra Las Minas in Guatemala (8,000 km²), La Amistad across the border between Costa Rica and Panama (6,227 km²), Darien in Panama (5,790 km²) and Rio Platano in Honduras (5,227 km²). Although not classified as Biosphere Reserves, there are two other large reserves in Nicaragua, Bosawas Natural Resources Reserve in the northern part of the country (8,000 km²) and Indio-Maiz Biological Reserve (2,950 km²) (Herlihy 1997). Most of these large protected areas were designed according to a model in which there is a nuclear or core area where human use of natural resources is prohibited. Surrounding this nucleus of absolute preservation, there is a "buffer zone" where some regulated human activities are permitted, but whose main goal is to contain the people from moving into the core area. Outside the buffer zone, finally, there is the humanized world, where conservation is considered rather difficult.

This conservation model based on the exclusion of people from large areas has faced many problems when it is implemented in practical conditions. In fact, many of the reserves have been established in areas already inhabited by human groups, sometimes for centuries. When governments announce that the use of the

forests will be restricted, the local residents react with anger and distrust. They continue exploiting the forest resources, sometimes even more intensely, fearing that government officers will soon ban access to the forest. Governments usually do not have the power, the resources, or the interest to evict people from protected areas. When governments attempt to prevent the use natural resources in protected areas, they tend to increase the insecurity and fear among the forest users (Utting 1994, Barraclough and Ghimire 1995, Barborak 1992).

Insecurity and conflicts with local populations have been common problems in protected area management throughout Central America in the past two decades. The Bosawas Reserve in northern Nicaragua was created in 1991 without consulting the Mayangna indigenous group that has inhabited the area for centuries. When the Mayangna people realized that the government had set up a Reserve in which the use of natural resources was going to be restricted, they felt threatened that they might lose their rights to freely fish, hunt and farm on their customarily-owned lands. They got very upset and mistrusted any later governmental proposition (Howard 1998). In the early 1990's, the Costa Rican agency in charge of the administration of the National Parks was supposed to remove the private owners from the lands declared protected areas, and compensate them with new lands or employment in other places. However, the government lacked both the force to expel the private owners from the parks, and the money to compensate them. Many poor peasants removed from the protected areas decided to resettle in

the lands adjacent to the reserves. When pressure upon the land became too acute, the peasants invaded the parks again (Utting 1993). In the 1980's, Honduras increased significantly the number of protected areas, so by the early 1990's there were near 50 reserves covering 22% of the national territory. Nevertheless, only in 5 out of the 50 protected areas a management plan had been designed. The protection of the numerous reserves was ineffective. The more than half a million hectares of the Rio Platano Biosphere Reserve were administered by only 12 governmental employees, and little had been done to involve the indigenous and peasant communities in the sustainable management of the ecosystem (Utting 1993, Richards 1997).

The exclusion of people from the forests usually backfires against conservation. When local people feel that they can no longer obtain concrete benefits from the protected forests, they lose any interest in forest protection. They even become hostile to conservation activities, and start behaving in a more destructive way in order to get "as much as we can" before the prohibition begins to apply and closes all access to the forest resources (Utting 1993). In addition, by separating the people from the forest, we miss the local knowledge about native plants and animals that can be used for *in situ* conservation (Wood 1995). In summary, the model of biological conservation through large protected areas from which people are excluded seems impractical and even counter-productive in Central America.

2. The importance of forest patches management

Although environmentalists still advocate the need for maintaining and expanding large reserves with minimal or no human use as the most important instrument for biodiversity conservation (Brandon 1995), they also recognize the importance of promoting conservation outside the large protected areas through the management of smaller forest patches scattered in the fragmented landscape (Turner and Corlett 1996). As shown in Table 1, smaller protected areas classified as Habitat / Species Management Area (IUCN category number IV) and Protected Landscape / Seascape (category number V) also account for a significant percentage of the total protected world lands (27% considering both categories). These categories are less restrictive than the first ones, allowing the human use of natural resources in a regulated way. The goal is to match the conservation of habitat and species diversity with the economic needs of local populations. If we look at the protected areas in Central America (Table 2), we can also appreciate the weight of these less restrictive categories in the regional network. Putting together categories number IV (Habitat / Species Management Area) and VI (Managed Resource Protected Area), less restrictive management types total 41% of the protected lands in the isthmus. It is also noticeable that even the strictest preserved areas have a mean size under the 500 km², which indicates the presence of smaller patches in those categories.

Table 2. Protected areas in Central America according to IUCN categories

IUCN Category	Name	Number	Area (Km ²)	%	% of total land	Mean size (Km ²)
Ia/Ib	Strict Nature Reserve / Wilderness Area	26	11,430	13%	2.11%	440
II	National Park	78	29,383	34%	5.41%	377
III	National Monument	27	9,591	11%	1.77%	355
IV	Habitat/Species Management Area	163	14,150	16%	2.61%	87
V	Protected Landscape/Seascape	9	54	0%	0.01%	6
VI	Managed Resource Protected Area	81	21,441	25%	3.95%	265
TOTAL		384	86,049	100%	15.85%	224

Source: Green and Paine, 1997.

Are these natural fragments relevant for biological conservation? Even though these patches do not hold the same qualities as the large undisturbed areas, their significance should not be dismissed. It is clear that vertebrate animals, mammals in particular, are unlikely to survive in a highly fragmented environment, however, forest patches may play an important role in the preservation of plants and invertebrates (Turner and Corlett 1996). Rainforest patches might provide refuge to species able to tolerate forest fragmentation, such as the hummingbirds in Brazilian Amazon or some frugivore vertebrates in Southern Mexico. Some neotropical migrant birds use the forest fragments as stepping stones where they feed and shelter during certain periods of the year (Turner and Corlett 1996). Patches containing primary forest may also be critical to recolonize secondary surrounding forests where the establishment of late successional species turns very difficult if there is no colonizing source nearby (Turner and Corlett 1996).

Further studies are needed to understand better the conservation potential of forest fragments, assessing the viability of small populations that might be tolerant to fragmentation under specific conditions. However, networking small protected forests may be a valuable strategy to shoulder conservation in larger undisturbed areas. Special attention should be paid to the influence of human disturbances in the configuration of mosaic landscapes. By regulating human practices such as burning, small-scale forest clearance and timber extraction, it might be possible to enhance old-growth forest patches and create secondary forest corridors joining them. At the same time, local people may make a better living obtaining a wider variety of forest products without abandoning their agricultural practices (Badola 1998, Shafer 1999).

In Nicaragua, besides the large reserves established in the early 1990's to protect the rainforests in the Atlantic region, many small protected areas have also been created, mainly in the already "deforested" Pacific and Central regions (Table 3 and Map 1). From the 61 Nicaraguan protected areas listed by the United Nations in 1997, 54 were medium to small reserves under the IUCN category number IV, which seeks to promote conservation by involving local people in natural resources sustainable management (World Conservation Monitoring Center 1992 and 1997). The Ministry of Natural Resources, in charge of the management of protected areas, is now concentrating its efforts and resources in the management of only a few (around 10) of the total protected areas that have been legally established.

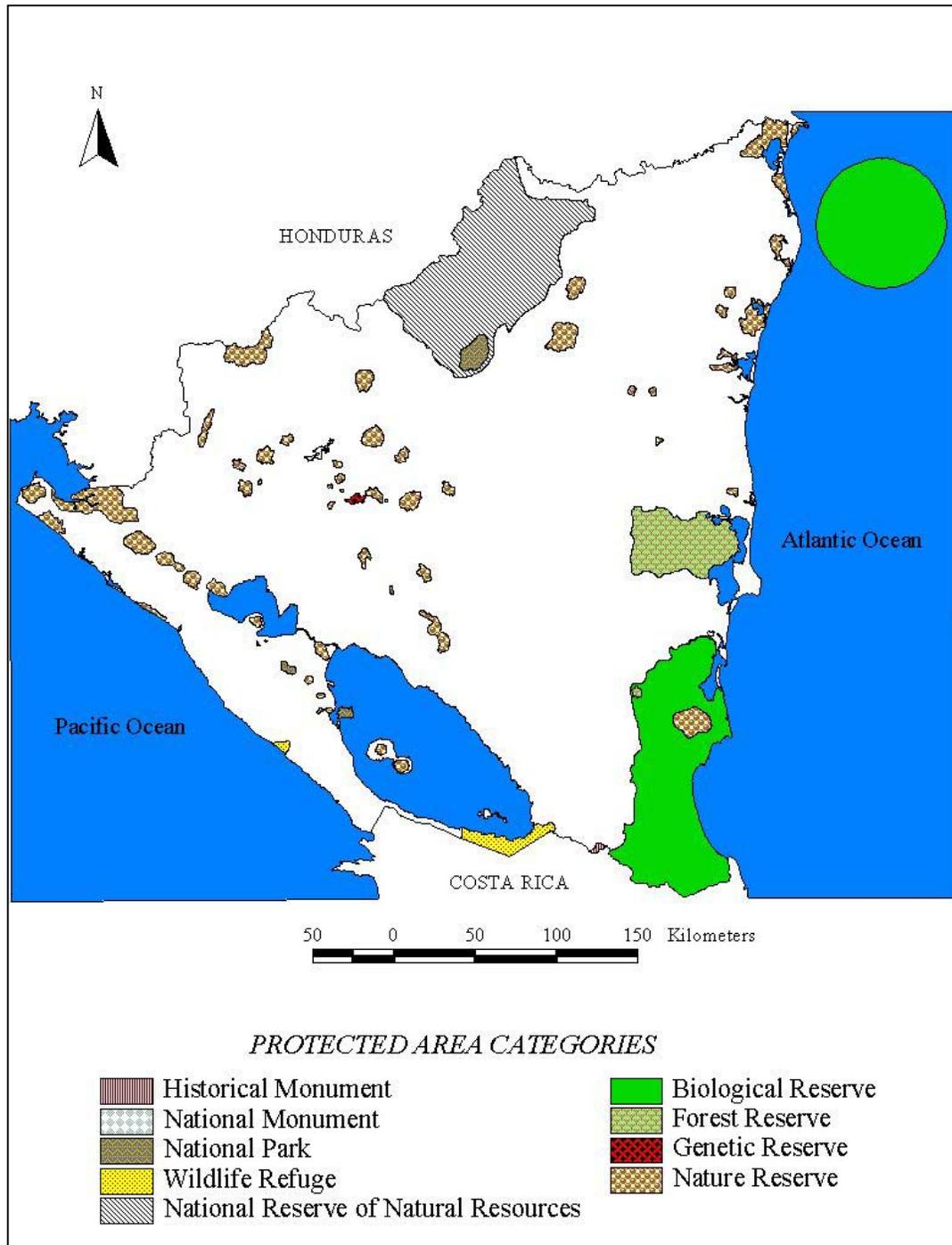
These areas prioritized for management programs are small reserves in the Pacific and Central slopes where local actors are active users of natural resources. My research will match this new interest in the conservation of small forested lands involving local populations by studying a Nature Reserve of modest size in the western region of the country.

Table 3. Brief description of National Protected Area Categories - Nicaragua

Category	Definition
Historical Monument	Area dedicated to protection of sites with historical, archeological and cultural values associated with natural features. Activities allowed: historical research and education, tourism and recreation.
National Monument	Extremely unique area with outstanding natural and cultural features, as well as scenic beauty, of national and international interest. Management activities include landscape restoration, environmental research and education, tourism and recreation.
National Park	Relatively broad and inhabited area, embodying habitats, landscapes and species of national and international importance. Allowed activities: scientific research, tourism, environmental education and recreation.
Wildlife Sanctuary	Area devoted to conservation and management of wild habitats and species. Management activities include species manipulation for scientific purposes, as well as use of natural resources for the benefit of local populations. Ecotourism is allowed under strict regulation.
Biological Reserve	Untamed area containing ecosystems and habitats of scientific value. This category is devoted to conservation of ecological processes and biodiversity. Low-impact ecotourism is allowed.
Nature Reserve	Area dedicated to conservation of landscapes, habitats, scenic beauty, biodiversity and cultural traits. According to a land use plan, management activities may include scientific research and education, tourism and local use of natural resources for the benefit of the community as well.
Genetic Reserve	Protected area devoted to preservation of habitats and species of high genetic value. Selective exploitation and enrichment of species is permitted, with the aim of improving genetic quality of natural resources.

Source: Ministry of Natural Resources and the Environment's calendar 2000.

Map 1. Protected Areas by National Categories - Nicaragua.



Source: GIS Department of the Ministry of Agriculture and Forestry (MAGFOR), Nicaragua.

3. How to preserve biodiversity in fragmented landscapes

Preservation of biodiversity has been stated as one of the main goals in natural resources conservation. The term has become so popular and so broadly used that it has lost its precise technical meaning (Barbour *et al.* 1999). Strictly, biological diversity refers to the number of species per unit area, technically named species richness. The term can also denote the diversity among complex units such as communities and ecosystems (Noss 1999). Preservation of this richness and variety of biological forms across the landscape is the subject to increasing concern both for the scientific community and the public.

Equilibrium models such as the island biogeography theory predict that low levels of species richness will be found in fragmented landscapes, since small and distant patches will not provide the best conditions for the species to colonize and maintain their populations. Several studies have empirically confirmed this correlation between small forest patch sizes and low levels of species richness. Simberloff and Wilson (1970, 1976) tested the island biogeography hypothesis by removing arthropod fauna from mangrove islands in Florida Keys, and studying the recolonization process. They found that islands closer to the species source were recolonized by a greater number of species, compared to distant islands. Iida and Nakashizuka (1995) found a negative correlation between patch size and species richness in suburban coppice forests in Japan. Nonetheless, these models and findings cannot be easily generalized for all the cases without looking at the

specific characteristics of species and ecosystems. Central American dry forests, for instance, have been largely cleared and reduced to a few small fragments, covering less than 0.1% of their original cover in the Pacific slope of the isthmus (Gillespie *et al.* 2000). A relatively high level of species diversity, however, was found when sampling a set of small protected areas in the dry region of Nicaragua and Costa Rica (Gillespie *et al.* 2000). No correlation was found between patch size and species richness. Environmental variables such as annual precipitation did not explain the differences either. Despite the variations in forest cover extension and key environmental factors, a great variety of species was found in relatively small areas, with different species combinations dominating at each place. These findings support the idea that many different species can coexist in small Neotropical dry forest areas, as it occurs in Neotropical humid regions. A large number of species seem to be adapted to survive in these conditions, and their distribution would be explained mainly by random events (Whitmore 1997).

Nevertheless, these hypotheses predicting either low or high species diversity in small forest fragments are still too mechanical and general, since they do not consider elements shaping forest dynamics such as species life's histories, their adaptive abilities and capabilities to face disturbances like fires, windthrow, logging and other human-caused alterations. Each tree is considered equal to all others, regardless of size, social position in the forest layer, ability to survive burnings, and other elements of its ecological behavior. Therefore, several authors

(Roberts and Gilliam 1995, Bengtsson 1997) call for the need of more research searching for those mechanisms that underlie forest structure and composition, instead of focusing on biodiversity per se. There is a lack of understanding on species ecology for the tropics in general and for Central American dry forests in particular. Although many people in Central America depend on dry forests to obtain key resources such as fuelwood, timber and medicines, very little information has been produced on biology, ecology and silviculture of native species (Sabogal 1992, Faurby and Barahona 1999). Thus, describing meaningful patterns of species diversity with such deficiencies of basic information is nearly impossible.

Besides the belief that forest fragmentation lessens species diversity, equilibrium models also propose that forests experiment a linear sequence of vegetation changes until they reach a climax or equilibrium stage, where species richness attains its maximum level (Roberts and Gilliam 1995). Any human disturbance, be it from logging, burning, cattle grazing, fuel wood gathering or any other activity, prevents the forest from reaching its equilibrium point and therefore lessens species richness. Nonetheless, other non-equilibrium models suggest that disturbances alter forest composition in a way that tree communities are in constant change and never reach a stable climax. Disturbances prevent the best competitors from dominating other species, thus creating opportunities for a wider variety of species to occupy the same area. If disturbances occur at a low to moderate

intensity, a balance among all species types is created, and species richness achieves its peak. This is known as the intermediate-disturbance hypothesis, proposed by Huston (1979). When disturbances are not moderate, but very frequent, wide and intense, a large proportion of species will be eliminated and it will be difficult to recover the former level of diversity. This is what happened in abandoned henequen plantations of Yucatan, Mexico, where secondary forests grew up after many years of exclusive henequen cultivation (Mizrahi *et al.* 1997). At the beginning, species richness increased as the woody vegetation developed, but after 26 years of growing a forest stand showed a very similar composition to that of another 12-year old plot. Late successional species were expected to appear in the oldest stands, but they did not emerge probably because there were no other tree individuals in close proximity that acted as seed sources (Mizrahi *et al.* 1997). Another example of alteration of forest composition due to the persistence of agricultural activities is presented by Foster *et al.* (1998) in their study on regional forest dynamics in central New England. After the expansion of agriculture in central Massachusetts during the colonial period, forests experienced a large recover in the 20th century mainly due to farm abandonment. The species composition of the new forest was considerably homogeneous throughout the region, in contrast with pre-colonial forest where species were more attached to environmental conditions. A long-term broad-scale disturbance has hence led to species homogenization throughout the study area (Foster *et al.* 1998).

Hence, the role of disturbances in shaping diversity and forest composition cannot be thought of in a simplistic way. It is necessary to know the specific type of disturbance, along with its frequency, intensity and range, in order to infer what the possible effects on forest diversity and composition are. Dense populations have settled in the Central American Pacific slope since pre-Columbian times, introducing important alterations to vegetation (Sabogal 1992). By the late 1990's, most of the original forests have been removed, leading to a deeply altered environment. There is little knowledge, though, about the characteristics of disturbances affecting the remnants of Central American dry forests. There is, for instance, very little and incomplete monitoring of fire frequencies on affected sections in small protected areas. Cattle graze in forested areas during the most difficult months of the dry season, and there is no understanding of this dynamic and its impact on forests. Other low-intensity human activities on forests are poorly understood, such as selective fuel-wood collection or selective logging for domestic purposes.

There is then very little understanding about both the nature of human-made disturbances and how tree species can react to these alterations. In order to preserve species richness of the Central American dry region and at the same time provide useful forest products to people relying on this natural resources, it is necessary to explore not only species richness per se, but also the factors shaping forest composition. Human activities appear to be one of these main factors.

II. Research question and study area

1. Research question

The central question this study addresses is how the main human groups residing in a small Nature Reserve in western Nicaragua contribute (or not) to the maintenance of broadleaf forest diversity, with an emphasis on conservation of late-successional tree species. Four specific aspects of this question will be considered:

1. What is the level of species diversity in the forest remnants? What is their forest composition and structure? What are the main factors that might explain such characteristics of the forests?
2. How do people transform the landscape mosaic? Are local populations contributing to forest fragmentation? What is the resulting landscape structure?
3. What practices do forest users, such as coffee farmers and peasant families, carry out that affect forest diversity in the remnant forest patches? Are they burning the forest for agriculture, selectively cutting timber or protecting small forest patches? In which ways and why?
4. How do human groups value forest diversity? What forest goods and services, such as timber, firewood and erosion control, do the people find valuable?

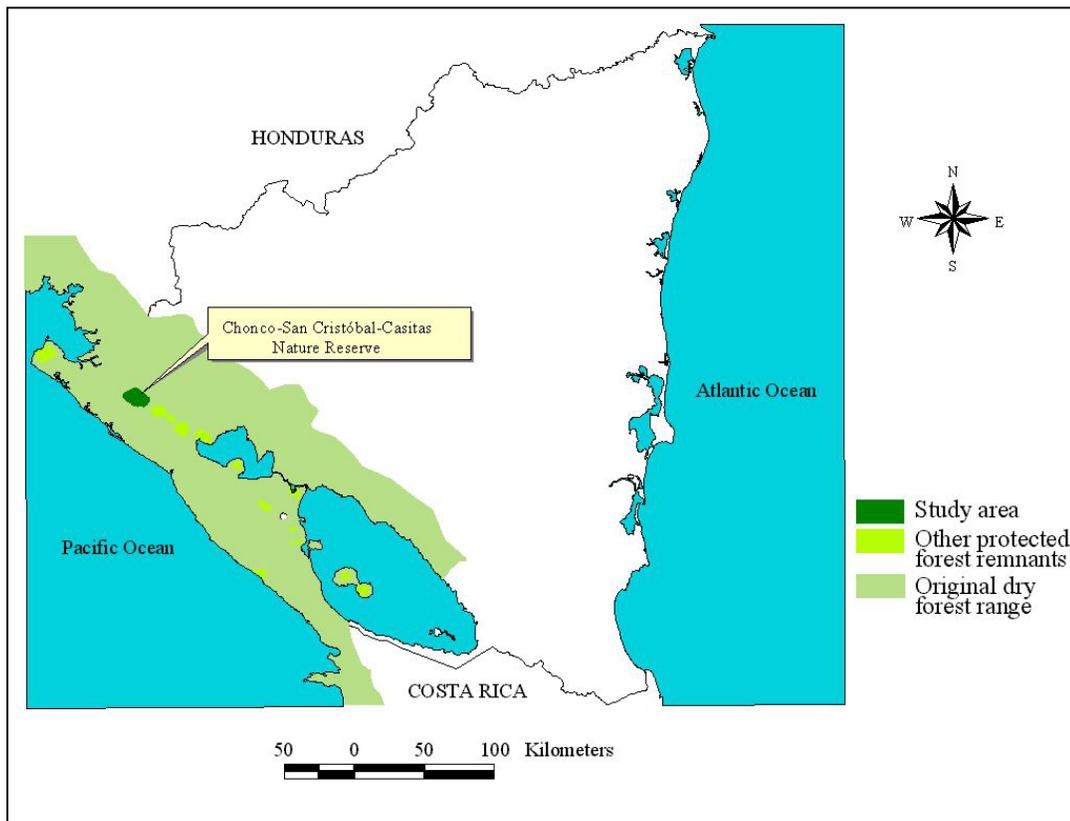
To answer these questions, the research will focus mainly on one of the two forest types found in the study area: the *deciduous broadleaf forest*. Since the broadleaf forest is more diverse in its composition and provides a wider variety of forest goods and services, ranging from firewood to shade for the coffee plants, it is more appropriate for the purposes of this study. I will limit the study to a rather small geographical area where the ecological conditions, such as predominant soil types, altitude, wind effects and other main factors, are similar, thereby focusing more on the impact of human practices on the ecosystem, controlling for ecological variation as much as possible. The variations in the ecological conditions of the forest will be due mainly to the characteristics of particular micro-sites within the study area such as edges and ridge tops retaining less moisture than concave sites.

The size of the specific study area should be small enough to guarantee ecological homogeneity, but large enough to include certain diversity of human inhabitants that represent at least some of the main residents in the Reserve.

2. The general study area: a small Nature Reserve in western Nicaragua

In order to address the problem of managing small protected areas surrounded by a highly humanized landscape, I have chosen for the current study a small reserve located on the volcanic chain that arises over the flatlands in western Nicaragua (Map 2).

Map 2. Location of the Study Area



Source: Based on Gillespie *et al.* (2000) and Arcview files from the Ministry of Agriculture and Forestry (MAGFOR).

This protected area was officially established in 1983 under the category of Nature Reserve, holding the highlands of three grouped volcanoes: “Chonco” (1,105 m.a.s.l.), “San Cristóbal” (1,745 m.a.s.l.) and “Casitas” (1,405 m.a.s.l.). The borders of the Reserve are defined by the 300 m.a.s.l. altitude line. All the lands above this limit are part of the protected area, accounting for a total area of 17,950 hectares, of which 60% falls in the “municipio” (administrative division similar to a county) of Chinandega. Two other municipalities, Chichigalpa and Posoltega, also cover part of the Reserve.

The area is located in the dry region extending along the Pacific slope. In this particular site the precipitation regime is relatively high (1400 to 1800 mm of rain per year) within the margins of the whole region, and the dry seasonality less marked (INETER 1997). This protected forest is a remnant of formerly widespread dry deciduous forests that extended throughout the Pacific region of Nicaragua. At present, however, the forests in the flatlands surrounding the Reserve have been cleared to take advantage of the fertile volcanic soils for agriculture.

The Chonco-San Cristóbal-Casitas Nature Reserve was established along with other similar protected areas created in the volcanic range that expands northward and southward, with the aim of protecting the remaining forests of the highlands from the agricultural pressure coming from the fertile lowlands. There

are two important ecosystems covering the flanks and tops of the three volcanoes (Cedeño 1987):

1. *The broadleaf deciduous forest* covers a significant area of the volcano flanks, and holds many of the native forest species typical of the dry forests of the Pacific region of Nicaragua. According to a forest report elaborated by Cedeño in 1987, 37% of the total Reserve area (around 6,600 hectares) was covered by closed forest, and there were another 700 hectares of coffee plantations preserving a forest canopy.
2. *The pine (*Pinus oocarpa*) forest*, scattered in small patches over 3,000 hectares of pastures in the highest areas of the San Cristóbal and Casitas volcanoes, represents the natural pine population that reached the southern limit of the species range (all pines planted in South America are introduced). The pine forest is not as widely distributed  the volcano flanks as the broadleaf forest is. The scope of the pine vegetation is limited to more acidic and sandy soils found only at the top of these two volcanoes, above the 700 m.a.s.l.

Although the highlands of the volcanoes have been declared a Nature Reserve, the remaining forests in the protected area are under strong pressure from nearby agricultural and pasture uses moving upward from the lowlands. During the 20th century, large entrepreneurs displaced traditional agriculture in the flats to

introduce export crops such as banana, sugar cane and cotton, forcing peasants to migrate either to the cities or to the highlands on the flanks of the volcanoes. Relatively wealthy landholders have also acquired properties in the highlands, some of them devoted to cattle raising, but most of them are engaged in coffee cultivation. Because of this gradual appropriation of the highlands, 85% of the lands within the Reserve are estimated to be in private hands. There are a variety of proprietors owning these lands, including large and medium farmers, individual and community peasants, agrarian reform cooperatives and State properties about to be privatized (Areas 1998). In theory, the State of Nicaragua is the holder of the remaining 15% of the Reserve lands that do not belong to a particular owner. However, several recent cases of private *de facto* appropriation of these “no man’s lands” have been reported, meaning that the historical trend of taking over the forested highlands has not stopped.

The various residents of the reserve and its surroundings modify the forest extent and composition according to their particular economic rationale. The main “users” altering the forest are (Barahona and Mendoza 1998):

- o Medium-sized farmers producing coffee in the flanks of the volcanoes.
- o Medium-sized cattle ranchers owning lands in the flanks of the volcanoes and in the lowlands.

- o Small-holder agricultural communities living in the flanks and at the foot of the volcanoes. There are also peasant cooperatives that received lands from the agrarian reform in the 1980's, owning small pieces of land.
- o Small-holder agriculturalists from the lowlands making temporary agriculture in the highlands.
- o Landless people from the lowlands who go to the forest to hunt deer and other smaller animals, and to collect honey.
- o The "San Antonio Sugar Refinery," which is developing *Eucaliptus* plantations in the piedmont of the volcanoes for fuel wood supply to power its thermoelectric plant.

Each of these local actors contributes to or threatens the conservation of forests in a particular way. While the coffee farmers tend to keep the forest canopy to provide shade to the coffee plants, the cattle ranchers prefer to clear the forest cover altogether to extend the pastures. In the middle of these two extremes, the peasant families hold a mosaic of agricultural lands mixed with patches of secondary forests. The outsiders coming from the lowlands (landless peasants, hunters and honey collectors) frequently affect the forests in the public areas by lighting fires that can easily spread to large areas. They do not clear the forest cover but probably have an impact on the structure of the ecosystem. However, it is very difficult to specifically identify who these outsiders are and monitor their practices

in the forest. Therefore, no studies have been done to document their impact on the forest composition and structure.

Although the management category of “Nature Reserve” chosen for the volcanoes, falling in the intermediate IUCN category number IV, recognizes the need to conserve the forest by involving the local actors in its sustainable management, very little research has been done to find out the impact of all these human practices on the forest composition and extent. The vegetation cover and the land use on the Reserve has been mapped and characterized in very general terms, often with a lack of accuracy and detail regarding the forest composition and the human practices influencing it. This aim of this research is precisely to know in more depth the state of the forest and to better understand the practices transforming it.

III. Methodology

In order to answer the research question in its four different aspects, it was necessary to combine diverse sources of information and apply various techniques of data collection and processing commonly used in scientific disciplines such as Geography, Ecology and the Social Sciences in general. The first step of my research work consisted of the collection of secondary sources of information about the study area, which provided a general understanding of its social and ecological features and helped me to define a narrower study area where to carry out the fieldwork. Once this specific study area was delimited, three main sets of data were collected and processed:

- a) *Geographical information*, consisting of maps and aerial photographs, was interpreted to identify main changes in landscape configuration.
- b) *Interviews of the owners* of those forest patches and other forested areas under similar management. This approach helps us to understand their rationale towards forests, and their forest management practices.
- c) *Samples of the woody vegetation* were carried out in various forest patches that resulted from different management regimes, in order to assess their forest diversity and composition.

Following, I will describe in more detail the steps I followed to collect and process all this information.

1. Gathering general information about land use and forestry in the Nature Reserve

I looked for secondary information on land use and forest management with the aim of defining a smaller area within the Reserve that captured a fairly homogeneous environmental setting but with different types of forest management and forest ownership. A report summarizing social and ecological characteristics of the region was prepared by Areas (1998) as a base for a future management plan of the Reserve. It contains, among other useful data, estimates of the extent and location of forest remnants, their species composition, and a list of the landowners in the Reserve. I interviewed several times the author of this report, William Areas, who knows the region very well and acted as a key informant. He provided great help to locate possible sampling sites and contact forest owners whom to interview.

I also looked for any other forest surveys done in the study area (Table 4). Most of them used different methodologies and correspond to samplings of small areas at different points in the volcano flanks. The following forest surveys were collected:

Table 4. Forest surveys carried out in the Chonco-San Cristóbal-Casitas Nature Reserve.

Site	Forest Description	Author	Year of Sampling
The whole Reserve	Areas with different characteristics	IRENA (Institute of Natural Resources and the Environment)	1986
“Las Banderas” coffee farm	Old-growth forest dominated by <i>Brosimum alicastrum</i>	Nicaragua Verde Foundation	2000
“S.C. Rojas” coffee farm	Old growth forest combining early and late successional species but with limited diversity	“Pikín Guerrero” Project	1996
“El Quebrachal” communal forest	Young forest, dominated by pioneer species	“Pikín Guerrero” Project	1995

2. Site selection

Based on the above information, I proceeded to choose a specific study area where to carry out the forest samplings and the interviews, trying to meet the following criteria:

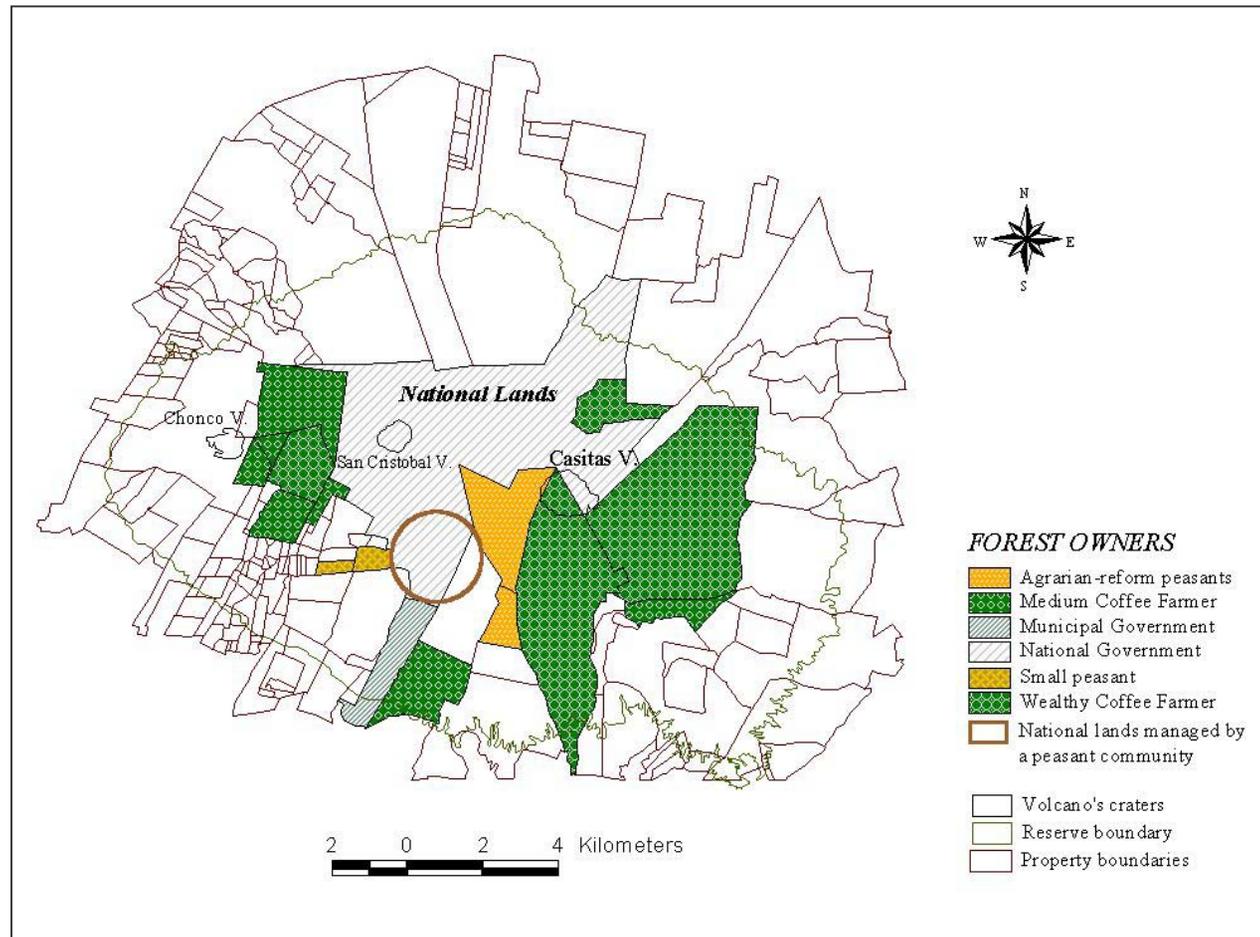
- o Its natural vegetation cover is broadleaf deciduous forest.
- o It is located within an altitudinal range between 300 m.a.s.l. (the line defining the boundary of the Reserve) and 500 m.a.s.l. This is the strip within the Reserve where the broadleaf forest is mostly found.
- o The soil types in the area are quite similar.
- o It is a small contiguous geographical area, not several different areas dispersed throughout the Reserve. This is important to maintain environmental similarities.
- o There is a certain level of human heterogeneity, including at least three broadly defined human groups.

The main problem I had when choosing the specific study area was to capture social heterogeneity in a relatively small area. Coffee farms extended over large areas, a few of them covering most of the area within the Reserve limits. To have samples from different coffee plantations, it was necessary to move among distant locations. In addition, other types of landowners such as small peasants, peasant cooperatives and the local government of Chichigalpa, were not always found close to the coffee farms. Hence, it was necessary to widen the study area in order to include properties belonging to various social groups.

I decided to work on a considerably larger area to capture this social diversity. I focused on the study of the Southern side of the three volcanoes, including areas within altitudes varying from 200 to 600 m.a.s.l. I chose the southern flank of the volcanoes because the main roads leading to the coffee farms, where the best-preserved old-growth forests are found. I also widened the altitudinal range to include some small peasant's properties in the low flanks and especially the public forest managed by the municipality of Chichigalpa. Because of this enlargement of the study area, environmental homogeneity was not fully assured, in particular regarding soil texture. In the highlands of the San Cristóbal, the youngest peak, soils were generally coarser than old soils in the Casitas' flanks. Topography in the Casitas slopes is more rugged than in San Cristóbal's. These environmental factors must be considered when explaining differences in forest composition among the various sites sampled.

I interviewed a diversity of forest owners and carried out a series of forest samples in various farm types (Map 3). As mentioned above, they are concentrated in the southern flank of the volcanic range, but spread over a relatively wide area. Coffee farmers are the best-represented group in the interviews. I visited the farms and/or interviewed almost all the owners of coffee plantations in the Reserve. I gave priority to this social group because they own most of the old-growth forest in the region. It was very difficult to find other type of farmers holding forested areas in their properties. Besides the coffee farmers, I found a municipal area managed by the local government of Chichigalpa, where there is an important patch of mature forest. In addition, the peasant community named “El Pellizco” manages a young forest in the San Cristóbal slope. Young forests are also found in the lands of individual peasants and cooperative members. However, some of these areas are still under a fallow cycle, being slashed and burned every few years, leaving little opportunity for the forest to regenerate. I was able to sample only one of the forests held by a small peasant, and interviewed relatively few people from this group. Therefore, this is the social group with the poorest representation in my study. According to Map 3, the properties involved in this study sum a total area of 89.8 km², corresponding to 50% of the total area in the Nature Reserve.

Map 3. Location of various forest owners in the Southern flank of the Ch-Sc-C Nature Reserve.



These data are based on information of the National Cadastre dating from the early 1960's (it has not been updated since that time), and some of the property boundaries have changed. Therefore, this figure should be taken with caution.

3. Analysis of land cover/land use through the comparison of aerial photographs from 1954 and 1996

With the purpose of appraising the evolution of forest remnants and the general configuration of the landscape through time, I interpreted and compared two sets of aerial photographs of the study area taken in 1954 and 1996. The scope and scale of the two series of photos differed. The 1954 photos were taken at a scale of 1:64,000 scale and cover a larger area that includes the agricultural flatlands near Chinandega city (to the Southeast of the Reserve). The 1996 photos are displayed at a scale of 1:40,000 and their scope is limited to a narrower area mainly in the Southern flanks of the three volcanoes.

The two sets of aerial photos were scanned and georeferenced using the Image Analysis extension of ArcView GIS, so they can overlie as layers. Looking at the rectified photos in the computer, I digitized the different vegetation patches and elaborated a map of land cover/land use for each year. Next, I overlaid the two land cover maps and identified the main changes within the area where the two sets of photos intercept.

4. Semi-structured interviews of the forest owners

In order to find out how the different human groups value and use the forests, I carried out semi-structured interviews of a series of forest owners representing the social diversity found in the Reserve (Table 5).

Table 5. Interviews of different forest owners (Ch-Sc-C Nature Reserve)

Social group	Persons interviewed	Total number of persons*
Wealthy coffee farmers	3	3
Medium coffee farmers	8	10
Peasant community	6	23
Individual peasants	3	6
Cooperative members	8	32
Municipal government	2	2
TOTAL	30	74

* Total number of landholders of each group in the specific study site, the southern flanks of the Chonco-San Cristóbal-Casitas volcanoes. In the case of the municipal government, it refers to the officers in charge of forest management.

The main areas of inquiry in the interviews were:

- o *General information about the owners and the property:* property size, past and current land uses (include a diagram of the farm), fallow cycle, size and composition of the family, other economic activities besides the exploitation of the land.
- o *Characterization of the different forest patches present in the property:* their size, their age, the dominant tree species.
- o *Uses of forests,* including different forest products (like wood, fuel wood, medicines, game) and services (wind and runoff control, soil fertilization, and

so on) (Jantzi *et al.* 1998) What are the most useful tree species? What are the periods of the year in which they get their forest products? How valuable are the forest uses within their whole economy? How dependent are they on forests? How would they be affected if there were a decrease of forest diversity? What are the differences in forest use and values among the members of the family?

- o *Land management practices their effect on forest diversity.* This includes fire use, land clearing, selective tree cuttings, tree protection, and other practices that alter the forest. What is the seasonal pattern of these practices? Are they willing to modify their practices to produce any specific change in forest composition and extent? For example, to protect forest patches from fires, to leave secondary forests for a longer time before cutting them down again, etc.
- o *Interest in forest preservation.* What percentage of their property would they be willing to keep with a forest cover? Are they interested in protecting old-growth forest patches? What tree species would they prefer to preserve?

With the data obtained from the interviews, I elaborated a database in Microsoft Access format summarizing the data of 18 interviews (peasant communities and cooperatives are recorded as a single interview, but in fact are the result of interviews of several persons). The detailed format and row data of the interviews are shown in the appendix.

5. Forest samples

5.1. Location of sampling sites

In order to assess forest richness and composition, I performed a series of forest samples along different sites in the farms belonging to some of the forest owners I interviewed. These forest samples aimed to cover the variety of forest stands existing in the Reserve. The two main criteria to classify the diverse types of forests were their management system (whether it is a coffee plantation, a forest under fallow cycle or a relatively non-disturbed forest) and their apparent age (whether it is an old-growth forest, a young forest or a regenerating forest). Based on these criteria, I prepared a simple classification of forest stands including:

- a) Coffee plantations with forest canopy.
- b) Old-growth forests.
- c) Young forests, some of them part of a fallow cycle.

Next, I distributed my samples to represent the different forest types (Table 6). I performed 12 forest samples in total, 3 of them carried out in coffee plantations, 5 in old-growth forests and 4 in young forests. Some of the samples were incomplete, so there is only one concluded sample of young forests and 3 finished samples of old-growth forests.

The classification of forest stands as old-growth or young woods was based on information about their land use history and observations of tree sizes and

species. El Quebrachal forest (YF-Quebra), classified as a young stand, was an agricultural and grazing field in 1990, showing mainly small diameter trees of early successional species that emerged recently. YF-Roger is an adjacent stand with similar characteristics, held by an individual peasant who started to protect the emerging shrub around the same time. The forest at the Versailles cooperative (YF-Versailles) is even younger, and can be considered a shrubby area in agricultural fallow that might be slashed and burned again.

Table 6. Forest samples (Ch-Sc-C Nature Reserve).

Code	Forest type	Farm	Owner	Location	Patch Size* (ha)	Points sampled
C-Concha	Coffee plantation	La Concepción	Ariel Terán Vargas	Casitas	35	20
C-Rojas	Coffee plantation	San Cristóbal de las Rojas	Isabel Tijerino de Gudián	Chonco & S. Crist.	56	20
C-Srafael	Coffee plantation	San Rafael	Eduardo Paniagua	Chonco	71	20
OF-Argelia	Old-growth forest	Argelia	Enrique Herdocia & family	Casitas	510	20
OF-Chichi	Old-growth forest	Las Brisas	Municipal Government of Chichigalpa	S. Cristóbal	35.2	20
OF-Concha	Old-growth forest	La Concepción	Ariel Terán Vargas	Casitas	207	1
OF-Rojas	Old-growth forest	San Cristóbal de las Rojas	Isabel Tijerino de Gudián	Chonco & S. Crist.	147	20
OF-Srafael	Old-growth forest	San Rafael	Eduardo Paniagua	Chonco	114	20
YF-Quebra	Young forest	El Quebrachal	“El Pellizco” peasant community	S. Cristóbal	281.7	20
YF-Meyrat	Young forest	Apastepe	Alain Meyrat	Casitas	48	14
YF-Roger	Young forest	San Antonio	Roger Aguilar	S. Cristóbal	42	3
YF-Versailles	Young forest	Versailles	“Pikín Guerrero” cooperative	Casitas	205	8

* This is an approximate patch size within farm boundaries. In the case some old-growth forests like OF-Argelia, OF-Rojas and OF-Concha, the forest patch extends far beyond the property boundaries.

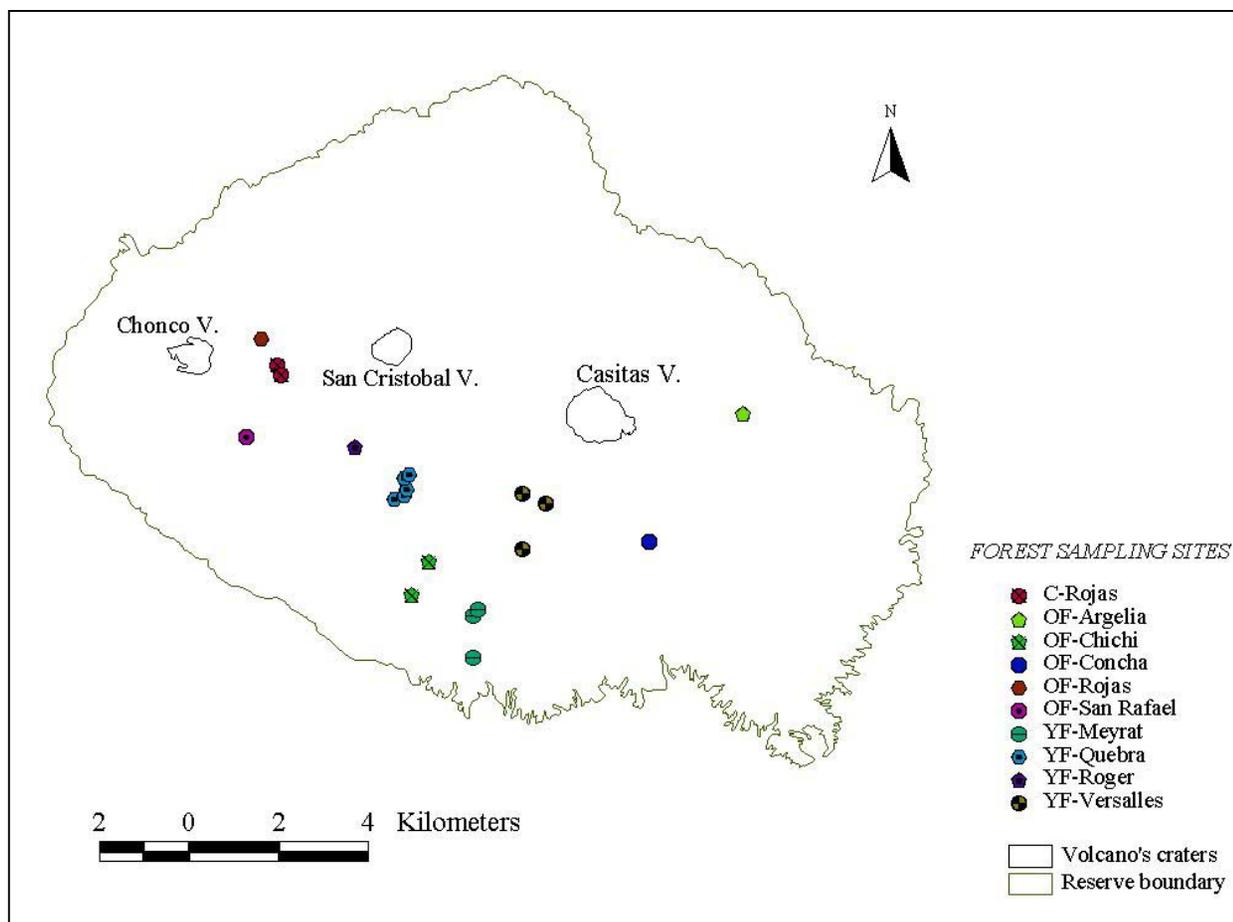
All these young woods are surrounded by mosaics of agricultural fields, grazing areas and shrubby lands under fallow, isolated from large mantles of old growth forest.

The case of YF-Meyrat is rather peculiar. This patch is located in a coffee farm that has been subject to fire disturbances creating a mixture of coffee plantation areas, scattered plots of old trees, young forests and shrubs. In contrast with the other young forest stands that emerged from a largely open field, the young forest sampled at YF-Meyrat makes part of a more complex variety of forest patches of different densities and stages of development.

In general, old-growth forest stands form part of large patches little affected by disturbances, and are composed of large diameter trees of late successional species. This is the case of OF-Argelia, OF-Rojas, and OF-Concha. They are well protected in the middle of large coffee farms. One notable exception is OF-Chichi, a small old-growth forest patch (only 35.2 ha size) isolated in the middle of agricultural and grazing fields. OF-San Rafael also has a border with agricultural lands, and has somewhat been affected by small scale and infrequent disturbances.

Coordinates of some points along transects in the sampling sites were registered in the field using a GPS receiver, except for OF-Argelia and OF-San Rafael, whose location in the map is not precise (Map 4). As shown in the map, the sampling sites are rather evenly distributed over the forested lands in the southern half of the Reserve.

Map 4. Forest sampling sites (Ch-Sc-C Nature Reserve).



5.2. *Sampling method*

The sampling method utilized in this research intended to cover the heterogeneity of tree species within patches, considering at the same time constraints of time and resources. In some cases, I had to deal with considerably large patches, like in the old-growth forests of the coffee farms. The size of these patches may be up to several hundred hectares, being difficult to cover a high percentage of the area with the samples. Since I was performing the sampling alone, with only the help of a local farmer, I needed a method that allowed me to cover the largest areas with the least resources.

I found the most appropriate sampling strategy to measure trees along a line transect, instead of using quadrat method consisting of measuring trees within defined plots. I chose the Point-Centered Quarter Method (PCQ), which consists of measuring the nearest four trees around several points distributed alongside the transect line (Barbour *et al.* 1998). The area around each point is divided into four 90° quarters and the nearest tree in each quarter is measured. I placed a minimum of 20 points along the total transect length. To locate these sample points, I divided the total transect into 20 segments of equal length, and then randomly placed the sampling point within each segment.

Depending on the patch size and shape, I squeezed or spread out this fixed amount of sample points along particular transects. In some cases, I broke up

transects into more than one section to cover a wider area of the patch. I drew, for instance, two 10 sampling-point transects to cover the two halves of an elongated patch. Nonetheless, some of the transects could not be completed where the topography was too rugged and slopes extremely steep, or where the vegetation was so young and full of lianas and vines that it was impossible to walk through. Hence, some of the samples appear incomplete in Table 6.

Two main sets of variables were measured in this sampling:

- o *Characteristics of the woody vegetation*: Only woody plants > 4 cm of Diameter at Breast Height (DBH) were taken into account. I registered the DBH in order to calculate dominance, and the distance from the line point to the tree in order to calculate density. I also recorded a value representing the social position of the individual with respect to other trees (dominant, codominant or overtopped) and another value indicating which forest layer this individual occupies (overstory, middlestory or understory). I performed a separate PCQ sampling only for saplings ≤ 4 cm DBH, recording only height category and distance to line point. I classified saplings into three different height categories: < 0.5 m, 0.5 to 1.5 m, and > 1.5 m.
- o *Environmental variables*: including topography, percent slope, apparent soil texture (measured through the feel test), and an estimation of percent canopy cover. These measurements were taken every five sample points along

transect, and then averaged or indexed to obtain a value representing the entire sample site.

All these measurements were stored in a database (see format and database file in the appendix) that is linked to the database on forest owners through a common field, so each sample can be related to the information about the forest owner.

Besides these quantitative measurements, I also made qualitative observations about the ecology of some of the most important species found (environmental requirements, dispersal abilities, social behavior towards the other individuals and species, etc), and the forest management practices in the site as well (selective logging, periodic burnings, clearing of the understory, etc.) Another database containing ecological features and economic uses of main tree species was elaborated, based on these observations (see format and row data in the appendix.)

Species diversity and composition were determined from the quantitative information of the samples. First, various indexes of forest diversity were calculated for each patch, and then compared to find out if there were similarities or differences among the diverse sites at this level. Next, in order to verify if there is a pattern of forest composition coherent with the pre-established patch types and forest users, I used the PC-ORD software (Ver. 3.18) to run a DCA (Detrended Correspondence Analysis) ordination exercise. The ordination tool arranges the different sampling sites in a graph according to their similarities in species

composition, and allows us to relate patterns in forest composition to other variables, such as patch types, forest users and measured environmental variables (Pielou 1984, Randerson 1993). I found DCA the most suitable ordination technique for my purposes because it assures that similarities in floristic composition among patches are expressed as similar distances in the ordination space, reducing the “arch” effect of previous ordination methods (Barbour *et al.* 1998). In addition, DCA first assesses species composition independently from environmental factors, and afterwards correlates the floristic composition patterns to external variables, allowing the researcher to better explore the factors underlying the arrangement of species in forest patches. Through the PC-ORD software, I run a correlation test to see whether environmental variables taken at the field explained variations in species composition.

The patterns suggested by the ordination were explored in more depth by looking at species frequency, density and dominance indexes for every patch sampled. Finally, trends of future forest composition were assessed through the elaboration of size-class histograms and the comparison between the species found in the PCQ sets of large (> 4 cm DBH) and small (≤ 4 cm DBH) trees.

Once forest diversity, composition and structure were assessed, I tried to link these findings to the information about the forest owners’ rationales and their management practices. I aimed to suggest causal relationships between the way humans manage the woods and the actual features of these forests. I qualitatively

evaluated if there is a positive correlation between the state of the forest and the management practices mentioned by the forest users during the interviews, mostly based on observations of the sampling sites. I tried to match some of these observations - a recently burned site, for instance - with the outcomes of the vegetation analysis for that site.

IV. Findings on land use change, forest diversity and forest management strategies

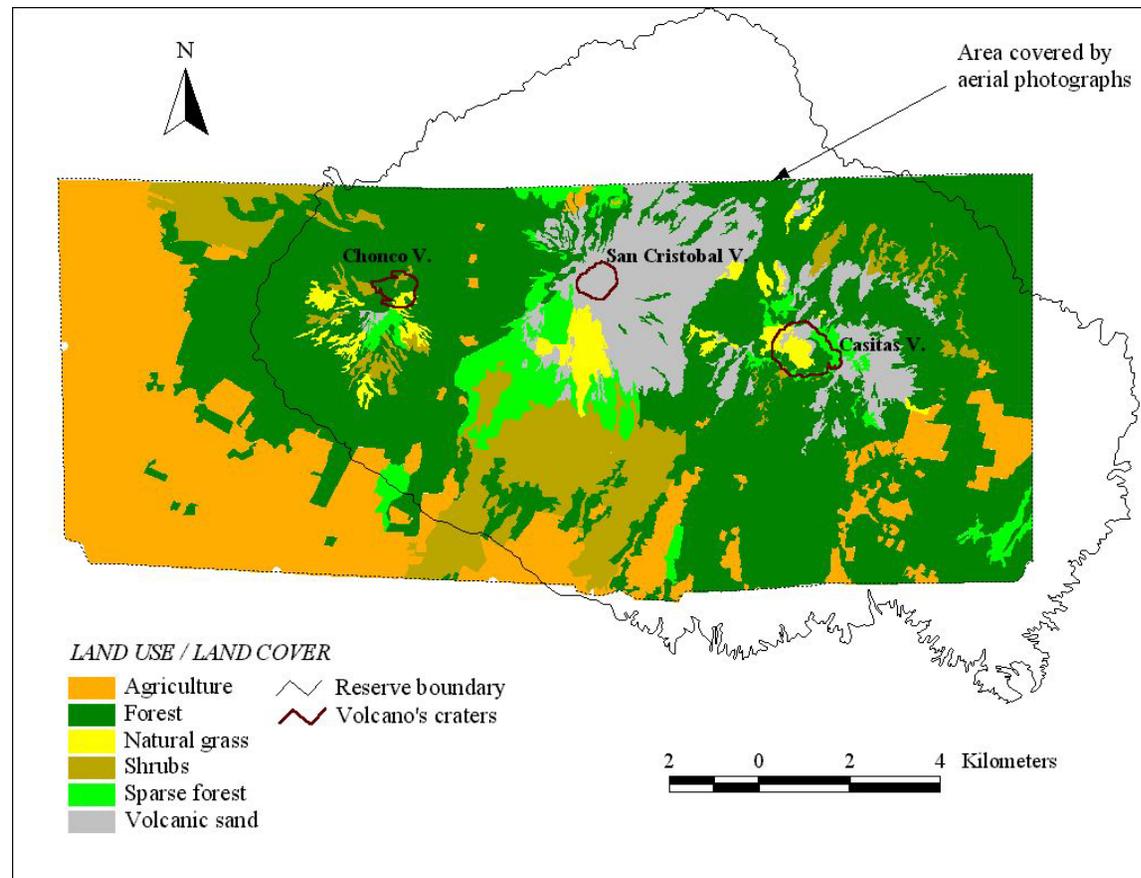
1. Findings on land use/land cover change from 1954 to 1996

The maps presented in this section, resulting from the analysis of the 1954 and 1996 aerial photos, describe and contrast the land use/land cover between these two dates. I will begin describing maps corresponding to the land use configuration for 1954 and 1996, pointing out the main differences between the two periods. Next, I will emphasize the changes that occurred between the two years by showing main patterns of change through comparative maps.

1.1. Land use/land cover in 1954

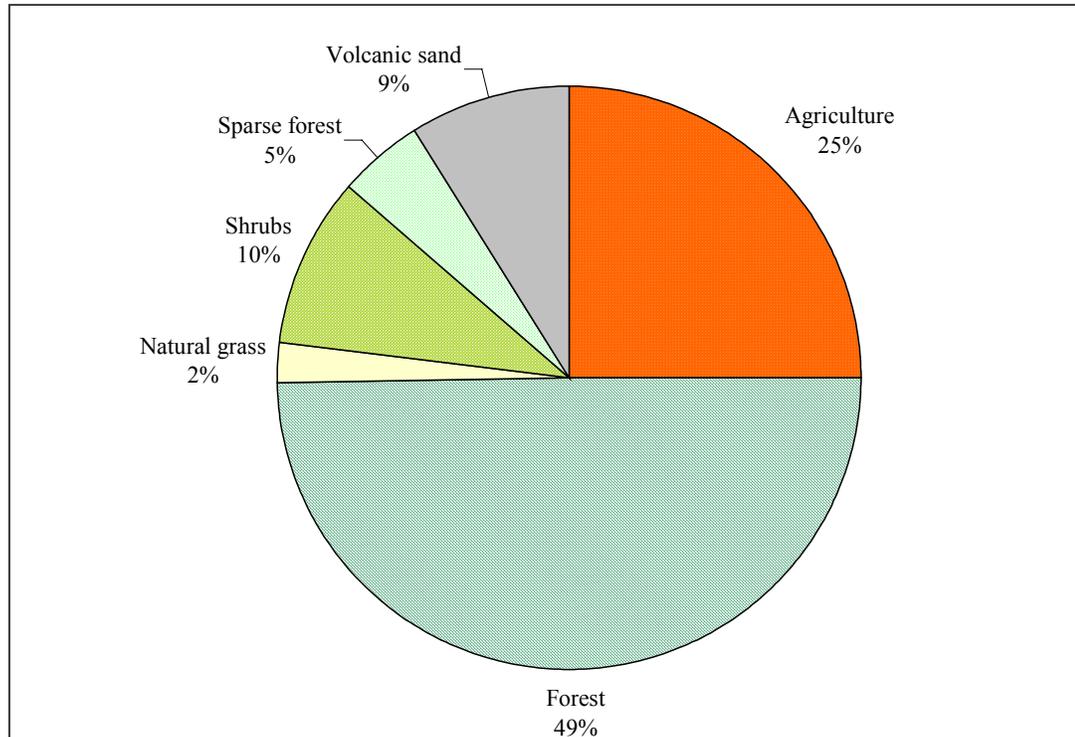
In the 1954 land use/land cover (Map 5) we can observe a significant part of the land covered by a relatively dense and continuous forest, extending over 93.8 km² representing almost 50% of the total mapped area (Figure 1). The Chonco and Casitas volcano's flanks appeared largely covered by this forest mantle, although there were no dense woods over the San Cristóbal's flanks. The forest mass looks unbroken and well separated from the agricultural areas. There were not many agricultural patches spotted over the forested matrix, as there were not many forest patches mixed in the agricultural matrix. Nonetheless, on the East side of the Casitas volcano there were several large agricultural patches in the middle of the forest. The largest ones correspond to grazing and cropping lands of the farm

Map 5. 1954 Land Cover / Land Use (Ch-Sc-C Nature Reserve)



Source: GIS digitizing and processing of 1954 aerial photos obtained at INETER (Instituto Nicaragüense de Estudios Territoriales)

Figure 1. 1954 Land cover / Land change distribution (Ch-Sc-C Nature Reserve)



named Argelia, a large property belonging to one of the wealthiest families settled in Leon city. The rest of the agricultural lands are mainly located to the west and south of the Chonco volcano, towards Chinandega city. Agriculture is already a very significant land use in 1954, covering almost 50 km², which corresponds to 25% of the mapped area. This agricultural land cover expands far beyond the mapped area, mostly covering the flat lands of Chinandega and Leon. However, we cannot appreciate all of its coverage in the map because it has been cut off to the limits of the 1996 map, so we can view exactly the same region for both years.

The southern flank of the San Cristóbal volcano is not covered by forest. A combination of shrubs, sparse forests and natural grass predominate in this area. These three land-cover types sum all together 17% of the area displayed in the map, extending over 31.1 km². The dense forests prevailing all over the Chonco and Casitas are not able to take over the flanks of the San Cristóbal probably due to the coarse texture of the soils characteristic of the areas surrounding the crater of this young and still active volcano. In the highest lands, where the volcanic sand is extremely coarse and the volcanic gases frequently spray the area, natural grass is almost the only vegetation covering the lands. There are also patches of scattered trees climbing these highlands in combination with the grassy vegetation. Bushes cover the lower lands of the southern side of the San Cristóbal. It is difficult to say whether the shrubs expand here because of the sandy and stony soil found along an ancient lava stream, or because the influence of agricultural and cattle raising activities leaving the land in rest during certain periods, thereby allowing the regeneration of young forests. This is probably the case of the shrubby area breaking through the forest in the northwest of the Chonco volcano.

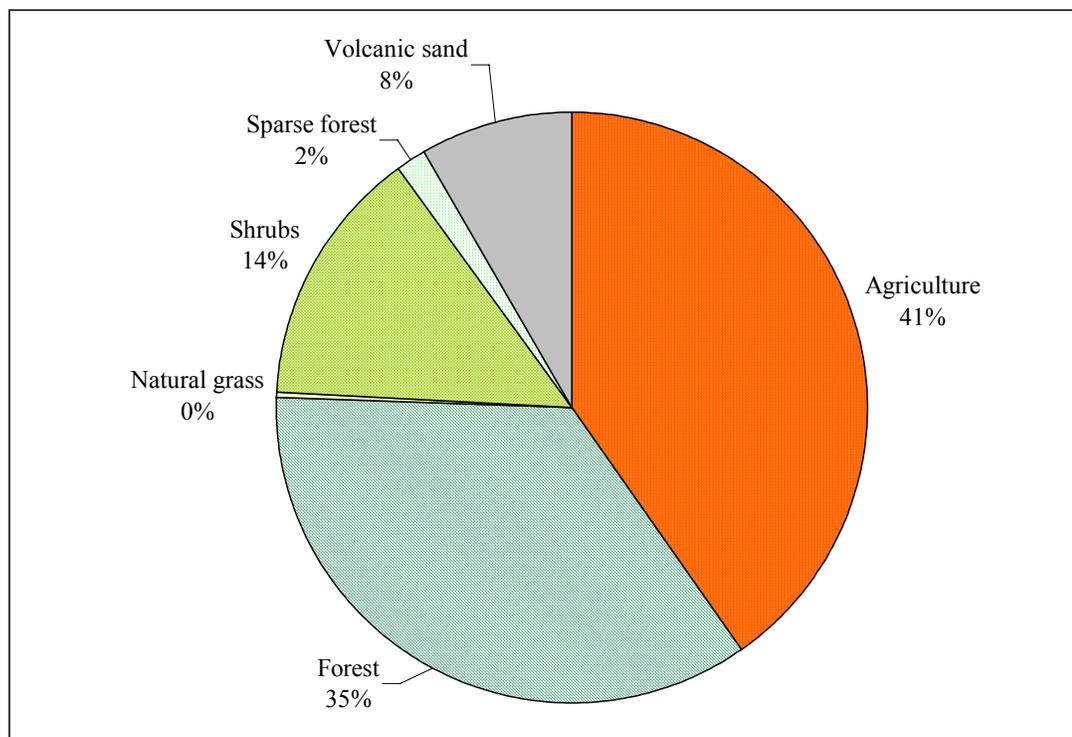
The eastern side of the San Cristóbal appears as bare land, made of very coarse volcanic depositions where vegetation is hardly able to establish. There was no vegetation in the area except for a few forest patches spread over the eastern flank and some thin forest prolongations coming from the northern woods. The

volcanic bare lands also occupy an important portion of the map, covering 16.6 km² (8.8% of the total extension).

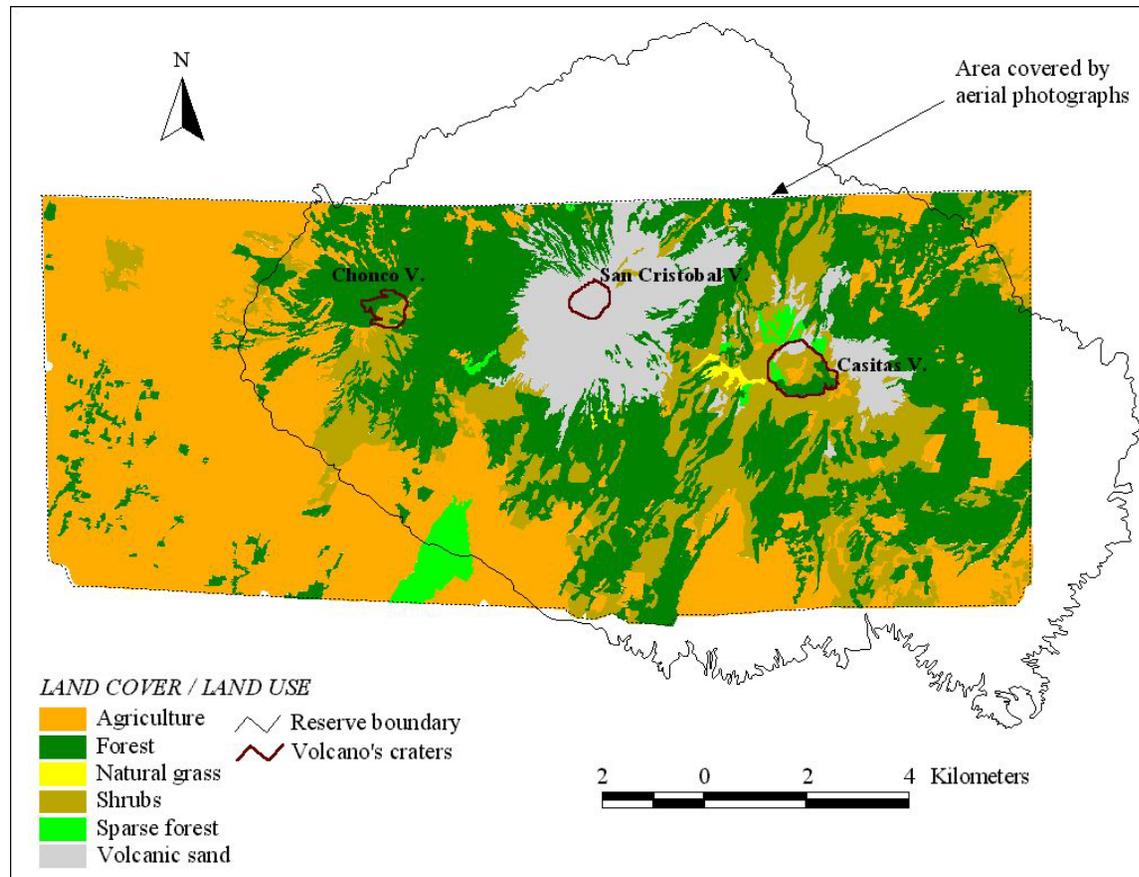
1.2. Land use/land cover in 1996

In 1996, the forested areas show considerable reduction and fragmentation (Map 6). By this date, dense forests covered almost 50 km², 14.5% less than they did in 1954 (Figure 2). This important diminution of forested lands has been caused, in great part, by the forward movement of the agricultural border over the forests.

Figure 2. 1996 Land cover / Land use distribution (Ch-Sc-C Nature Reserve)



Map 6. 1996 Land cover / Land use (Ch-Sc-C Nature Reserve)



Source: GIS digitizing and processing of 1954 aerial photos obtained at INETER (Instituto Nicaragüense de Estudios Territoriales)

The forest rings surrounding the volcanoes have become smaller, particularly in the on Chonco and Casitas. The western and southern low flanks of the Chonco, formerly forested, are now widely broken by agricultural fields. The same is true for the northern and southern sides of the Casitas, where large agricultural patches have appeared. In addition, there are many shrubby patches breaking through the forest. They are present throughout the Casitas' highlands and in the southern slope of the Chonco. In many cases, these shrubs might be an intermediate type of land use in between agriculture and woods. They could be lands under a fallow cycle, cultivated or grazed during a year and left in rest for another period, until the young forest cover is ready to be burned and cultivated again.

Despite this phenomenon of forest cover shrinking, there are areas where dense forests remain and places that exhibit a slight forest recovery. We still observe large compact forests in the eastern and northern slopes of the Chonco, as well as in the northeastern side of the Casitas. Most of these areas correspond to large coffee farms where coffee plantations are commonly mixed with forests. It is also noteworthy that there is a significant forested area the south slope of the San Cristóbal that was not there in 1954. In 1954, the area was mainly covered by shrub vegetation, and the forest patches were few and small. In 1996, the picture is the reverse. Former shrubs have developed to forests except a few small patches that continue under the initial land cover. This forest resurgence suggests a decline of agricultural exploitation in the area that might have allowed the forest to recover.

By 1996 agriculture had become the main land use in the region, gaining nearly as much territory as forests lost (Table 7). It occupies nearly 76 km², corresponding to 40.3% of the total mapped area (15.4% more than in 1954). Agriculture expansion has transformed the previous solid forest mantle in an increasingly fragmented landscape where agricultural gaps break apart the large forest. It is curious to notice that some small forest patches begin to appear in the agricultural landscape as well. There are many minute forest spots marking the Southwest agricultural corner of the map, towards Chinandega City. This indicates that there might be a sporadic forest recovery in the agricultural matrix too. Nonetheless, these new forest patches emerging in the flat lands are too small and sparse to create a larger forest cover that somehow compensates for the forest loss in the volcano flanks.

Table 7. Land use/Land cover, 1954 and 1996
Chonco-San Cristóbal-Casitas region

Land Use/Cover	1954		1996		Variation	
	Area (km ²)	(%)	Area (km ²)	(%)	Area (km ²)	(%)
Agriculture	46.91	24.9%	75.96	40.3%	29.04	15.4%
Forest	93.82	49.8%	66.57	35.3%	-27.25	-14.5%
Natural grass	4.13	2.2%	0.38	0.2%	-3.76	-2.0%
Shrubs	18.19	9.6%	26.98	14.3%	8.79	4.7%
Sparse forest	8.78	4.7%	2.93	1.6%	-5.84	-3.1%
Volcanic sand	16.65	8.8%	15.66	8.3%	-0.99	-0.5%
TOTAL	188.48	100.0%	188.48	100.0%		

Areas covered by shrubs have increased to some extent since 1954. In 1996, bushes cover almost 27 km², accounting for 14.3% of the region displayed in the map (4.7% more than in 1954). As mentioned before, they replaced forested areas. This deterioration of former forests into shrubs is likely human-induced. Besides, grass areas have decreased substantially by 1996, covering less than 1% of the total region. Grass covering the Southern flank of the San Cristóbal in 1954 is no longer present in that area in 1996. The grassy patches are now constrained to small areas in the western edge of the Casitas. Sparse forests have experienced a very similar trend. They cover in 1996 only 1.6% of the total mapped area, 4.7% less than in 1954. They are no longer present in the San Cristóbal higher lands, remaining only in the Casitas. These patches of scattered trees might correspond to plots of pine forests mentioned in other studies about the Nature Reserve (Incer 1970, Cedeño 1987, Areas 1998). Then, the disappearance of these patches from the map might mean the reduction of a very particular vegetation type that would be now constrained to the Casitas western edge.

Volcanic sand areas cover nearly the same extension in 1996 as in 1954 (almost 16 km², or 8.3% of the total area), although the distribution of its coverage has slightly changed. In 1996, there is more bare land in the South and West sides of the San Cristóbal, while forests cover a larger fraction of the Northeastern flank compared to 1954. This new distribution has to do with the relocation of forest and shrub spots along the volcano flanks. They appear and disappear probably due to

natural factors like the deposition of new volcanic sand layers and the effects of volcanic gasses on the nearby vegetation.

1.3. Main land cover / land use changes

Summarizing 1954 and 1996 maps, the following main trends in land cover/land use change become evident:

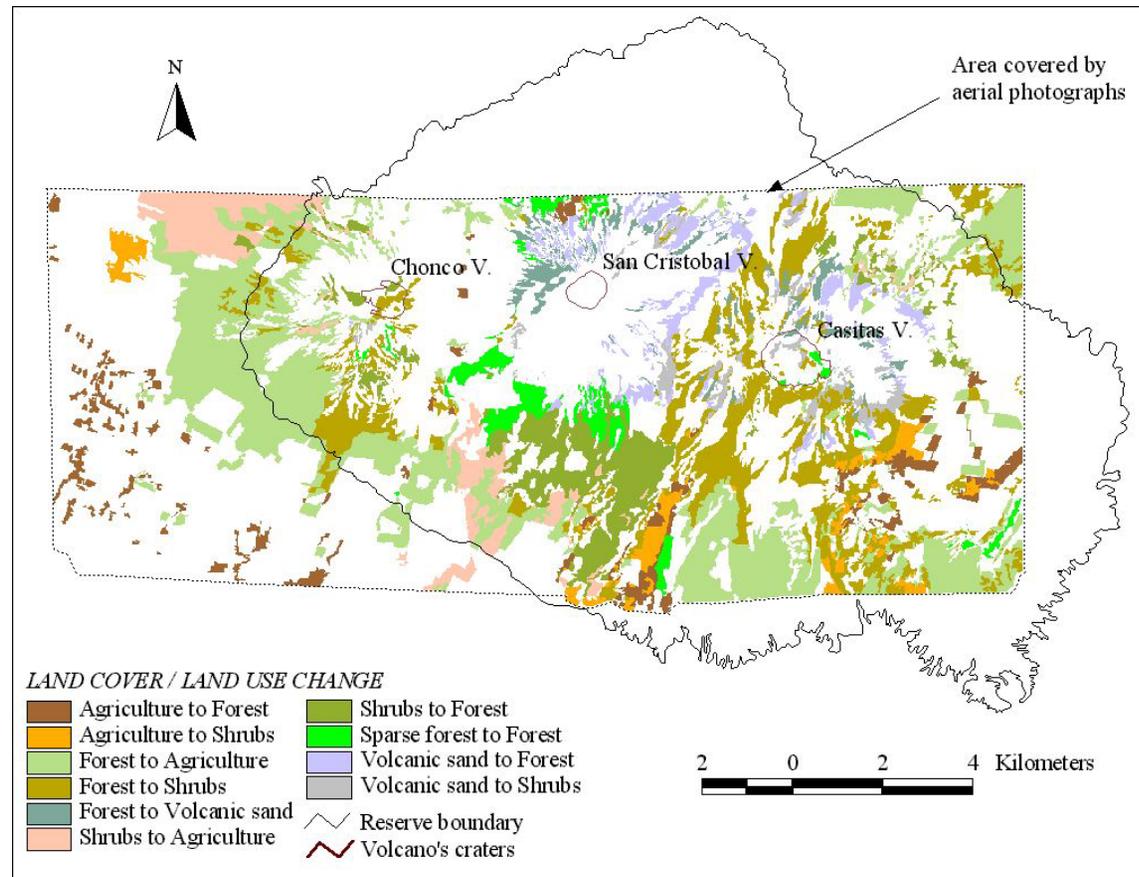
1. Forest shrinkage and fragmentation, mainly due to the advance of agricultural fronts over the woods.
2. Sporadic forest recovery in the southern slope of the San Cristóbal volcano.
3. Permanence and expansion of agricultural areas, slightly altered by the emergence of scattered small forest patches.

Each one of these main tendencies will be discussed in detail as follows.

1.3.1. Forest reduction and fragmentation

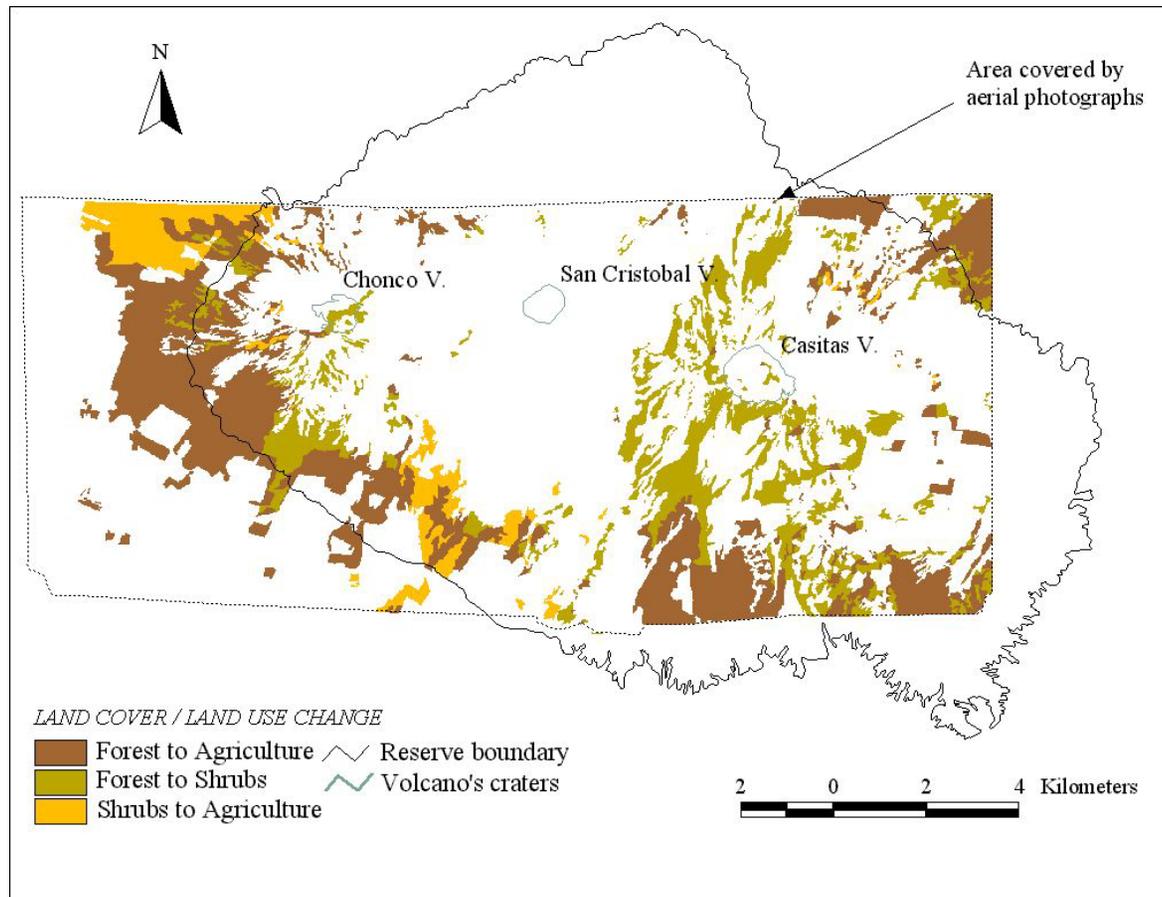
The following maps (Map 7 and Map 8) showing land use change between 1954 and 1996 reveal a significant conversion of forests to other land uses. There is a large shift of previously forested areas to cropping lands. An area of 21.1 km² has experienced this transformation, representing 15.4% of the total mapped area. The most important moving front of the agricultural border over the forest comes from the Chinandega's flatlands and advances over the western and southern flanks of the Chonco. Almost the whole West side of this volcano has become deforested.

Map 7. Main land cover / land use changes from 1954 to 1996 (Ch-Sc-C Nature Reserve).



Source: GIS digitizing and processing of 1954 and 1996 aerial photos obtained at INETER (Instituto Nicaragüense de Estudios Territoriales)

Map 8. Forest loss between 1954 and 1996 (Ch-Sc-C Nature Reserve).



Source: GIS digitizing and processing of 1954 and 1996 aerial photos obtained at INETER (Instituto Nicaragüense de Estudios Territoriales)

Agriculture has expanded very close to the peak of the Chonco, leaving no lowlands with forest cover. The Southern and Northeastern low flanks of the Casitas also display large forested areas converted to agriculture, restricting the woody ring around the volcano to the higher lands. This land use conversion from forest to agriculture is abrupt and does not seem to leave opportunity for forest recovery. The conversion of areas covered by shrub vegetation to agriculture is another change in the same direction. Land classified as shrub vegetation might contain young trees that could become adult forests if left undisturbed. Nonetheless, shrub vegetation has become annual crops in an area of 6 km², thereby making more difficult any forest recovery in these sites. This transformation has taken place in areas that form part of the agricultural belt enclosing the Chonco volcano, where both forests and shrubs have become crops.

Another important transformation of forests is their conversion to shrubs, a change that affected 15 km² (8.5% of the mapped territory). This shift can be observed in the Southern slope of the Chonco, integrated within the agricultural band mentioned above. In addition, there are many other forested areas converted to shrubs spread throughout the Casitas flanks. They indicate a process of forest deterioration probably due to a combination of sporadic agricultural activities and other disturbances such as fires initiated by hunters and honey collectors that may have spread out of control to larger areas.

The process of forest shrinkage and fragmentation can also be perceived by looking at patch number, size and shape. In general, patches of the various land cover categories were fewer and larger in 1954 than in 1996, indicating that landscape has become more fragmented (Table 8). In 1954, there were 46 forest patches, with a mean size of nearly 204 ha. In 1996, the number of forest patches greatly increased to 125, while the mean patch size diminished to 53.3 ha. Similarly, the number of agricultural patches changed from 42 in 1954 to 129 in 1996, while the mean patch size dropped from 111.6 to 58.9 ha. Hence, agriculture and forest patches turned smaller and mixed with each other, gradually creating a mosaic of intermingled patches. The shape of the patches has also changed. Agricultural patches in 1954 had a mean shape index of 1.64, compared to 1.87 in 1996. The closer to 1.00 the index value is, the more regular (circular) its shape is.

Table 8. 1954 and 1956 Landscape metrics (Ch-Sc-C Nature Reserve).

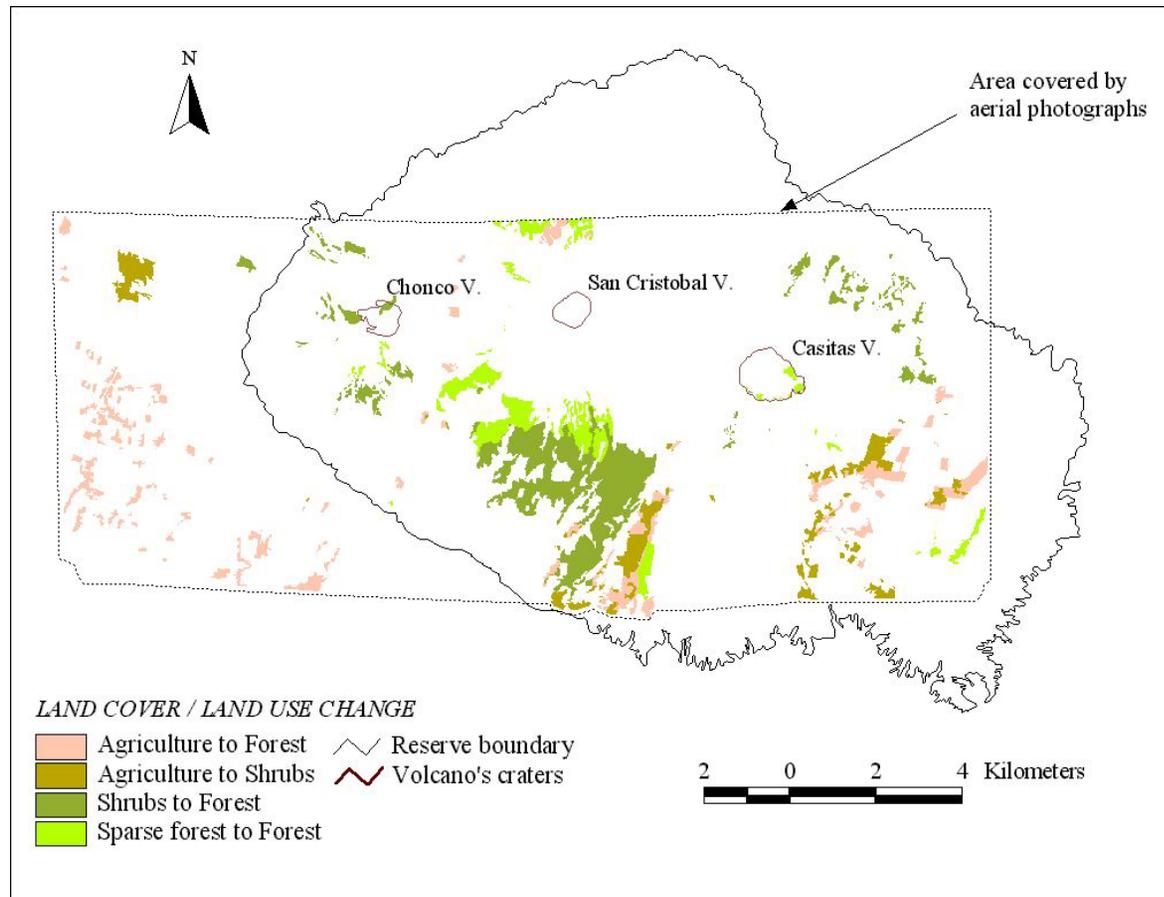
Land Use	N. of Patches	Mean Patch Size (ha)	Patch Size Std. Dev. (ha)	Total Edge (m)	Mean Patch Edge (m)	Mean Shape Index	Area Weighted Mean Shape Index	Mean Perimeter/Area Ratio
1954								
Agriculture	42	111.60	552.69	165548.83	3941.64	1.64	2.92	381.84
Forest	46	203.99	925.10	484910.25	10541.53	2.92	8.30	6232.36
Natural grass	19	21.79	32.77	75742.41	3986.44	2.66	2.89	286.46
Shrubs	47	38.72	180.69	155933.20	3317.73	2.07	4.47	1303.73
Sparse forest	17	51.60	75.93	117500.74	6911.81	2.88	3.61	244.85
Volcanic sand	37	45.02	172.76	179695.90	4856.65	2.60	4.34	4783.12
1996								
Agriculture	129	58.88	521.76	449265.16	3482.68	1.87	6.86	989.29
Forest	125	53.27	315.70	700295.11	5602.36	2.17	9.87	1383.94
Natural grass	4	9.47	10.29	11277.85	2819.46	2.56	3.36	389.50
Shrubs	133	20.26	68.83	445287.97	3348.03	2.20	4.79	790.57
Sparse forest	9	32.58	62.36	30402.04	3378.00	2.25	2.01	266.99
Volcanic sand	46	34.07	182.54	175900.88	3823.93	2.16	7.67	984.97

Therefore, the shape of agricultural patches in 1954 was slightly more regular than it was in 1996, probably because the largest patch showed rather regular shape and showed little fragmentation. Conversely, forest patches had higher mean shape index in 1954 (2.92) than in 1996 (2.17), meaning that they had a more regular shape in recent years. This is because at the beginning of the fragmentation process the former unbroken large patch had many cavities where agriculture began to break through, thereby having a very toothed shape. Once the large patch broke up, the resulting patches were more regular, exhibiting a shape closer to a circle or a square. Nevertheless, when the shape index is weighted by area, 1954 forest patches become more regular, since the area of the original patch was far larger than the area of the broken remnants. In summary, landscape metrics for the two years confirm the process of forest fragmentation perceived at first sight, indicating the gradual creation of a mosaic of mixed agricultural, forest and shrub patches.

1.3.2. Forest recovery

Despite these powerful trends of deforestation and forest deterioration, there are other land cover changes indicating a certain degree of forest recovery (Map 9). The most significant transformation in this direction is the change from shrubs to forests, which occurred along an area of 7.8 km², mainly in the Southern slope of the San Cristóbal volcano, although small spots with these characteristics are also found in the Chonco and Casitas' flanks. As suggested before, this development

Map 9. Forest recovery between 1954 and 1996 (Ch-Sc-C Nature Reserve).



Source: GIS digitizing and processing of 1954 and 1996 aerial photos obtained at INETER (Instituto Nicaragüense de Estudios Territoriales)

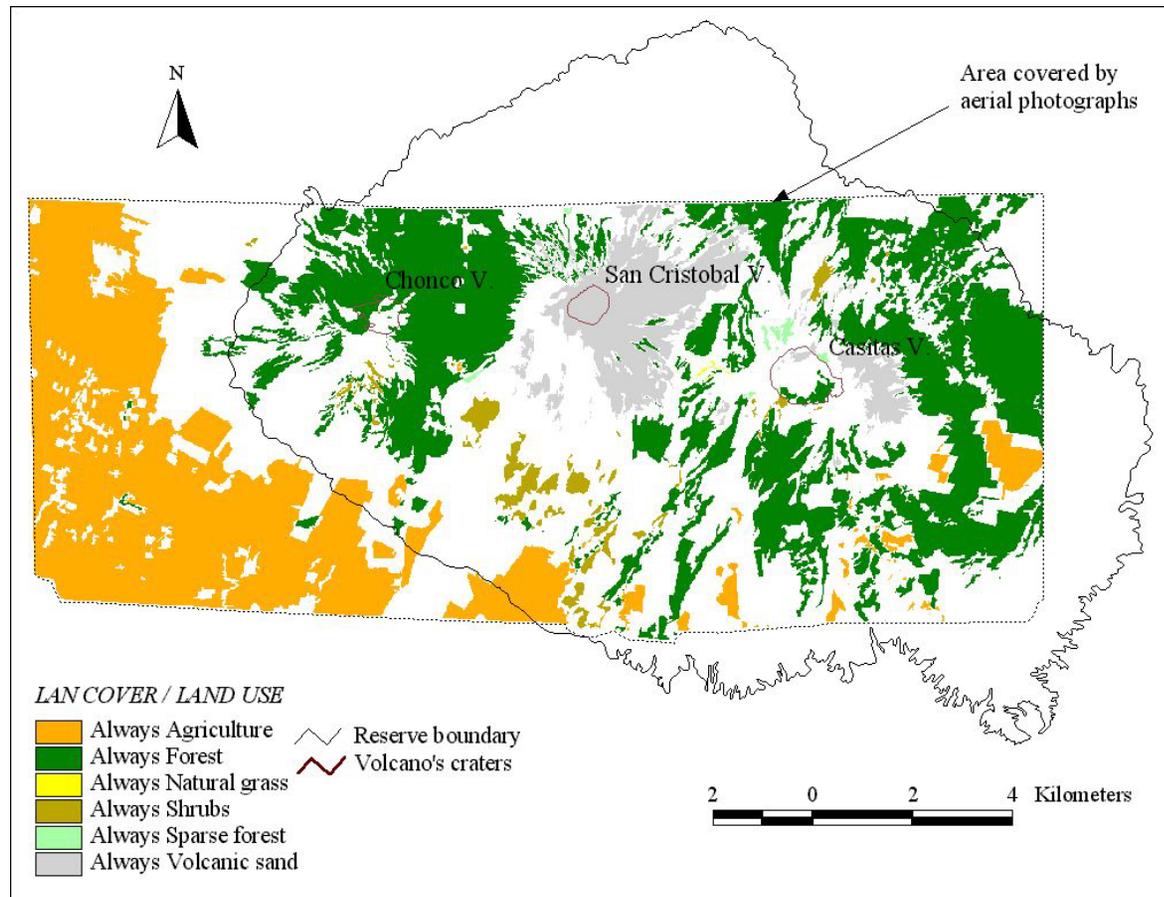
from shrubs to forests might be due to lack of agricultural and fire disturbances in the area during a period of several years, so the forest was able to grow up and become dense and tall.

In addition, there are many minute forest patches emerging in the middle of the vast agricultural fields along the Chinandega flatlands. The agricultural areas that became forest sum together 5 km², representing a small part of the map (2.7%) that may yet have an interesting potential for expansion and creation of larger forest spots along the agricultural matrix. Another important source of forest recovery are spots of former scattered trees, classified as sparse forest, that have become solid patches of dense forest. They are mainly located in the Southern slope of the San Cristóbal, connected to the other forested areas that were shrubs in 1954, and cover a relatively small proportion of the total mapped area (3.3 km², 1.7%). Finally, it is also notable that some areas of former volcanic sand in the San Cristóbal's flanks shifted to forest. They are minute strips of forest attempting to climb the coarse soils of the San Cristóbal, and may appear or disappear over time according to the environmental conditions of the area.

1.3.3. Permanence of agricultural areas

It is remarkable that most of the agricultural areas persist in 1996, keeping 36.7 km² out of the 46.9 km² they covered in 1954 (Map 10).

Map 10. Areas where land cover did not change from 1954 to 1996 (Ch-Sc-C Nature Reserve).



Source: GIS digitizing and processing of 1954 and 1996 aerial photos obtained at INETER (Instituto Nicaragüense de Estudios Territoriales)

There are very few changes in the agricultural land cover of the flatlands southwest of the Chonco, and the large 1954-patches in the East side of the Casita still exist in 1996. There are only minute blank spots in the agricultural large patch of the flatlands, indicating a loss of this land use category. However, the area remains mostly solid and large.

The preserved forested area, instead, only covers 45.5 km² out of the 93.8 km² it initially embodied in 1954 (nearly a 50% reduction). There is still a large and compact forest preserved in the Northwest side of the Chonco, showing little or none fragmentation. There are also elongated and wide patches preserved all over the Casitas flanks, yet here the forests are more disintegrated and there is not such a compact area as in the Eastern Chonco.

In summary, the maps described in this section provide evidence of significant reduction of large compact forest areas in the Chonco and Casitas' flanks between 1954 and 1996. The mechanism of this process is, on one hand, the advance of an even agricultural line moving from the flatlands towards the volcano flanks, constraining the forest mantle to central areas like the edge between the Chonco and San Cristóbal. On the other hand, irregular agricultural and shrubby patches create gaps throughout forests on the Casitas slopes, leading to large patches of fragmented forest. Nonetheless the net balance of deforestation and forest deterioration, there are some dynamics of forest recovery at small scales. In the southern slope of the San Cristóbal, it is noticeable the transition of former shrubs to forests, creating a new forest patch of considerable dimensions. A series of small forest patches also begin to spread over the agricultural lowlands, although they still represent a little fraction of the landscape.

2. Findings on people's interests towards forests

There are a variety of landholders in the forested lands of the Conco-San Cristóbal-Casitas volcanic complex, including proprietors with very different land-use strategies. I interviewed a series of persons including wealthy and medium coffee farmers, small individual peasants, a peasant community, members of cooperatives and the officers of the municipal government of Chichigalpa. Depending on their power and resources, their history and goals, they perceive and manage the forest in different ways (Table 9). Their management practices greatly influence the outcome characteristics of the forest patches. By understanding the forest user rationales and practices, we hope therefore to understand the forest itself.

2.1. Rationales towards forests

2.1.1. Wealthy coffee farmers

Starting in the middle of the 19th century, coffee became one the main export commodities in Nicaragua. To promote coffee farming, many indigenous and national lands were taken over by powerful families who began to plant coffee in the most suitable places, such as fertile valleys in the Central region of the country and the volcano flanks in the Pacific region (Barahona, A., 1990). In the study area, wealthy families with political influence in Chinandega and León (the two main cities in Western Nicaragua) established large coffee properties

Table 9. General profile of different forest owners in the Chonco-San Cristóbal-Casitas Nature Reserve

Forest Owners	Number / Property Size	Total Area in the Reserve		Land Use	Workers	Technologies	Interest on Forest
	(ha)	(ha)	(%)	(%)			
Wealthy coffee farmers	2 / 1,200 to 1600	2872	15.8%	Agriculture 13% Coffee 34% Pastureland 5% Old-growth forest 48%	Permanent workers: 20 - 50 Temporary workers: 500 - 800	Agrochemical- intensive coffee farming	For coffee shade For domestic and commercial wood and fuel wood
Medium coffee farmers	10 / 50 to 400	1378	7.6%	Agriculture 3% Coffee 10% - 40% Old-growth forest 60% - 90%	Permanent workers: 1-5 Temporary workers: 20 - 100	Coffee farming with minimum investment	For coffee shade For domestic and commercial wood and fuel wood
Small peasants	4 / 30 to 60	120	0.7%	Agriculture / Pastureland 20% - 30% Young forest 70% - 80%	Family + 1 or 2 temporary workers	Slash-and-burn and plowing agriculture	For domestic and commercial fuel wood For soil fertility
Peasant community	1 / 282	282	1.5%	Young forest 100%	Temporary forest guards: 30	Fire protection and prevention	For domestic wood and commercial fuel wood
Cooperative members	38 / 20	633	3.5%	Agriculture / Pastureland 70% Shrubs 30%	Family + 1 or 2 temporary workers	Slash-and-burn agriculture	For soil fertility
Municipal government	1 / 35	35	0.2%	Old-growth forest 100%	1 forest guard	Fire protection and prevention	For species richness conservation

in the best soils of the San Cristóbal and Casitas's slopes. They took over lands that did not have any specific owner that time, which used to belong to the Spanish crown during colonial times and were now property, in theory, of the recently formed State of Nicaragua. Descendants of these families have inherited the coffee properties and remain present-day owners.

Currently, there are two large coffee farms belonging to two of the wealthiest families of Chinandega and León City. They are neighbor properties, both located in the southeastern flank of the Casitas volcano. The farm named "Bella Vista" belongs to the Callejas family from Chinandega, one of whose members occupies a chair in the Nicaraguan Senate. The other farm, called "Argelia," belongs to the Herdocia family from León, and is the largest private property in the Reserve as well as the farm equipped with the most expensive infrastructure and machinery. Both properties total approximately 2,872 ha within the Reserve (nearly 16% of the protected area), yet this figure should be taken with caution because it comes from a very old plot map. These farms provide a significant number of jobs for landless peasants especially during the coffee-harvesting season, when several hundreds of workers are employed temporarily. Landlords cultivate coffee in some 34% of their lands, usually in the flat and most fertile soils. They also leave a small part of their property for agriculture and cattle grazing (18%), while nearly half of the property remains uncultivated under the cover of an old-growth forest (Table 9).

Coffee farmers are interested in keeping the greatest proportion of their land forested mainly for coffee protection. Since climatic conditions in the volcanoes are not ideal for coffee production (a little dryer and warmer than the optimum), they need a relatively dense forest canopy to provide shade, maintain moisture and low temperatures in the coffee plantations. Uncultivated forests surrounding the coffee plantations also contribute to create a suitable microclimate for the well being of the coffee plants. Besides coffee protection, coffee farmers see forests as a source of timber to fulfill the needs of the farm (fences, tools, houses for the temporary workers) and eventually for trade. In the case of wealthy farmers, however, the most important forest service is the protection of coffee plants, while timber harvesting remains as a secondary product for domestic purposes. They adapt and modify the forest mainly to create the adequate environment for the coffee plants to be productive, regardless other benefits.

As these wealthy landlords have enough capital to afford cropping investments, they choose a model of coffee management that maximizes the harvest but at the same time requires the use of greater resources to increment coffee plant density, fertilize the coffee, remove weeds and regulate the amount of light filtered through the forest canopy. This usually results in a more homogeneous coffee plantation, with higher density of coffee plants and less density and richness of tree species. Although they transform the forest to obtain as much coffee as possible, coffee farmers also hold in their properties large areas of old-growth forest that

have been little affected by recent human-made disturbances. Wealthy coffee landlords are afraid that poor peasants will invade their properties or steal the production of plantains and fruits that are usually mixed with the coffee plants. “People from the neighbor cooperative trespass my property and take part of my production of plantains”, asserted one of the wealthy farmers. To avoid intruders, they fence their property boundaries and pay a few guards to ensure that nobody enters without permission. Thereby they protect, indirectly, the forests within their properties. This is why some persons consider large coffee owners a positive factor for forest conservation in the Reserve, since they prevent the agricultural border led by small peasants to move forward into the highlands (Areas 1998).

Protection does not equal untamed forests. The proportion of cultivated and uncultivated forest might still vary in large coffee farms. Eduardo Callejas, one of the wealthy landholders, is expanding his coffee plantations at the expense of forested areas, thus removing the majority of trees from the original woods. Enrique Herdocia is also replanting coffee fields destroyed by Hurricane Mitch and creating new plantations in forested lands. Therefore, wealthy coffee farmers are also transforming the forests they protect from outsiders.

2.1.2. Medium coffee farmers

There is another group of coffee farmers who do not own such large properties nor have enough capital to cultivate coffee in a capital-intensive way. They own farms between 50 and 400 ha, with coffee plantations covering 10% to

40% of that area. The remaining 60% to 90% of the land is covered by old-growth forests, with a very small proportion of the property for agriculture or pastureland (3%). There are around 10 medium coffee farmers in the Reserve, and their lands total 1,378 ha, which corresponds to 7.6% of the total protected area.

Their financial capacity varies from case to case. Duilio Gurdían, for instance, is the manager and co-owner of the most prosperous farm within this group. He has enough money to guarantee the maintenance of the coffee plantations that cover 26% of his farm, hiring temporary workers to do the weeding and replant old coffee trees. The farm also has a small plant to process the raw coffee grains to an intermediate level. In contrast, other farmers like Ariel Terán (“La Concepción” farm, Casitas volcano) and Eduardo Paniagua (“San Rafael” farm, San Cristóbal volcano), do not have the resources to even maintain the actual extension of their coffee plantations. They cannot hire enough workers to do the weeding, so vines and lianas are starting to cover and kill the coffee plants in some areas.

In addition to the problem of capital scarcity, some of these coffee farmers also have little presence and control on their properties. Most of them live in Chinandega or León City, and have other business to care about. Rodolfo Chávez, for example, is a lawyer settled in Chinandega city. He recently had an accident and is now physically unable to visit his farm in the flanks of the San Cristóbal. His wife and sons have other occupations and are not able to take care of the farm

either. Hence, he relays on a “mandador”, a local peasant hired as an *in situ* manager, to take care of the farm. However, Mr. Chávez claims that in his absence the manager has been extracting significant amounts of wood and fuelwood without his authorization, thereby depleting the forest in his farm. “They are destroying the forest in my absence, and the authorities do not do anything about it” (Rodolfo Chávez). He cannot prevent this resource leaking because the last time he visited the farm was six months ago.

A general fact influencing infrequent visits of owners to their farms is that the San Cristóbal volcano threw out large amounts of sandy ashes in February 2000, which accumulated in its flanks and run off towards the coffee farms pushed by the first rains in May. Flows of sandy soil cut off the roads that lead to some of the coffee farms in the highlands and covered part of those properties. Since a similar phenomenon, yet of greater magnitude, happened with Hurricane Mitch in October 1998, farmers fear to be buried under volcanic sand and prefer to wait for the volcano to calm down. Isidoro Gómez, owner of “La Suiza” farm in the San Cristóbal slope, practically abandoned his property since that happened (Figure 3). Nobody is taking care nor watching the farm, and consequently neighbor peasants go in to harvest and collect fuel wood for commercial purposes. Agricultural fires from neighbor farms have also expanded into the property affecting forested areas.

Due to both financial and management problems, medium coffee farms are not able to cultivate coffee plantations in a capital-intensive way. In general, they

have on their farms lower coffee plant densities and higher tree density and richness. They transform the forest to an intermediate level, keeping many of the original tree species. However, their pure-forest areas are not as well protected as in the farms of the wealthiest landlords. They are prone to suffer from human-made and natural disturbances such as wood harvesting, fuel wood collection, and uncontrolled fires.

Figure 3. Abandoned farmhouse in “La Suiza” (San Cristóbal volcano flanks).



Outsiders are not the only ones harvesting timber and fuel wood in the medium coffee farms. Medium farmers themselves see woody species as an economic complement of coffee crops. Ariel Terán, owner of “La Concepción” farm, was extracting two pickup loads per week of commercial fuel wood during several months in 2000. Duilio Gurdían, who is in charge of “Las Rojas” farm, also sells the fuel wood he collects in the farm in a small store his family owns in Chinandega City. They would probably like to extract greater amounts of fuel wood and timber, especially after Hurricane Mitch blew down many ancient trees in their coffee plantations, but local officers of the Ministry of Natural Resources do not allow them to extract such quantities. “If we take care of the forests in our farms, it is fair that we make some profit from it too”, they claim. Indeed, these medium farmers value timber and fuel wood species more than any other coffee owner, and are more likely to preserve them as well.

2.1.3. Small peasants

There are only a few small peasants owning forested lands in the volcano flanks. The majority of the small properties are concentrated in the lowlands, between Chinandega city and the piedmont of the Chonco and San Cristóbal. Small peasants have been constrained to this narrow area because of the expansion of large entrepreneurial cotton production in the flat lands since the 1950’s, on one side, and the barrier of medium and large coffee farms in the highlands since the mid 19th century, on the other side.

Most of the small peasants in the lowlands do not hold compact forested areas in their properties. They also engaged in cotton production during the second half of the 20th century, changing their forestland cover to annual crops. Nowadays, there are only small forest spots scattered in the peasant lowlands, as a timid sign of forest recovering. Within the Reserve, I identified only 4 small peasants with forest on their properties. They hold properties between 30 and 60 ha, totaling a very little proportion of land that represents less than 1% of the protected area.

These peasants have usually bought the land from former proprietors who cultivated annual crops throughout the area. There was no forest when they acquired the land. At most, there were only shrubs emerging on agricultural fields in fallow. The new owners started to protect some of these shrubby fields, which became young forests after a few years. They attempt to balance the land use of their properties between forest (70% to 80% of the area) and agriculture or grazing lands (20% to 30% of the property). They cultivate a small area of grains (maize, rice, beans) and graze a small herd of cattle. They do not need to crop the entire area at once. Forest areas are kept as a source of fuel wood and rustic timber for domestic and commercial purposes. If there is need, however, forest might eventually be converted to agricultural fields or pasturelands again, thus starting over a sequence of fallow cycle. Indeed, forests are not equally dense in the farms of Melanio Bustamante and Róger Aguilar, the two peasants whose properties I visited. They are a mixture of shrubby patches intermingled with spots of dense

young forests and openings covered by graze or veins. Cattle feed in these areas, eating graze and veins, as well as some leaves and seeds from the trees. Therefore, it is not clear whether these patches of young woods will become adult forests including late successional species.

2.1.4. Peasant community

National lands in the Reserve usually remain under open access or have been taken over by the most powerful families in the region. However, there is an extraordinary case of national land management by a peasant association in the San Cristóbal's slope. The young forest they manage today, known as "El Quebrachal", used to be an open access area in 1990. Peasants coming from different places in the flat lands used to go there to collect fuel wood for trading in Chinandega City and nearby towns. Fuel wood gathering was uncontrolled, and peasants were extracting as much as they could. Hunters and honey collectors also used to visit the area. They lighted fires for trapping animals, which often went out of control and burned large forest extensions. They overexploited the forest to a point where timber and fuel wood turned very scarce. Shrubby vegetation developed instead.

In 1994, the "Pikín Guerrero" project offered a group of fuel wood gatherers from "El Pellizco" community to create a peasant association to regulate the extraction of fuel wood and protect El Quebrachal forest. The peasants from "El Pellizco", a community near to the forest area, would have the right to collect rustic timber and fuel wood if they cooperated protecting the forest from fires and from

outsiders. At the beginning, a small group of 7 peasants joined the initiative. But in the next years the association increased its membership to nearly 70 families of the community. They organized fire-fighting brigades and enriched the forest by planting high-value timber species. After 6 years, peasants began to see the fruits of their efforts. A young forest has developed, from which they collect timber and fuel wood again.

Nevertheless, peasants from “El Pellizco” do not have solid legal basis to claim ownership over El Quebrachal forest. Originally, El Quebrachal made part of open-access lands that were occupied by a powerful man named Julio Fornos, connected to Somoza dictator’s family, who came to own a vast amount of land covering more than one third of the actual Reserve. After the Sandinistas took over the power (1979), Forno’s property was confiscated and redistributed into cooperatives. A part of the land, however, came back to its previous state of nobody’s lands, and was considered national public property. In the mid 1990’s, by initiative of the “Pikin Guerrero” governmental project, the municipal government of Chichigalpa claimed ownership of these lands and gave the responsibility of forest protection and management to El Pellizco community, under the name of “El Quebrachal cooperative”. They claim ownership and exploitation rights over 282 ha, although the property boundaries are not clearly demarcated, and neither the municipality of Chichigalpa nor the peasant community has a legal title over those lands. From a strictly legal point of view, El Quebrachal makes part of the national

lands within the Reserve, and consequently belongs to the central government. Obviously, the central government does not have the resources to take care of the public lands in the Reserve, and so it is not worried about other actors taking over these areas. Instead, a local government and a local community have the interest and the energies to manage this piece of forest.

The communal administration of the forest has not worked without problems and conflicts. Not all the cooperative members are benefiting from the forest. Only the families who own oxen and carts can go to highlands to gather fuel wood and cut timber. The rest of the peasants, who are the majority, cannot collect fuel wood. Yet, it is impressive how they still participate in the firefighting and other forest protection tasks, even though many of them do not get a direct profit from the forest besides the food-for-work sometimes offered by the municipality. Because they do not take direct advantage of the forest, membership of the cooperative has decreased. Some former members no longer want to invest time and effort in protecting the forest. The active members have become a small group of some 20 peasants. However, despite the conflicts and disappointments, this can be considered a successful experience of communal forest management, something very rare in Nicaragua, where forested lands are either in open access or have a private owner.

In addition, the other 4 individual peasant households owning 35-ha parcels surrounding El Quebrachal, like Roger Aguilar, have also protected the forest in

their properties, developing young woods similar to those under communal management. Thus, private and communal peasant forest protection reinforces each other.

2.1.5. Cooperatives

The case of El Pellizco contrasts with the lack of interest in forest management observed in cooperatives that directly received lands from the agrarian reform. Cooperatives like “Las Brisas” and “Versailles”, in the Casitas volcano flanks, have been unable to take care of their forested lands. “Las Brisas” was Forno’s former central property, embodying nearly 1400 ha. It was difficult for the cooperative, made of a large group of poor peasants, to manage such amount of land, and they started to cede and sell their property to other parties. They first gave up 100 ha of their land to another peasant group to form a new cooperative, locally known as “the land belonging to Los Sarria”. In the mid 1990’s they donated 35 ha of forested land to the municipal government of Chichigalpa, which wanted to preserve that particularly rich piece of forest. Finally, in 1999, they sold most of the remaining land to a cattle rancher coming from the central region of the country. They only kept 7 ha of bare land per person for agriculture and small cattle raising. At this moment, they own no forest.

“Versailles” is another cooperative that did not work well as a group. During the 1980’s they cleared old coffee plantations and forests to make agriculture and cattle ranching, with massive credit support from the Sandinista

government. They were not able to pay back their debts and by the mid 1990's they had sold most of their cattle and decided to split up their land into individual family parcels. At this time, every family independently manages 14 ha of land, half under annual crops and half under very young forests that has recently regenerated. In addition, the cooperative still keeps 140 ha in collective ownership, where it also emerges a young forest. Many of the families are now practicing slash-and-burn agriculture on their forested lands, leaving reduced areas in fallow. These shrubby lands have the potential to become something similar to El Quebrachal, a young forest populated by useful pioneer species, but the cooperative members do not seem motivated to go that way. Their priorities are the annual crops and the small-scale cattle rising for survival (Figure 4).

Figure 4. Agricultural field at “Versailles” cooperative.



2.1.6. Municipal government

The municipal government of Chichigalpa is trying to preserve the 35-ha forest it received from “Las Brisas” cooperative. The municipality identified this piece of forest as particularly interesting for preservation because of the high species diversity it holds. The local government wanted to set this forest as a reserve with conservation, scientific and educational purposes. It does not have the resources, however, to finance the infrastructure needed for students and researchers to visit the site. In the meanwhile, the municipality is only paying a

young man from El Pellizco to work as forest guard to prevent neighbors from extracting wood or burning the municipal forest as well as El Quebrachal forest. Three years ago, the municipality enriched the forest by planting high-value and rare timber species in the area, with the support of a shrimp-farming company that belonged to the Pellas family, one of the wealthiest in Chinandega and Nicaragua. This support was given as a compensation for the deforestation caused by the shrimp farm in the Pacific coast. When shrimp farms were destroyed by hurricane Mitch in 1998, the company stopped supporting forest improvement at Las Brisas. Currently, the municipal government is looking for new sources of support to manage this woody patch.

2.2. Management goals and practices

2.2.1. Coffee plantations: between the preservation and cutback of woody species diversity

Coffee farmers have modified the forest composition by planting coffee under the natural forest canopy. They have eliminated part of the former vegetation to make room for the coffee and to transform the original closed canopy in a moderate grid-like coverage regulating the amount of solar radiation reaching the coffee plants. This transformation has not been homogeneous in all the cases, and has produced qualitatively different outcomes. There have been at least two ways

of changing the forest composition in the coffee plantations, depending on whether the owner is a wealthy landlord or a medium farmer.

The wealthiest coffee landowners prefer a model of dense coffee plantation that needs large amounts of agrochemicals (fertilizers and pesticides) and more solar radiation. They carefully select tree species with fine leaflets that provide a grid-like canopy filtering the sunlight (Table 10). These are usually early successional species, either pioneers or gap colonizers. Therefore, they tend to eliminate, little by little, the late successional species from the original forest, and favor only a few species that are good for coffee shade. This is what I observed in the large “haciendas” that belong to Eduardo Callejas and Enrique Herdocia, the two wealthiest landowners in the Reserve. They have coffee plantations where there are only a few species dominating the overstory, typically *Enterolobium cyclocarpum*, *Lysiloma spp.*, *Inga vera* and *Gliricidia sepium*. They regularly weed the understory eliminating the small trees that emerge, only leaving a few selected woody plants. In addition, they plant new trees of the species they prefer, like *Gliricidia sepium*. These wealthy landowners are currently investing in the renovation and expansion of their coffee areas, thus incorporating more old-growth forestlands to this system.

Table 10. Uses of forest by the different landowners

Owner type	Uses of forest	Valued features of species	Management practices
Wealthy coffee farmer	Shade for coffee	Fine leaflets creating a grid-like shade	Elimination of saplings in the understory. Plantation of new species.
	Microclimate favorable for coffee	Large forest patches	Forest protection. Fire prevention, and protection against outsiders.
	Timber and fuel wood to use in the farm	No especial requirements	Selective logging from time to time.
Medium coffee farmer	Shade for coffee	Both fine and broad leaflets	Partial elimination of saplings, selective protection of desired species.
	Microclimate favorable for coffee	Large forest patches	Some forest protection, although disturbances affect patches.
	Timber for the farm	Hardwood	Selective logging from time to time.
	Commercial fuel wood	Long-lasting burning with constant heat	
Small peasants / Peasant community	Rustic timber for domestic use	Hardwood	Selective logging from time to time, harvesting the best individuals.
	Commercial fuel wood	Long-lasting burning with constant heat	Frequent thinning of species for fuel wood.
	Part of an agricultural fallow cycle	No especial requirements	Slash-and-burn agriculture after the fallow period.
Cooperatives	Agricultural short-fallow cycle	Bushes	Slash-and-burn agriculture after a short fallow period.
Municipal government	Species diversity preservation	Species rarity and diversity Late successional species	Forest enrichment, planting rare late successional species

Medium coffee farmers transform the forest in a different way. Instead of favoring only a few pioneer species, they combine some remnant late successional species from the original forest with pioneers and gap colonizers, thereby producing a good shade for coffee at a lower cost (Table 10). This is the case of the farms owned by Duilio Gurdian (hacienda Las Rojas), Ariel Teran (hacienda La Concepcion) and Alain Meyrat (former hacienda Apastepe). They have also cleared part of the original vegetation to make space available for the coffee plants, but keeping some trees that used to dominate the overstory, like *Brosimum alicastrum*, *Terminalia oblonga*, *Guarea glabra*, and *Masthcodendron capiri*. A wide range of long-lived pioneers and gap colonizers such as *Cordia alliodora*, *Tabebuia chrisanta*, and *Guazuma ulmifolia* are repopulating the understory. The outcome is a rich and dynamic combination of late and early successional species. Indeed, there is higher species diversity in this modified forest than in some of the patches of pure old-growth forest, where a few species have become very dominant, as in the case of the forest dominated by *Brosimum alicastrum* in the hillsides surrounding the coffee plantations in La Concepcion hacienda. In all these cases, the coffee farmers do not have enough investment capacity to manage the coffee plantations in a capital-intensive way. They do not have enough resources to remove all the old trees and replace them with different species, nor weeding and fertilizing the entire plantation at once. On the other hand, they look for an

economic complement to the coffee income, provided in part by the selective extraction of trees for timber and fuel wood (Figure 5).

Figure 5. Fuel wood extraction in a coffee plantation at “La Concepción” farm, Casitas volcano.



2.2.2. Protected and disturbed old-growth forests

Besides the coffee plantations themselves, there are large separated areas of old-growth forests in the coffee farms. The degree to which these forests are protected also varies depending on the resources of the landlords. Wealthy coffee farmers protect their properties vigorously from outsiders. Therefore, they are less likely to be affected by fires or fuel wood collection (Table 10). It is expected, then, that late successional species occupy a major place in these forests. Medium coffee farmers do not always guarantee, nonetheless, the protection of their forested areas, which are more prone to be affected by disturbances like fires and wood extraction. In addition, some farmers like Duilio Gurdían used to feed their cattle in the forest during the dry season. Cattle feed on leaves and fruits from the trees, thereby complementing its diet from pastures. They also favor the development of certain species, by transporting their seeds, and hinder the expansion of others, by smashing saplings on their way. All these different disturbances might open space for early and intermediate successional species to fill in, thereby creating a mixture of species with different life histories.

The preservation of such forest patches depends on the farmer's willingness and ability to transform them into coffee plantations. If they feel they have enough coffee, or they do not have enough money to afford the coffee expansion they would like to carry out, then these old-growth forests have a chance to be preserved. Usually, these forest remnants are located in inaccessible places where

the topography is rugged and unsuitable for the establishment of coffee plantations. Therefore, coffee plantations are not likely to expand far beyond their present limits, so the proportion of forests and coffee plantations in the farms remain rather similar.

The 35-ha woodland set up by the municipality of Chichigalpa as a reserve for species diversity conservation is also an old-growth forest. How this piece of adult forest came to persist in the middle of grassy and shrubby surroundings remains a mystery. It is part of former “Las Brisas” farm, which has been mainly dedicated to cattle ranching and agriculture. Currently, a mosaic composed of grassy, shrubby and agricultural fields covers most of the land around this forest patch. Although the management history of this preserved piece of forest is not clear, we can infer that it has suffered from disturbances coming from the vicinity. For instance, a forest guard reports an agricultural fire affecting the east edge of the forest three years ago. As in the case of forest patches preserved in medium coffee farms, it is expected that the woods at Las Brisas have been somewhat altered by fires and fuel wood collectors. Species composition might reflect these alterations.

2.2.3. Emerging young forests

Associated and individual peasants are protecting young forests at El Quebrachal and neighbor areas. By preventing fires, they have allowed pioneer species to regenerate and grow considerably. They have also slowed down the rate of timber and fuel wood extraction, permitting the former overexploited species to

recover. This is a still young forest dominated by early successional species, mainly *Lysiloma spp.* and *Cordia alliodora*. In fact, the name “El Quebrachal” comes from “Quebracho”, which is the common name of *Lysiloma spp.*, pointing out the abundance of this species. In contrast, there is little or no presence of late successional species at El Quebrachal. Saplings of intermediate species, such as the gap colonizer *Tabebuia chrisantha*, have recently appeared. If peasants want to have more valuable late successional species in their forest, they will need to perform additional management practices. They might need to thin populations of early successional species to open space for other species to develop. In addition, since seed sources of the desired late successional species are far away, they might need to introduce them artificially. Indeed, peasants from El Pellizco planted a series of new species in El Quebrachal forest in 1998, including fine timber late successional species. There were relatively few trees planted, though, so they are not significant in forest composition yet.

Nevertheless, small peasants do not clearly state high-value timber production as one of their main forest goals. Their needs for fuel wood and rustic timber are already fulfilled with the young forest. Whether they become interested in management of late successional species remains to be seen.

2.3. Species use

Among the large set of tree species found in the various forest patches, owners tend to prefer only some of them for specific purposes. Following, there is a list of the most popular species to provide coffee shade, timber, fuel wood and other services (Table 11).

Table 11. Different uses of most popular species

Species	CS	FW	T	SD	CF	F
<i>Acacia mangium</i>	X					
<i>Ardisia revoluta</i>						X
<i>Bombacopsis quinata</i>				X		
<i>Brosimum alicastrum</i>	X	X			X	X
<i>Cedrella odorata</i>			X	X		
<i>Cordia alliodora</i>			X			
<i>Enterolobium cyclocarpum</i>	X	X	X	X		
<i>Eucaliptus camaldulensis</i>		X				
<i>Gliricidia sepium</i>	X			X		
<i>Guarea glabra</i>	X	X				
<i>Guazuma ulmifolia</i>		X				
<i>Inga vera</i>	X					
<i>Lysiloma spp.</i>	X	X				
<i>Mastichodendron capiri</i>	X	X				
<i>Pithecellobium saman</i>	X		X			
<i>Simarouba glauca</i>				X		
<i>Swietenia humilis</i>				X		
<i>Tabebuia crisantha</i>	X					
<i>Terminalia oblonga</i>	X	X	X			

CS = Coffee Shade, FW = Fuel Wood, T = Timber, SD = Species Diversity, CF = Cattle Food, F = Food.

2.3.1. Species preferred for coffee shade

Wealthy coffee farmers choose a narrow variety of tree species to provide moderate shade in the coffee plantations. The most common species are *Enterolubium cyclocarpum*, which naturally regenerates in the coffee fields, and *Gliricidia sepium*, which is often artificially planted. These species have fine leaflets that allow solar radiation to filter and reach the coffee plants with less intensity. Other species that are also preferred for the same characteristics are *Acacia mangium*, *Inga vera*, *Pithecellobium saman* and *Lysiloma spp.*

Medium coffee farmers also include in their plantations other tree species that produce a rather dense shade, such as *Brosimum alicastrum*, *Terminalia oblonga*, *Tabebuia crisantha* and *Mastichodendron capiri*. They are good for coffee varieties that are more shade tolerant, and provide complementary benefits like fuel wood and timber as well.

2.3.2. Species preferred for timber

Some of the species that are good for coffee shade are also worthy for timber, such as *Enterolubium cyclocarpum*, *Pithecellobium saman* and *Terminalia oblonga*. *Cedrella odorata* is another high-value timber species sometimes found in coffee plantations. From time to time, coffee farmers harvest small amounts of timber from this species, as an economic complement of coffee production.

The most valuable timber species found in the young forests protected by peasants is *Cordia alliodora*. Small peasants use it to build and repair their houses, as well as to craft working tools.

2.3.3. Species preferred for fuel wood

Lysiloma spp. is species number one for fuel wood, and is mainly collected in the lands of small peasants and cooperative members. *Guazuma ulmifolia* is also collected as fuel wood in peasant's parcels, although it is not the best species for that purpose.

Coffee farmers also trade small amounts of fuel wood by harvesting trees of *Brosimum alicastrum*, *Mastichodendron capiri*, *Guarea glabra* and *Terminalia oblonga* in their coffee plantations. *Eucaliptus camaldulensis*, an exotic species, has been planted in La Suiza farm with the explicit intention of harvesting commercial fuel wood.

2.3.4. Other uses

The municipality of Chichigalpa wanted to enrich the forest at Las Brisas with a series of supposedly endangered species. They planted lines of *Swietenia humilis*, *Cedrella odorata*, *Bombacopsis quinata*, *Enterolobium cyclocarpum*, *Pithecellobium saman*, *Simarouba glauca* and *Gliricidia sepium* within the established forest. Indeed, many of these species are not endangered, since they are abundant in coffee plantations, like *Enterolobium cyclocarpum* and *Gliricidia*

sepium. Other species, such as *Swietenia humilis*, are more difficult to find in the reserve, and their plantation for species diversity conservation is better justified.

Other less obvious services of trees that forest owners mentioned were food for cattle and humans. The fruits produced by *Brosimum alicastrum* are eaten by cattle, and local people prepare with them flour to make a substitute for corn tortillas. Fruits of *Ardisia revoluta*, similar to grapes, are also good to eat.

In brief, findings presented in this section reveal the importance of coffee farmers as the main forest holders in the Reserve. They protect and manage large forest patches of old-growth forests, and keep a forest canopy in their coffee plantations. The way they manage the forest depends on their investment capacity. Wealthy landowners substantially transform the forest to establish expensive coffee plantations with few different tree species, while medium coffee farmers balance coffee cropping and the maintenance of relatively rich forest. Besides coffee farmers, there are other forest holders of minor importance. Independent and associated peasants from “El Pellizco” community are protecting young forests as a source of domestic timber and commercial fuel wood. The forest they manage emerged from bush fields left in fallow in the early 1990’s. Thanks to their fire prevention practices, this forest has developed considerably. In contrast, cooperative members in nearby areas do not allow bushes in fallow to grow taller. As many peasants in the area, they convert shrub fields to agriculture or pasture before they have the chance to become forests. Finally, the municipal government of Chichigalpa has identified particularly rich small forest that is being protected for educational and scientific purposes. All these experiences of forest protection and management carried out by peasants and the mentioned local government are still minor, but have the potential to expand and inspire other similar experiences along the flanks of the volcanoes.

3. Findings on forest richness, composition and structure

The forest sample analysis was carried out to test whether there was a significant influence of the management practices described in the previous section on species richness and composition of the different patches. If there were a significant influence of human practices on forest composition, forest samples classified under the same category (old growth forest, young forest or coffee plantation) or showing a similar land use history would probably display similar compositional characteristics. The main tool to test this hypothesis was the ordination technique, through which the various sample sites are grouped in a two-dimensional or three-dimensional space according to similarities in species composition. The characteristics of the different clusters of samples in the ordination space can be explored in more depth to relate the graph axes to certain causal factors, such as human-made alterations.

The forest analysis also aimed to project how forest composition might change in the future. Human practices might be bringing about important changes in the forest, so their future composition might be substantially different from what it is now. To assess such changes, the analysis focused on diameter variations among individuals of the various species, through the construction of size-class histograms. In addition, a separate analysis of forest composition was performed only with saplings ≤ 4 cm DBH, to evaluate what species were regenerating more abundantly in the understory. The future of the forest is thus hypothesized based on

the presence of saplings and small diameter trees that will potentially dominate the forest stands.

3.1. Adequacy of sampling

Before developing the ordination exercise, the adequacy of sampling test (Bonham 1989) was carried out to evaluate the reliability of forest samples. This test is based on the assumption that tree density should be regularly distributed among all sampling points. If there are significant differences among the density values of the various sampling points (a high standard deviation), the sample is not reliable enough and more points must be taken. The figures obtained applying this test (Table 12) indicate that not enough points were included at any of the sites in order to obtain a representative sampling.

Table 12. Indicators of adequacy of sampling

Forest Sample	N of points sampled	N of points for an adequate sample	Index of Distribution Pattern*
C-Concha	20	30	3.49
C-Rojas	20	36	2.52
C-Sraf	20	23	1.50
OF-Argelia	20	36	2.08
OF-Chichi	20	33	1.70
OF-Concha	1	55	3.25
OF-Rojas	20	41	1.54
OF-Sraf	20	32	1.36
YF-Meyrat	14	36	1.79
YF-Quebra	20	29	1.41
YF-Roger	3	49	2.72
YF-Versa	8	39	1.69

* A value > 1 means that organisms are aggregated.

A value < 1 indicates that they are distributed in a regular pattern.

The most complete samples I performed included 20 points, while many of the sites required between 30 and 40 points to be consistent. C-Sraf was the site where the sample was closer to the requirements (20 points sampled vs. 23 points needed). This site, along with OF-Sraf and YF-Quebra, shows the pattern of distribution values closer to 1, indicating rather regular spatial distribution of trees in the sample.

On the other extreme, OF-Concha was not a trustworthy sample at all. Topography was so rugged and slopes so steep that I was not able to carry out the sampling. I only recorded measurements in one point. Obviously, figures indicate high differences in plant density (highest pattern of distribution value) and point out that many more points are necessary to reach an adequate sample. Other sites with very few sampling points are YF-Roger and YF-Versa. Because of the insufficiency of sampling points, I decided to altogether exclude these three sites (OF-Concha, YF-Roger and YF-Versa) from the forest analysis.

The figures and results of the rest of the samples should also be considered with caution, since they did not meet the sampling requirements either. They should not be taken as conclusive findings, rather as elements suggesting patterns that may form the basis for further research.

3.2. General attributes of the forest samples

Before analyzing the species composition of the different forests sampled, some broad figures about diversity, density and dominance features will be presented in this section (Table 13). They will show a background picture of the various patches, indicating some general similarities and differences among them.

Table 13. Diversity, Density and Dominance features of the different forest samples (Ch-Sc-C Nature Reserve).

Forest Sample	Number of Species	Simpson's dominance index	Shannon-Wiener's information diversity	Stand Density (trees/ha)	Stand Basal Area (dm ² /ha)
C-Concha	18	0.16	2.24	71.05	3618.18
C-Rojas	18	0.10	2.50	197.31	5105.75
C-Sraf	18	0.11	2.49	240.30	2020.12
OF-Argelia	20	0.20	2.24	303.27	3232.35
OF-Chichi	28	0.07	2.95	376.11	5101.82
OF-Rojas	17	0.15	2.27	690.70	1454.17
OF-Sraf	22	0.10	2.65	540.17	2608.14
YF-Quebra	23	0.11	2.57	428.94	1271.96
YF-Meyrat	22	0.09	2.71	404.64	4674.62

In terms of species diversity, OF-Chichi presents an outstanding value. This is the forest sample showing the greatest number of species (28) and the highest Shannon-Weiner's index (2.95). As this index is more sensitive to species evenness and rarity (Barbour et. al., 1999), this high value indicates that there is a wide variety of well-distributed species in OF-Chichi. In contrast, Simpson's dominance index expresses the degree to which the forest stand is dominated by a few species.

Rather than accounting for species diversity and rarity, it gives more importance to dominant species. Its low value for OF-Chichi confirms that there is no particular species dominating this stand. The exceptional species richness and evenness found in this sample clearly differentiates it from the rest of the patches. Other old-growth and young forest stands, including OF-Sraf, YF-Quebra and YF-Meyrat, also present relatively high Shannon-Weiner's values and low Simpson's dominance index, suggesting the same trait of even species distribution although, although species richness is not as high as in OF-Chichi.

In general, coffee plantations exhibit lower species diversity, probably because forests have been thinned in these areas to make room for coffee plants, thereby reducing the total amount of individuals and species in the patch. The thinning effect is clearly reflected in low-density values for the three coffee plantation sites (C-Concha, C-Rojas, C-Sraf), with figures under 240 trees/ha. It does not mean that the stand basal area is equally low. Indeed, Coffee-Rojas shows one of the highest figures (5105.75 dm²/ha), suggesting that although there are relatively few trees, large-diameter individuals dominate an ample area. Two old-growth forests, OF-Argelia and OF-Rojas, also show relatively low diversity figures and high dominance values. Although these patches have been little altered by human practices, there is a tendency for a few species to dominate the stands, thus reducing species richness.

In short, general diversity, dominance and density features show some initial differences among forest stands. Perhaps the most important is the relatively low species diversity and density found in coffee plantations in general, which seems to reflect a forest thinning practice. Diversity and dominance values vary in the rest of the patches. While some forests as OF-Chichi exhibit outstanding species richness and evenness, a few species tend to dominate other stands like OF-Argelia. These differences need to be explored in more depth in terms of species composition.

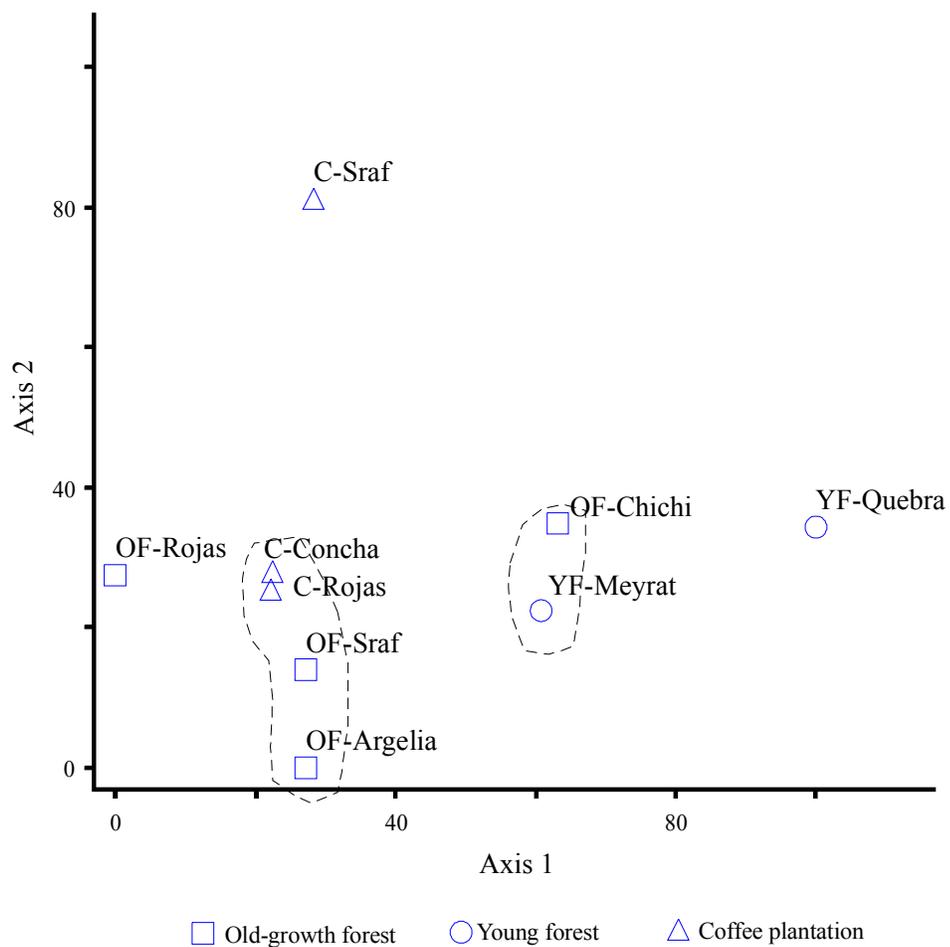
3.3. Forest composition (trees > 4 cm DBH)

The above indicators give a general idea on forest species diversity, density and dominance, but do not provide any insight on forest composition and structure. In order to describe and compare the forest samples at the species level, ordination graphs and forest analysis indicators will be presented as follows. The ordination exercise is based on species importance value (IV) (an average of density, dominance and frequency of each species) for trees > 4 cm DBH, and was performed using the DCA (Detrended Correspondence Analysis) method. To minimize distortions, poorly sampled sites have been excluded from this ordination exercise (Figure 6).

Axis 1 tends to differentiate young forests, located in the right extreme of the axis, from old forests and coffee plantations placed in the opposite low-value

side. YF-Quebra, the youngest forest stand, and OF-Rojas, an old-growth forest, represent extreme endpoints of Axis 1, and are clearly separated from the rest of the samples. YF-Meyrat and OF-Chichi, a young and old-growth forest respectively, appear nonetheless clustered at the same level of the axis, indicating that these young and old-growth stands are not distinguished at this point.

Figure 6. DCA Ordination based on species' Importance Value (IV) showing clusters of forest samples



All the coffee plantations (C-Sraf, C-Concha y C-Rojas) line up at the same point on Axis 1, along with two old-growth forest stands, OF-Sraf and OF-Argelia.

Along Axis 2, C-Sraf is the sample that clearly detaches from the rest of the group, representing one extreme on this axis. Such differentiation suggests that C-Sraf exhibits particular features that separate it from the rest of the samples, especially from old-growth forest OF-Argelia, which is placed at the opposite end of the axis. The other two coffee plantations, C-Concha and C-Rojas, occupy an intermediate position along with the young forests (YF-Meyrat, YF-Quebra) and two old-growth forests (OF-Rojas and OF-Chichi).

The meaning of ordination axes does not seem to rely on measured environmental factors, since no significant correlation was found between environmental variables and axes gradients. Samples with different environmental characteristics, such as soil texture, topography and % slope, were clustered together and vice versa (Table 14). OF-Chichi and YF-Meyrat, for instance, appear close to each other in the ordination graph although they possess different soil texture. YF-Meyrat, located in the older soils of the Casitas volcano, grows on loamy sand soils with a relatively finer texture than the sandy soils found in OF-Chichi, located closer to the recently formed lands of the San Cristóbal. Other environmental variables do not correspond to axis gradient either. C-Concha is located on a flat hilltop of an old volcanic crater, contrasting with the slopes where

the other coffee plantations are found. Despite differences in percentage slope, they are all clustered together.

Table 14. Environmental variables measured for the different forest patches

Patch	% Slope ^a	Topography ^b	Soil texture ^c	% Forest cover ^d
C-Concha	0%	6	2.00	27%
C-Rojas	16%	7	1.33	35%
C-Sraf	8%	3	1.33	31%
OF-Argelia	13%	4	1.50	41%
OF-Chichi	13%	4	1.00	38%
OF-Concha	50%	1	1.00	50%
OF-Rojas	30%	5	1.50	30%
OF-Sraf	20%	8	1.25	49%
YF-Meyrat	25%	5	2.00	37%
YF-Quebra	17%	4	1.00	47%
YF-Roger	29%	2	1.00	52%
YF-Versailles	46%	3	1.00	49%

^a Average of percent slope taken at various points in the sample

^b Index representing topography features that can hold moisture, in ascending order (1 = can hold less moisture; 8 = can hold more moisture)

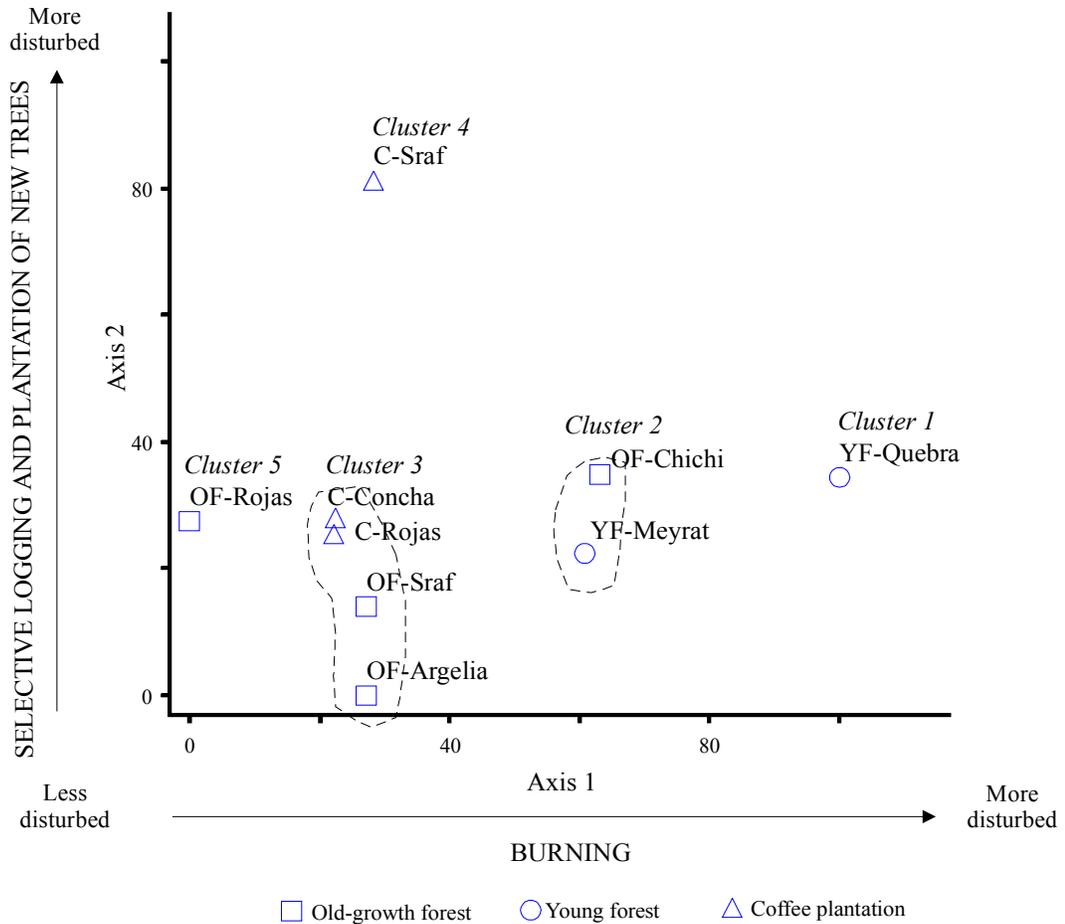
- 1: Steep slope
- 2: Rugged landform
- 3: Moderate slope
- 4: Gently slope
- 5: Hilly
- 6: Flat
- 7: Slope + Terraces
- 8: Creek bank

^c Soil texture index going from coarser to finer sand. 1 = sand, 2 = loamy sand. Values are averages of various measurements in the same sample.

^d Average of percentage forest cover taken at various points in the same sample.

The meaning of the ordination axes has hence to be searched in other causal factors. Based on the land use history of the different patches and the way the various forest types (old-growth forests, young forests and coffee plantations) are clustered, I would like to suggest some correlation between ordination axis and the impact of different types of human-made disturbances (Figure 7). YF-Quebra and OF-Rojas represent two opposite extremes of a disturbance gradient along Axis 1. In the right extreme of this axis, YF-Quebra is the youngest stand, mainly dominated by pioneer species. The land use history of this patch suggests that there was a large forest clearing caused by fires lighted for agricultural or hunting purposes sometime before the peasant community began to protect it. Such burning largely removed late successional species from the area, creating an open field to be colonized by pioneers. On the other extreme of the axis, OF-Rojas appear as an old-growth forest showing no signs of major disturbances. It rather seems to be a well-preserved stand with an important presence of late successional species. Samples at an intermediate point along the axis might have experienced similar but less widespread fire disturbances. This is the case of OF-Chichi and YF-Meyrat, two forest patches surrounded by agricultural and grazing fields exposed to periodical burning. Fires lighted in neighbor areas could have affected the edges of these forests, as it happened three years ago in OF-Chichi. Thus, the land use history of samples differentiated along Axis 1 support the idea that there is a gradient of fire disturbance associated with it.

Figure 7. Suggested correlation between Ordination axes and different types of disturbances (Ch-SC-C Nature Reserve)



Axis 2 represents a different type of disturbance gradient associated with the management practices applied in coffee plantations. This axis differentiates certain coffee plantations (C-Concha and C-Rojas) from some old-growth forests

(OF-Argelia and OF-Sraf), but groups most of these with young forest sites, suggesting that coffee management affects forest composition in a different way. The main forest alteration carried out by coffee landowners is the thinning of the forest to make room for coffee plants, selectively logging from the original forest unsuitable species to provide moderate shade for coffee, and planting new species purposely chosen to combine with coffee plants. C-Sraf, placed in the high extreme of Axis 2, is the coffee plantation where this type of forest alteration has been practiced most intensively. Almost all the original forest cover has been removed in this stand, to be replaced with a few new species actively planted by the landowner.

In the other two coffee plantations, located in a mid point along Axis 2, logging has been less intense and indiscriminate, leaving many late successional species from the original set in combination with other new species introduced by the farmer. YF-Quebra, also placed at an intermediate level along Axis 2, has been moderately logged by peasants to obtain fuel wood and rustic timber, but such practice has not removed any species altogether. We also know that the Municipality of Chichigalpa attempted to enrich the forest at OF-Chichi, purposely planting a few tree lines across the stand. Little is known, however, about logging practices at OF-Chichi and YF-Meyrat.

In old-growth forest stands OF-Sraf and OF-Argelia, displayed at the low extreme of the axis, logging practices were very unusual. Farmers might have

occasionally cut down a few trees to repair farmhouses or replace fence posts, and they have planted no trees purposely. OF-Argelia seems to be a particularly well-preserved stand with minimum human intervention, which corresponds to its location at the bottom of axis.

In summary, the two ordination axes can be interpreted as two different types of human-made disturbance gradients. Axis 1 represents disturbances created by agricultural practices, such as periodic forest burning as part of a fallow cycle. Axis 2 represents the gradient of human disturbances practiced in coffee plantations, consisting of selective logging and plantation of new trees. The combined effect of both axes creates the following clusters or groups of forest samples:

Cluster 1: Recently burned forest (YF-Quebra)

Cluster 2: Forests partially affected by fires (OF-Chichi and YF-Meyrat)

Cluster 3: Intermediate disturbed forests and coffee plantations (C-Concha, C-Rojas, OF-Sraf and OF-Argelia)

Cluster 4: Intensively logged coffee plantation (C-Sraf)

Cluster 5: Undisturbed old-growth forest (OF-Rojas)

Species composition associated with the various forests clusters tends to reflect disturbance gradients as well (ordination in Figure 8, species codes in Table

Table 15. Species codes and classification according to their life-history strategies (based on qualitative observations in the field)

Species	Code	Life-History*	Species	Code	Life-History
<i>Acacia angustissima</i>	Acaang	NC	<i>Erythrina berteroana</i>	Eryber	NC
<i>Acacia collinsii</i>	Acacol	I	<i>Ficus cotinifolia</i>	Ficcot	L
<i>Acacia mangium</i>	Acaman	P	<i>Genipa americana</i>	Gename	NC
<i>Albizia caribaea</i>	Albcar	I	<i>Gliricidia sepium</i>	Glisep	P
<i>Albizia guachapele</i>	Albgua	NC	<i>Guarea glabra</i>	Guagla	Late
<i>Andira inermis</i>	Andine	NC	<i>Guazuma ulmifolia</i>	Guaulm	P
<i>Annona reticulata</i>	Annret	I	<i>Inga vera</i>	Ingver	P
<i>Apeiba tibourbou</i>	Apetib	I	<i>Karwinskia calderonii</i>	Karcad	NC
<i>Ardisia revoluta</i>	Ardrev	LU	<i>Lippia cardiostegia</i>	Lipcar	U
<i>Bauhinia variegata</i>	Bauvar	NC	<i>Lonchocarpus parviflorus</i>	Lonpar	P
<i>Bixa orellana</i>	Bixore	NC	<i>Luehea candida</i>	Luecan	P
<i>Bravaisia integerrima</i>	Braint	U	<i>Lysiloma spp.</i>	Lysspp	P
<i>Brosimum alicastrum</i>	Broali	L	<i>Mastichodendron capiri</i>	Mascap	L
<i>Bursera simarouba</i>	Bursim	NC	<i>Muntingia calabura</i>	Muncal	NC
<i>Byrsonima crassifolia</i>	Byrcra	NC	<i>Persea americana</i>	Perame	NC
<i>Calycophyllum candidissimum</i>	Calcan	I	<i>Pisonia spp.</i>	Pisspp	NC
<i>Cananga odorata</i>	Canodo	NC	<i>Pithecellobium saman</i>	Pitsam	I
<i>Casearia corymbosa</i>	Cascor	NC	<i>Pseudolmedia oxiphyllaria</i>	Psuoxi	NC
<i>Castilla elastica</i>	Casela	I	<i>Rehdera trinervis</i>	Rehtri	NC
<i>Cecropia obtusifolia</i>	Cecobt	P	<i>Sapium macrocarpum</i>	Sapmac	NC
<i>Cedrella odorata</i>	Cedodo	I	<i>Saprahus nicaraguensis</i>	Sapnic	IU
<i>Ceiba pentandra</i>	Ceipen	NC	<i>Sciadodendron excelsum</i>	Sciexc	NC
<i>Clorophora tinctoria</i>	Clotin	I	<i>Senna nicaraguensis</i>	Sennic	I
<i>Cochlospermum vitifolium</i>	Cocvit	NC	<i>Simarouba glauca</i>	Simgla	NC
<i>Cordia alliodora</i>	Corall	P	<i>Spondia mombin</i>	Spomom	I
<i>Cordia dentata</i>	Corden	P	<i>Spondias purpurea</i>	Spopur	NC
<i>Cordia gerascanthus</i>	Corger	P	<i>Stemmadenia obovata</i>	Steobo	NC
<i>Crataeva palmeri</i>	Crapal	NC	<i>Sterculia apetala</i>	Steape	NC
<i>Cupania cinerea</i>	Cupcin	P	<i>Tabebuia crisantha</i>	Tabcri	I
<i>Cupania spp.</i>	Cupspp	P	<i>Tabebuia rosea</i>	Tabros	I
<i>Diospyros nicaragüensis</i>	Dionic	NC	<i>Terminalia catappa</i>	Tercat	L
<i>Enterolubium cyclocarpum</i>	Entcyc	I	<i>Terminalia oblonga</i>	Terobl	L

* L=Late, I=Intermediate, P=Pioneer, LU=Late understory, IU=intermediate understory, U=Understory, NC=Non-classified.

There is also another cluster of species close to this forest, although a little separated along Axis 2, including *Lonchocarpus parviflorus*, *Spondia mombin* and *Tabebuia crisantha*. It is notable that most of these species are colonizers of open spaces, like *Lysiloma spp.* and *Lonchocarpus parviflorus*, or small trees adapted to populate the understory of thin forests, such as *Diospyros nicaragüensis* and *Cupania spp.* There are only a few species able to grow under the shade of other trees, as may be *Tabebuia crisantha*. This set of species match with the classification of YF-Quebra as a young forest, where pioneers tend to dominate.

Cluster 2 is composed of OF-Chichi and YF-Meyrat, two forest stands somewhat affected by fires that created openings at their edges. OF-Chichi presents a slightly higher value along Axis 2, indicating that occasional logging might have affected forest composition in this stand. More recently, the Municipality of Chichigalpa carried out the plantation of several lines of new trees in this patch, clearing narrow belts in the understory to introduce species other than the ones that were naturally regenerating. This patch experienced, therefore, a combination of low-intense burning and logging disturbances. Species arranged near Cluster 2 are *Enterolubium cyclocarpum*, *Guarea glabra*, *Simarouba glauca*, *Acacia collinsii* and *Sterculia apetala*. Other species found at the same longitudinal level, although spread out along Axis 2, are *Cordia alliodora*, *Guazuma ulmifolia*, *Sapium macrocarpum* and *Saprathus nicaragüensis*. This list of species includes a combination of early and late successional species. There are long-lived pioneers

such as *Cordia alliodora*, gap colonizers like *Enterolobium cyclocarpum* and also very shade tolerant species able to grow up under other trees' canopy, such as *Guarea glabra*. This mixture of different types of species reflects a forest composition clearly different from the species association found near to YF-Quebra, solely dominated by pioneers. Moderate disturbances affecting Cluster 2 seem to have enhanced species richness and evenness, creating some openings shared by a mixture of pioneers and gap colonizers, while late successional species remain in undisturbed areas.

Coffee plantations and old-growth forests combine to form Cluster 3. Within the cluster, the two coffee plantations (C-Concha and C-Sraf) lie very close to each other in the vertical line, while the forests (OF-Argelia and OF-Sraf) are slightly separated. This separation reflects the fact that coffee plantations have been more altered by selective logging, while old-growth forests have been mainly affected by infrequent and minor fires. Fire disturbance signals are more evident in OF-Sraf, where a mosaic of tall-forest patches and short woods create an uneven forest canopy. Short-vegetation spots probably represent openings created by fires, from which young trees have developed. Species placed around this cluster reflect both logging and fire disturbances affecting old-growth forests dominated by late successional species. One set of species close to Cluster 3 includes *Cedrella odorata*, *Ficus cotinifolia*, *Casearia corymbosa*, *Stemmadenia obovata* and *Cecropia obtusifolia*. Another cluster of species between this group of samples and

C-Sraf is composed of *Mastichodendron capiri*, *Castilla elastica* and *Muntingia calabura*. In addition, one more group of species is found in the same region but closer to OF-Rojas, including *Tabebuia rosea*, *Cordia dentata*, *Persea americana*, *Psudolmedia oxiphyllaria*, *Lippia cardiostegia*, and *Ceiba pentandra*. *Brosimum alicastrum*, *Bixia orellana* and *Terminalia catappa* are also placed nearby, particularly close to OF-Argelia. *Brosimum alicastrum* is a dominant late successional species present in different combinations in all of the stands. It is especially dominant and widespread in OF-Argelia, suggesting that this patch is in a late successional stage little affected by disturbances. In OF-Sraf, *Brosimum alicastrum* combines with typical colonizers of open fields such as *Cecropia obtusifolia* and *Castilla elastica*, indicating that disturbances in this old-growth forest have opened gaps where pioneers take over. In the coffee plantations, *Brosimum alicastrum* mixes together with other late successional species like *Mastichodendron capiri* and *Cedrela odorata*, as well as species planted by the landowners, such as *Gliricidia sepium* and *Acacia mangium*, which display closer to C-Sraf in the ordination space. It seems that the various stands in this cluster represent variations of a common type of old-growth forest dominated by *Brosimum alicastrum*, which has been altered by different types of disturbances leading to deviations from the same original forest.

Cluster 4 (C-Sraf) represents a coffee plantation where the forest has been excessively logged to the point of removing most of the original late successional

species. Farmers have replaced them with early successional species they have introduced to better combine with coffee plants, such as *Inga vera*, *Gliricidia sepium* and *Acacia mangium*. Only few late successional species, like *Terminalia oblonga*, plot out close to this cluster, as a sign of the mature forest that existed before.

Extremely altered Cluster 4 contrasts with well-preserved Cluster 5 (OF-Rojas), located in the low extreme of Axis 1. Along with OF-Argelia, this is the best-preserved forest stand, showing no sign of disturbance. *Brosimum alicastrum* is again an overstory dominant species at OF-Rojas, this time in combination with *Ardisia revoluta*, an understory species that lies very close to this stand in the ordination graph. Another important species clustered in the area near to OF-Rojas is *Cordia dentata*, adapted to colonize small gaps and survive in the understory. There are no real pioneers in this cluster, confirming its stage of undisturbed old-growth forest.

Forest composition at each cluster will be presented in more detail as follows. I assumed that stands in the same cluster were similar enough to be treated as a single unit, so all the individuals sampled in the different patches were grouped by clusters and processed to portray their forest composition.

3.3.1. Forest composition at Cluster 1

Cluster 1 is clearly dominated by pioneer species, particularly *Lysiloma spp.*, *Cordia alliodora* and *Lonchocarpus parviflorus* (Table 16). *Lysiloma spp.*, the

main species in the sample, is a pioneer with the ability of colonizing stony and dry sites (Faurby and Barahona, 1999). *Lonchocarpus parviflorus* is also a colonizer of open fields, and so is *Cordia alliodora* (Figure 9), yet the last can remain in the stand for longer periods, forming part of an old-growth forest.

Apeiba tobourbou and *Spondia mombin* are the only significant non-pioneer species in this cluster. *Apeiba tibourbou* develops under the shade of pioneer species and quickly dominates the surrounding area producing a wide and dense shade that inhibits the growing of many pioneers. *Spondia mombin* is not as dominant as the former, for it develops in small gaps left by pioneers and shares the space with many other species.

Table 16. Main attributes of the 10 most important species at Cluster 1

Species	Life-History Strategy	IV	AD	ABA	PF
<i>Lysiloma spp.</i>	Pioneer	22.2%	96.5	326	60%
<i>Cordia alliodora</i>	Pioneer	13.2%	69.7	122	45%
<i>Apeiba tibourbou</i>	Intermediate	12.1%	37.5	235	30%
<i>Lonchocarpus parviflorus</i>	Pioneer	7.9%	42.9	56	30%
<i>Spondia mombin</i>	Intermediate	7.7%	26.8	115	25%
<i>Guazuma ulmifolia</i>	Pioneer	7.3%	26.8	103	25%
<i>Luehea candida</i>	Pioneer	3.8%	16.1	57	10%
<i>Cupania spp.</i>	Pioneer	3.0%	10.7	45	10%
<i>Cochlospermum vitifolium</i>	Pioneer	2.4%	10.7	21	10%
<i>Saprathus nicaraguensis</i>	Intermediate Understory	2.4%	10.7	21	10%

IV = Importance Value; AD = Absolute Density (trees/ha); ABA = Absolute Basal Area (dm²/ha); PF = Percent Frequency

Figure 9. *Cordia alliodora* tree in the middle of a grazing field in Costa Rica. *Cordia alliodora* is one of most dominant pioneer species at Cluster 1.



Source: The Evergreen West College.
Olympia, Washington. <http://www.evergreen.edu>

There is no other group besides Cluster 1 where pioneers dominate the forest in the first place. They might appear in other samples, but they are always mixed with other late successional species. This confirms the young nature of YF-Quebra, the only sample in Cluster 1, which emerged from an agricultural field some years ago.

3.3.2. Forest composition at Cluster 2

Cluster 2 displays a rich combination of species with different life histories, including pioneers, gap colonizers, understory shrubs and shade-tolerant trees (Table 17). *Guarea glabra*, *Mastichodendron capiri* and *Brosimum alicastrum* are able to grow up under other trees' shade, taking advantage of very small openings. They are characteristic of adult forests. *Enterolobium cyclocarpum* (Figure 10) colonizes gaps left by pioneer species (Faurby and Barahona, 1999). *Annona reticulata* is a medium-height tree adapted to live with little solar radiation in the low forest layer. *Guazuma ulmifolia* behaves as a pioneer, able to colonize open fields and big gaps.

Such a variety of species with different profiles indicates a very dynamic forest where early- and late-successional species exchange places according to opportunities. Disturbances play an important role in creating small environments favoring the emergence of certain species and preventing the strong competitors to dominate the forest.

Table 17. Main attributes of the 10 most important species at Cluster 2

Species	Life-History Strategy	IV	AD	ABA	PF
<i>Guarea glabra</i>	Late	15.1%	59.83	931	60%
<i>Ficus cotinifolia</i>	Late	7.9%	2.85	1084	5%
<i>Guazuma ulmifolia</i>	Pioneer	7.8%	39.89	232	45%
<i>Sapium macrocarpum</i>	Intermediate	6.2%	25.64	321	30%
<i>Apeiba tibourbou</i>	Intermediate	5.8%	19.94	336	30%
<i>Annona reticulata</i>	Intermediate	5.2%	28.49	46	40%
<i>Enterolobium cyclocarpum</i>	Intermediate	4.9%	5.70	558	10%
<i>Castilla elastica</i>	Intermediate	4.7%	22.79	87	35%
<i>Cecropia obtusifolia</i>	Pioneer	3.5%	14.25	104	25%
<i>Acacia collinsii</i>	Intermediate	3.4%	19.94	27	25%

IV = Importance Value; AD = Absolute Density (trees/ha);

ABA = Absolute Basal Area (dm²/ha); PF = Percent Frequency

Figure 10. *Enterolobium cyclocarpum* tree in a coffee plantation in the Carazo region, Nicaragua. This is one of the intermediate species found at Cluster 2.



Source: Taken by the author in 1999.

3.3.3. Forest composition at Cluster 3

There is a contrast between late- and early-successional species composing Cluster 3 (Table 18). *Brosimum alicastrum*, a typical late species, reproduces conspicuously and commonly dominates the forest, along with *Terminalia oblonga*. Pioneers like *Gliricidia sepium*, *Cecropia obtusifolia* and *Cordia dentata* mix with these late species, suggesting that disturbances are creating openings in mature forests where pioneers become established. *Gliricidia sepium* has been intentionally promoted in coffee plantations because it provides an ideal level of shade to coffee plants, whereas *Cecropia obtusifolia* and *Cordia alliodora* grow naturally both in the coffee fields and in gaps created by fires affecting the edges of old-growth forests.

This combination of late successional species and pioneers, with little presence of intermediate species, suggests that mature forests that reached a climax stage, indicated by the presence of strongly dominant late species, have been recently disturbed both by logging and fires, which accommodates pioneers.

Table 18. Main attributes of the 10 most important species at Cluster 3

Species	Life-History Strategy	IV	AD	ABA	PF
<i>Brosimum alicastrum</i>	Late	24.5%	45.1	1747	95%
<i>Terminalia oblonga</i>	Late	6.3%	5.9	504	40%
<i>Gliricidia sepium</i>	Pioneer	6.2%	16.0	106	75%
<i>Ficus cotinifolia</i>	Late	5.7%	4.7	532	25%
<i>Cecropia obtusifolia</i>	Pioneer	5.0%	14.2	80	55%
<i>Cordia alliodora</i>	Pioneer	4.5%	12.5	57	55%
<i>Cordia dentata</i>	Pioneer	4.2%	12.5	40	50%
<i>Castilla elastica</i>	Intermediate	4.0%	8.3	65	60%
<i>Mastichodendron capiri</i>	Late	3.7%	4.7	244	30%
<i>Guarea glabra</i>	Late	3.6%	5.9	137	45%

IV = Importance Value; AD = Absolute Density (trees/ha);
 ABA = Absolute Basal Area (dm²/ha); PF = Percent Frequency

3.3.4. Forest composition at Cluster 4

Cluster 4 is widely dominated by a single pioneer species purposely planted by the farmer for the good of coffee, *Inga vera* (Table 19). *Acacia mangium* is another exotic species introduced with the same goal. They indicate the deep forest transformation carried out by the farmer in this patch, replacing the original old-growth forest by an artificial arrangement of pioneer species. Only *Terminalia oblonga* remains as an important late successional species in this sample. In no other coffee plantation sampled, has the forest composition been so drastically modified by humans as in this patch.

Table 19. Main attributes of the 10 most important species at Cluster 4

Species	Life-History	IV	AD	ABA	PF
<i>Inga vera</i>	Pioneer	21.5%	57	506	50%
<i>Terminalia oblonga</i>	Late	10.7%	30	141	40%
<i>Guazuma ulmifolia</i>	Pioneer	8.2%	18	156	30%
<i>Acacia mangium</i>	Pioneer	7.7%	18	190	20%
<i>Cordia alliodora</i>	Pioneer	7.6%	21	92	30%
<i>Castilla elastica</i>	Intermediate	7.5%	15	168	25%
<i>Gliricidia sepium</i>	Pioneer	6.7%	15	154	20%
<i>Albizia caribaea</i>	Intermediate	6.4%	12	161	20%
<i>Senna nicaraguensis</i>	Intermediate	4.5%	3	217	5%
<i>Clorophora tinctoria</i>	Intermediate	3.3%	12	7	15%

IV = Importance Value; AD = Absolute Density (trees/ha);
 ABA = Absolute Basal Area (dm²/ha); PF = Percent Frequency

3.3.5. Forest composition at Cluster 5

Cluster 5 is mainly composed of a combination of overstory and understory late successional species. *Brosimum alicastrum*, in the overstory, and *Ardisia revoluta*, in the understory, are the most important late successional species dominating the forest (Table 20). *Ardisia revoluta* (Figure 11) is a very shade-tolerant species with great dispersal ability. It has adapted to live in the understory, beneath the canopy of late successional species *Brosimum alicastrum*. The only pioneer species found in this cluster is *Cordia dentata*, which also has the ability to persist as an understory species beneath the canopy of late species.

The major occurrence of late species in this cluster, with little or no presence of pioneers and intermediate species, suggests that this forest has reached a sort of climax stage, with no disturbances creating opportunities for other species to fill in.

Table 20. Main attributes of the 10 most important species at Cluster 5

Species	Life-History Strategy	IV	AD	ABA	PF
<i>Ardisia revoluta</i>	Late Understory	20.2%	189.9	138	70.0%
<i>Cordia dentata</i>	Pioneer	18.2%	146.8	241	50.0%
<i>Brosimum alicastrum</i>	Late	11.7%	69.1	192	35.0%
<i>Castilla elastica</i>	Intermediate	10.7%	60.4	243	20.0%
<i>Terminalia oblonga</i>	Late	7.4%	43.2	156	15.0%
<i>Guarea glabra</i>	Late	4.9%	34.5	43	20.0%
<i>Senna nicaraguensis</i>	Intermediate	6.8%	25.9	170	15.0%
<i>Bravaisia integerrima</i>	Understory	2.6%	17.3	28	10.0%
<i>Clorophora tinctoria</i>	Intermediate	3.0%	17.3	45	10.0%
<i>Lippia cardiostegia</i>	Understory	2.4%	17.3	20	10.0%

IV = Importance Value; AD = Absolute Density (trees/ha);
 ABA = Absolute Basal Area (dm²/ha); PF = Percent Frequency

Figure 11. Leaves and fruits of *Ardisia revoluta*, a widespread understory species in Cluster 5



Source: Texas A & M Bioinformatics Working Group
 Vascular Plant Image Gallery. <http://www.csdl.tamu.edu/FLORA/gallery.htm>

3.4. Forest dynamics

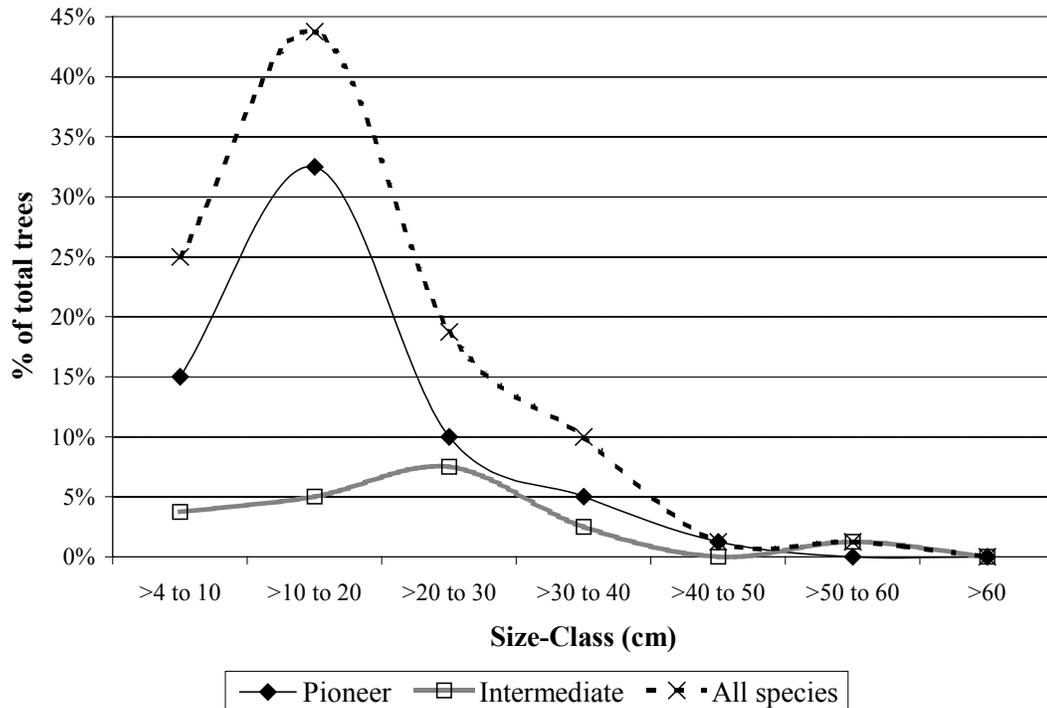
The current species composition at the different sites is likely to change over time. Various techniques allow us to anticipate some of these future trends by looking at the age structure of species populations. The following graphs, representing histograms of species size categories for plants > 4 cm DBH, are one of the instruments to forecast forest dynamics. Size classes plotted in the histograms are taken as indicators of different periods of plant recruitment, with trees in small size categories representing emerging young plants and trees in large size classes meaning mature individuals dominating the forest. If the histogram shows a good amount of individuals in small size classes, gradually decreasing in the larger categories (reverse-J curve), then the population is likely to perpetuate itself in the future, for young trees recruiting at a constant rate will replace the old ones little by little. The histogram might also display periods where tree recruitment is interrupted, represented by the absence of individuals in certain size classes. If there is few or no recruitment in the small size classes, a decrease or total lack of future adult populations can be expected.

Separate size-class histograms were elaborated for pioneer, intermediate and late successional species at each cluster, in order to assess future trends of each one of these species categories. These histograms provide clues on forest succession, indicating which species type are more likely to dominate the forest in the future.

3.4.1. Size-class structure at Cluster 1

In general, pioneers are recruiting more abundantly in Cluster 1, contrasting with minimal regeneration of intermediate successional species (Figure 12). The histogram for pioneer species exhibits a bell-shaped curve, with more individuals in the middle size-class between 10 and 20 cm DBH, but very few trees of smaller or larger diameters. It seems that pioneers experienced a period of intense recruitment, leading to the relatively high number of trees in this middle category. Pioneer recruitment probably increased when the stand was an open field, but later reached the point where competition forces the recruitment of new trees to slow down. This decrease of the curve happened earlier in the case of intermediate successional species. In the 20 to 30 cm DBH size-class, intermediate species present almost the same number of individuals as pioneers, but the curve drops in the smaller categories, suggesting that intermediate species were not able to take over the site as fast as pioneers did.

Figure 12. Size-class histograms for Cluster 1



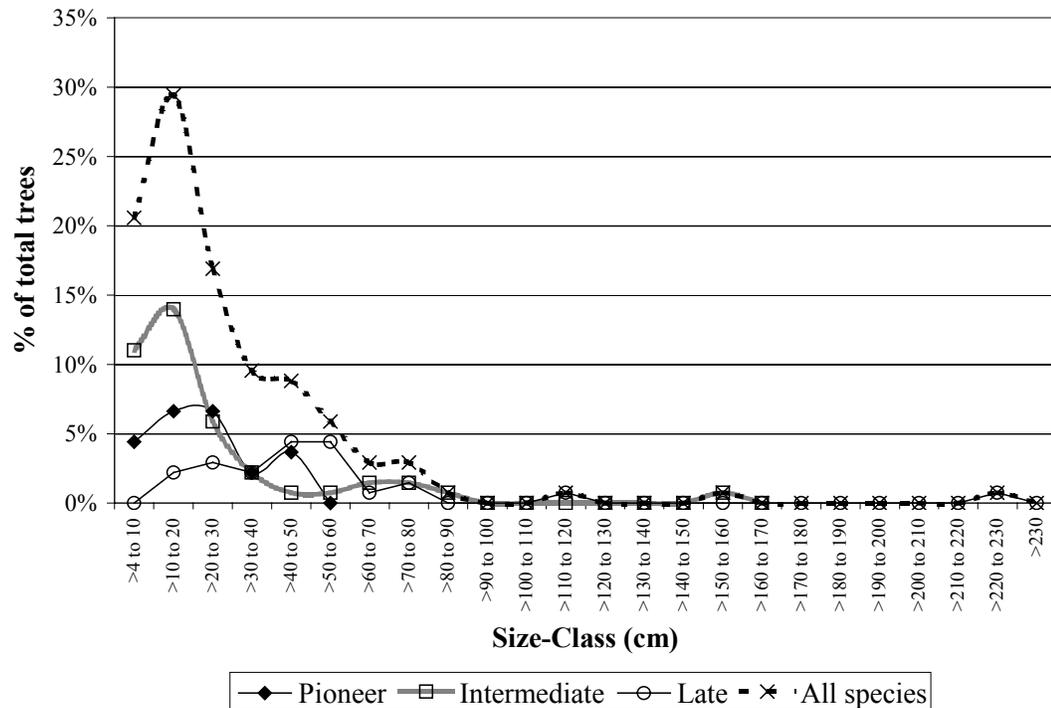
There is no sign that intermediate species will recruit more conspicuously in the near future. Pioneer species will probably continue dominating the forest in Cluster 1, although intense competition among these early species is leading to a decrease in their recruitment rates, which in the long run might mean an opportunity for intermediate species to become more frequent and important. If a new fire strikes this forest stand, though, pioneer species are likely to recolonize the area, taking advantage of the open field more quickly than any other species type.

3.4.2. Size-class structure at Cluster 2

Histograms for Cluster 2 show a pulsating recruitment of the different species types (Figure 13), with periods of intense regeneration followed by episodes of decreasing rates of renewal. This is particularly true for late and pioneer species, whose curves peak and drop several times. It is notable that there are few individuals of late species in the small size classes, between 0 and 30 cm DBH, while greater number of trees are found in larger categories, especially between 40 and 60 cm DBH, where the curve reaches its highest point. Decreasing recruitment of late species in recent periods contrast with the irregular increase of early and intermediates species regeneration in recent times. Instead of becoming increasingly abundant, late species have almost stopped their recruitment while intermediate and pioneer species are reproducing intensively. Reduction of late species and increase of pioneers might be an effect of fires reaching the forest edges, to which species respond differently according to their life histories.

Given the pulsating nature of the histograms at Cluster 2, however, the increasing recruitment of intermediate and pioneer species might be only episodic. Regeneration of late species could peak again, thus maintaining its presence in the woods. Forests composing Cluster 2 are so dynamic that it is not possible to predict that any particular species type will become dominant in the future. It seems that the space will always be shared by early, intermediate and late species replacing each other in a pulsating fashion.

Figure 13. Size-class histograms for Cluster 2

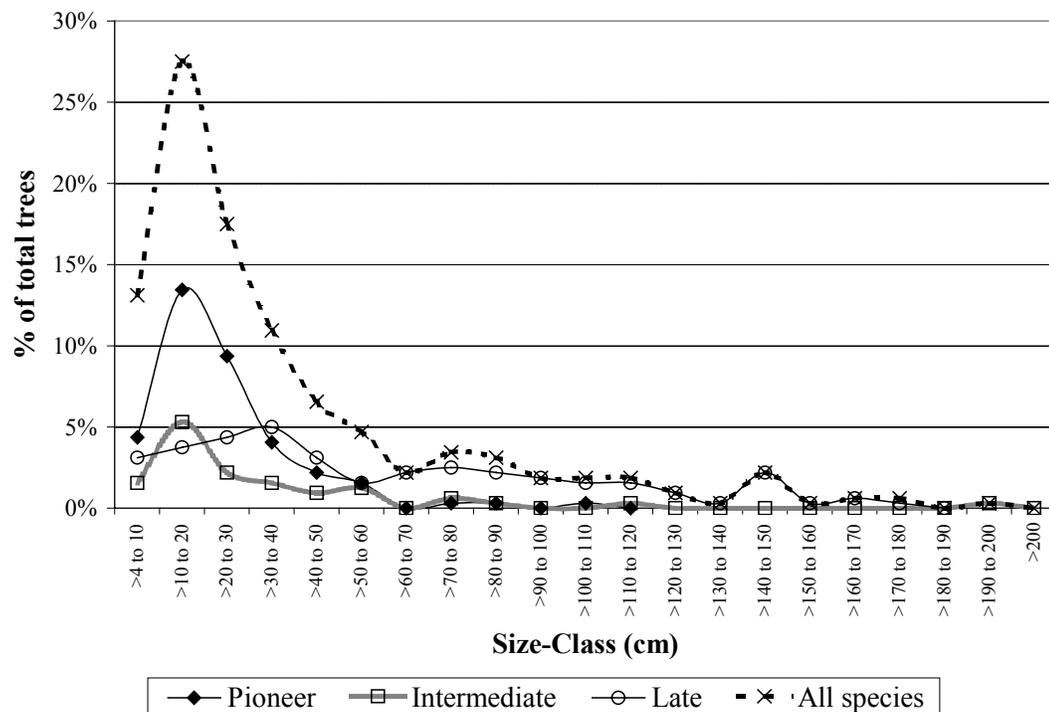


3.4.3. Size-class structure at Cluster 3

Late and intermediate successional species present relatively constant rates of recruitment in Cluster 3, showing no sharp variations in their histograms especially for the large size classes (Figure 14). Late species had a period of increasing regeneration represented by high numbers of individuals in the 30 to 40 cm DBH size-class. The curve descends gently, nonetheless, in the smaller size classes (10 to 20 cm DBH), precisely where pioneers and intermediate species histograms reach their peak. This pioneer boost does not correspond to a sharp drop

in late species recruitment, whose curve tends to maintain former levels in spite of its gentle descent. It gives the impression that minor disturbances in an old-growth forest allow pioneer species to fill in, but without inhibiting the constant recruitment of late and intermediate species. If such disturbances (fires, logging) do not become too frequent and extensive, it is likely that late species will continue recruiting and maintaining their importance in forests of Cluster 3.

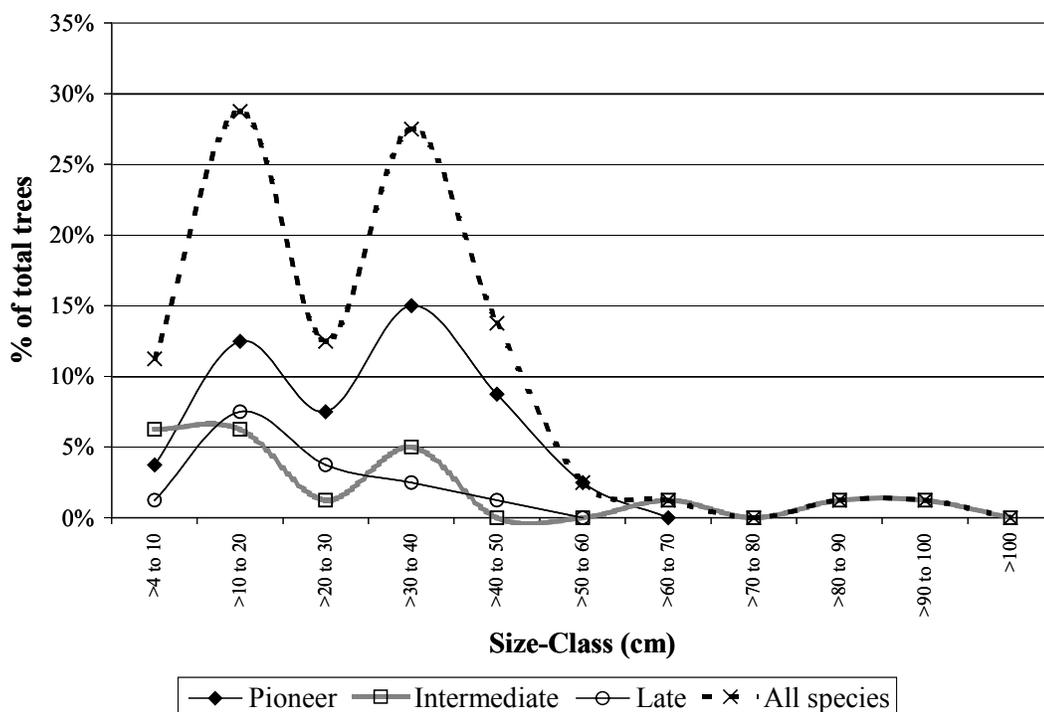
Figure 14. Size-class histograms for Cluster 3



3.4.4. Size-class structure at Cluster 4

The histogram for all species at Cluster 4 presents a bi-modal shape with two peaks interrupted by episodes of sharp decrease (Figure 15). This tendency is particularly clear in the case of pioneer species, whose curve shows high numbers of trees in the 10-to-20 and 30-to-40 cm DBH size classes, the two moments where the line reaches its highest points. The histogram for intermediate species tends to follow the same pattern, although this curve does not deep in the smallest 0-to-20 cm DBH category, as the former does. Late species histogram, finally, only peaks in one of the two moments, presenting a steep rise in the 10-to-20 cm DBH category and gentle descent towards the larger size classes.

Figure 15. Size-class histograms for Cluster 4



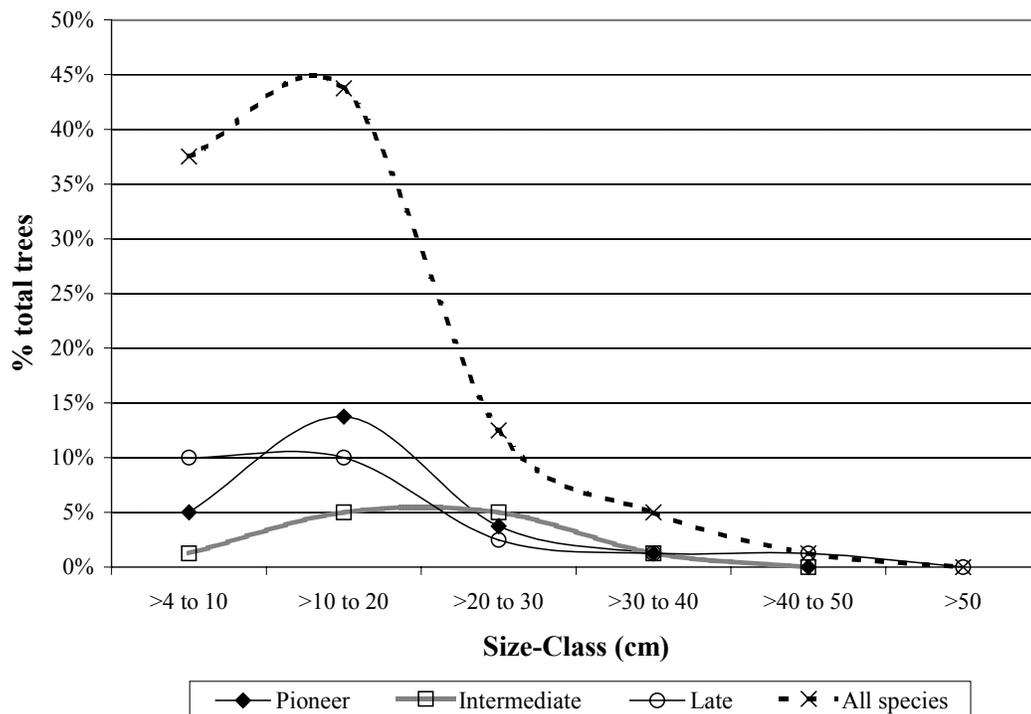
The bi-modal histogram shape taken by pioneer and, to some extent, intermediate species as well, suggests periods of general recruitment interruption, probably triggered by understory clearing practices carried out by the coffee farmer. Such interruptions make the species regenerate in waves, showing only short periods of intense recruitment. The coffee landowner might be actively assisting episodic species regeneration by planting the desired species at once. The wavy pattern of the curves reflects active regeneration of pioneers, which are better prepared to take over a site and develop in a short period. Intermediate and late species need more time to fasten their position in the forest, and frequent recruitment interruptions inhibit their development towards a stable stage. They are thus recruiting slowly before the new interruption catches them. In such scenario, late and intermediate species are not likely to become dominant, although they will not disappear altogether either.

3.4.5. Size-class structure at Cluster 5

Histograms at Cluster 5 are based on relatively few trees, so it is difficult to infer firm trends from their analysis. The tendencies suggested by the shape of the curves should be therefore taken with caution. The profile of the histogram for late species contrasts with the shape of the curve for pioneer and intermediate species (Figure 16). Pioneer species present a period of high regeneration in the 10-to-20 cm DBH class, but its curve drops in the more recent period (the 0-to-10 cm DBH category). Late species, in contrast, start recruiting at moderate rates in the larger

size classes, but regenerate more abundantly in recent periods, when pioneer and intermediate species have decreased their rhythms of renewal. This contrast might signify a shift in species dominance, transiting from a forest dominated by pioneers to a stand where late species become more and more important. Such shift from early to late species correspond to a linear pattern of forest succession in which pioneers favor the further development of late species that tend to maintain themselves in the climax stage.

Figure 16. Size-class histograms for Cluster 5



The insufficient amount of trees composing the histograms does not allow us, however, to consider these trends as conclusive patterns. It is not certain that late species are going to eternally maintain themselves while intermediate and early species cease recruiting. It is necessary to observe the forest at Cluster 5 for a longer period to confirm if the linear sequence of succession is going to persist.

3.4.6. Regeneration of saplings (≤ 4 cm DBH)

Another instrument I used to assess forest dynamics was performing a separate PCQ sampling for saplings smaller than 4 cm DBH, as an indicator of species that are regenerating more or less abundantly. It does not necessarily mean that these species will survive and populate the forest in the future, but gives an idea of which might have a chance from the beginning. Importance values of sapling species were calculated for every cluster (Table 21), so it is possible to contrast species of large trees already established in the forest with species of saplings that are just regenerating.

Saplings of pioneer species already present at Cluster 1 as dominant trees are also regenerating on the ground. *Lonchocarpus parviflorus* and *Cordia alliodora* are the two pioneer species with higher importance values in this cluster. They are also present as important species in the overstory, meaning that these early species are still reproducing conspicuously and probably will remain dominant for a longer time. This is not the case of *Lysiloma spp.*, currently the most important species among adult trees, which does not appear with such extreme

importance among saplings. Conversely, *Tabebuia crisantha* does not occupy a significant position in the overstory but shows a high importance value among regenerating plantlets, suggesting that this intermediate species might gain space in future forest composition when pioneers start to die out due to competition pressures. Besides *Tabebuia crisantha*, there is not truly intermediate or late species producing saplings at Cluster 1. Other species found among seedlings are either pioneers, like *Luehea candida*, or undrestory shrubs such as *Saprathus nicaragüensis*, *Casearia corymbosa* and *Dyospiros nicaragüensis*. The lack of late species saplings represent a constrain for this forest to evolve into a more complex patch, integrating a variety species with diverse life-history strategies.

Saplings in Cluster 2 balance the importance of pioneers, such as *Cordia alliodora* and *Guazuma ulmifolia*, and late successional species, like *Brosimum alicastrum* and *Guarea glabra*. Also present in the overstory, these species are producing enough plantlets to supply their future persistence. Intermediate species, instead, are difficult to find among saplings. Species such as *Enterolobium cyclocarpum*, *Annona reticulata* and *Sapium macrocarpum*, all present in the overstory, are not generating samplings. If these intermediate species are not able to reproduce and maintain their importance, late and pioneer species might occupy the forest, thereby reducing species diversity in Cluster 2.

Table 21. Importance values of the main 20 species saplings regenerating in all clusters

Species	Life-History Strategy	Cluster			
		1	2	3	5
<i>Ardisia revoluta</i>	Late understory			0.5%	29.7%
<i>Lonchocarpus parviflorus</i>	Pioneer	26.6%		1.5%	
<i>Brosimum alicastrum</i>	Late		6.2%	8.1%	10.4%
<i>Senna nicaraguensis</i>	Intermediate			13.0%	9.1%
<i>Cordia alliodora</i>	Pioneer	8.8%	5.4%	3.4%	1.6%
<i>Tabebuia crisantha</i>	Intermediate	13.8%	1.7%	1.7%	
<i>Stemmadenia obovata</i>	Understory		2.5%	3.2%	10.7%
<i>Luehea candida</i>	Pioneer	4.4%	7.3%	1.5%	
<i>Capparis flexuosa</i>					12.6%
<i>Castilla elastica</i>	Intermediate		6.1%	3.9%	1.6%
<i>Guazuma ulmifolia</i>	Pioneer		7.3%	3.9%	
<i>Saprahus nicaraguensis</i>	Understory	4.4%	2.5%	3.6%	
<i>Rehdera trinervis</i>		7.4%	2.9%		
<i>Diospyros nicaraguensis</i>	Understory	6.6%	3.3%		
<i>Casearia corymbosa</i>	Understory	5.9%	0.8%	2.6%	
<i>Lysiloma spp.</i>	Pioneer	4.4%		3.9%	
<i>Bauhinia variegata</i>			4.1%	3.7%	
<i>Guarea glabra</i>	Late		4.1%	1.0%	2.2%
<i>Cupania spp.</i>		2.9%	2.5%		1.6%
<i>Lippia cardiostegia</i>		2.9%		1.5%	1.6%

Only based on sapling sampling, though, it is not possible to be certain that this is a trend. Size-class histograms for this cluster show a different picture, with intermediate species abundantly recruiting in the small-size categories.

Late species *Brosimum alicastrum* and intermediate species *Senna nicaraguensis* are producing abundant saplings in Cluster 3. Most of the saplings of *Brosimum alicastrum* were seedlings < 0.5 m height, while there were very few individuals in the > 1.5 m height category. This indicates that although *Brosimum alicastrum* is regenerating abundantly, not all the seedlings are developing successfully, since only a minor proportion of them are reaching the height level

where they have a better chance to persist in the forest. Pioneers such as *Cordia alliodora*, *Guazuma ulmifolia* and *Lysiloma spp.* are also present among saplings, but in minor quantities. Abundant regeneration of late species saplings support the hypothesis that forests at Cluster 3 will keep dominated by late species, with the addition of few pioneer trees taking advantage of small and infrequent disturbances. It is notable that none of the pioneer species purposely planted by coffee farmers in this cluster are regenerating naturally. They depend on human assistance to reproduce and maintain their presence in the forest.

I found no saplings in Cluster 4, for the ground was largely covered by vines and lianas that enveloped even the coffee plants. It is not possible to know which species are likely to regenerate in the current conditions of this site.

Late species *Ardisia revoluta* and *Brosimum alicastrum* are the most important among saplings in Cluster 5. These are exactly the same species dominating among established trees, which indicates that the present forest composition is likely to perpetuate in time. *Brosimum alicastrum*'s saplings are, however, in the lowest height category (< 0.5 m). It is not clear then how many seedlings of this species will develop into larger trees. Other understory shrub species like *Stemmadenia obovata* and *Capparis flexuosa* are also significant among saplings, but they will never become dominant in the forest. No pioneer species are regenerating significantly, confirming the undisturbed nature of this forest.

In brief, the main findings presented in this section suggest that human-made disturbances are a key factor influencing the forest composition of the various patches sampled. The forest samples cluster or differentiate from each other according to two gradients of human-caused disturbances. The first gradient corresponds to fire disturbances triggered by agricultural practices, while the second gradient corresponds to selective logging and plantation of new trees commonly practiced in coffee plantations. The combination of both gradients produces different clusters or groups of samples that are similar in forest composition. In one extreme, there are deeply disturbed forests (Clusters 1 and 4) where pioneer species tend to dominate. The other extreme is represented by undisturbed patches (Cluster 5) where late successional species seem to have reached a climax stage, maintaining themselves over time inhibiting other pioneer or intermediate species to fill in. Intermediate clusters (2 and 3) hold the richest and most dynamic forests, combining early, intermediate and late successional species replacing each other over time.

V. Discussion: the challenges regarding species diversity conservation in fragmented forests

Findings from the empirical research indicate a trend of forest fragmentation where different social groups have influenced forest disappearance, as well as the transformation of the remaining patches. Species composition of forest remnants strongly reflects the influence of different management practices. In this chapter, we will discuss social and management implications of these findings regarding the preservation of species diversity in these forest remnants, which is the core of the research question put forward in this study.

1. The social forces driving forest fragmentation

The maps comparing land cover / land use in 1954 and 1996 show a clear trend of forest shrinkage and fragmentation, counterbalanced by timid signs of forest recovery in certain areas. Deforestation does not stop at the boundaries of the Nature Reserve. It has broken through the limits of the protected area creating irregular forest patches around the volcano flanks. To assess how the actual forest remnants have been shaped and whether this tendencies will continue or not, it is necessary to understand the social forces driving the deforestation process.

The deforestation front has moved on from the flatlands towards the volcano flanks, driven by two broad social groups. On one hand, large landowners engaged in entrepreneurial production of cotton for exportation, expanded their properties in the flatlands around Chinandega and León, thereby concentrating land

ownership and expelling landless peasants. Cattle ranchers to the north and west of the Reserve also expanded their pasturelands towards the volcano slopes. Both cotton producers and extensive cattle ranchers converted forested lands in the piedmonts of the volcanoes to agriculture or grazing uses. The second broad group is composed of peasants that could not find lands or employment in the flatlands and moved on to the volcano flanks to establish small farms or perform temporary agriculture. They slashed and burned the forest to introduce annual crops as well. The advance of this agricultural border has been contained by the presence of large and medium coffee farms in the highlands. These coffee farms hold, precisely, the less disturbed old-growth forests. It seems that the agricultural expansion has reached a barrier it cannot go beyond. We could expect, then, that the current proportion of forested and agricultural lands will remain roughly the same in the next years.

The pressure of peasants seeking lands is still strong in certain areas. It has been recently reported, for example, that a group of 10 peasant families has settled in the crater of the Casitas volcano known as “La Hoyada” (the hole), where they practice subsistence agriculture and small-scale cattle raising. Nearby, members of the “Versailles” cooperative are progressively burning small pieces of young forest to make short-fallow agriculture. Hence, the pressure of peasants over the forests is still important in those woody areas that belong to cooperatives or form part of national lands, where no specific owner is defined nor access rules are established.

Indeed, the problem of peasants lacking lands to cultivate and forests to collect fuel wood has no easy solution. It will be always present in a socioeconomic system where the land ownership is highly concentrated in a few hands.

Peasants can also be a factor of forest recovery and conservation. The main forest recovery shown in the comparative land cover / land use maps occurs in the area managed by the peasant community of “El Pellizco” and other individual peasants holding lands in the southern slope of the San Cristóbal volcano. Although this young forest has been protected only for a few years, it is evidence of effective participation of local peasants in natural resources conservation. The main motivation for them to protect the forest is that they can extract fuel wood and timber from the woods they take care of. They have prevented outsiders from harvesting trees and have regulated their own rates of extraction to moderate levels. Combined with fire fighting and prevention, moderate harvesting has allowed forest development.

Other peasant communities and cooperative members in the volcano flanks that live near or hold shrubby areas in their properties have the potential to develop similar initiatives of forest protection for their own benefit. Along with the coffee farmers, they could become local actors assuring forest conservation in the Reserve. To do that, however, they might need the impulse of an external authority or project that provides advice and legitimizes their actions before the neighbors. In the case of El Pellizco community, it was the Pikín Guerrero development project

and the local government of Chichigalpa that provided support and advice to the peasants. Similar agreements could be established for the management of the whole Reserve. National and local governments could support groups of peasants, cooperative members or coffee farmers so they act as forest protectors and managers.

2. The impact on forest diversity

Social actors have not only triggered forest fragmentation, but also altered forest composition in the remaining patches. Differences in forest composition reflect the management practices carried out by the landholders. Forests that recently emerged from agricultural fields in peasant lands are dominated by pioneer species, while undisturbed old-growth forests preserved in some coffee farms are mostly dominated by late successional species. Neither deeply disturbed forests nor well-preserved stands show high levels of species diversity. Either excessive or no forest alteration (the extremes of the disturbance gradients) can lead to a decrease in species richness. Instead, those samples that have been affected by slight disturbances exhibit the highest levels of species composition, and the most complex interactions between early, intermediate and late successional species. This probably suggests that a moderate degree of human transformation of the forests can contribute to foster species diversity, creating opportunities for species with various life histories to interact in the same patch. These findings correspond

to the “intermediate disturbance hypothesis”, which relates species diversity to the influence of disturbances that are small, moderate and infrequent.

In terms of species richness preservation, it is a challenge to increase the diversity of species in the forest samples located in the extremes of the disturbance gradients. In the case of Cluster 1, dominated by pioneer species *Cordia alliodora* and *Lysiloma spp.*, widening species diversity would imply the development of intermediate and late successional species common in adult forests, but without eliminating the current pioneers. Size-class histograms for this patch indicate that pioneers are still recruiting significantly, although in recent years the rhythm of development of young individuals is not as conspicuous as in past years. They might be slowing down their recruitment rate, leaving the opportunity to other intermediate species, such as *Tabebuia crisantha*, to populate the forest. This is a good sign that Cluster 1 is evolving towards a more complex forest. Nevertheless, other late successional species might not easily settle in this young forest because there are not adult trees acting as seed sources in the close vicinity. Thus, the succession of species would be limited to certain intermediate species that are already present in the forest. Regarding this problem, the Pikín Guerrero project advised the peasant community in charge of the management of El Quebrachal forest, to enrich the stand planting series of species that were not found in that patch. They planted lines of high-value timber species like *Cedrella odorata* and *Enterolobium cyclocarpum*, along with pioneers like *Gliricidia sepium*. In addition,

the moderate extraction of fuel wood and timber focuses on dominant pioneer species, thus helping to control their importance in the forest composition.

The problem of narrow species diversity is more acute in coffee plantations where the original forest cover has been largely removed to favor a limited set of species for coffee shade, as in the case of Cluster 4. The same type of coffee plantation can be observed in other coffee farms, such as Argelia and Bella Vista large properties in the Casitas' flanks, where coffee plants are covered by the canopy of almost a single woody species, mainly *Enterolobium cyclocarpum*. Forest diversity has been narrowed to a minimum. The sample of plantlets in Cluster 4 shows that many late species are still regenerating on the ground, though. They do not grow to become established trees probably because farmers periodically clear the understory, removing most of woody saplings. Therefore, species diversity in such deeply altered coffee plantations could be easily enhanced if farmers actively protect saplings emerging in the understory, instead of removing them indiscriminately.

Low species diversity can also be found in the opposite extreme of the disturbance gradient, where little or no alteration has changed forest composition. This is the case of Cluster 5, where late successional species *Brosimum alicastrum* and *Ardisia revoluta* are largely covering the forest and replacing themselves without being displaced by any other species. This forest patch seems to have reached the climax stage of succession suggested by equilibrium theories, in which

species composition no longer changes. The same set of dominant species stay in the forest for very long periods, excluding other competitors from the prominent positions in the community. In order to change the current array of species and break the climax equilibrium, the forest would have to be impacted by any disturbance removing the actual dominant species. Such disturbance might be intentionally created by the landowner, with the aim of increasing species diversity and make an economic profit at the same time. The landowner could harvest, for instance, *Brosimum alicastrum* trees to produce fuel wood to sell in Chinandega. Thereby he would open room for other species to develop and would earn complementary income simultaneously.

All these manipulations of forest patches to improve species diversity would require the motivation of landowners to introduce innovations in their management practices. They will be more likely to carry out such changes if they perceive an advantage in managing a wider variety of species.

3. The economic motivations to manage species diversity

The management of forests to enhance species diversity requires changes in the way the forest holders manage their woods and their properties in general. The introduction of such innovations might imply additional efforts for them. If the management of forests in the Reserve is going to involve local owners, it is important to assess whether or not they will be motivated to change their

management practices to maintain species richness. More precisely, the question is under which conditions they will be willing to implement these changes.

To improve species diversity in their lands, wealthy coffee farmers would have to manage their coffee plantations in a different manner, protecting saplings of a variety of species emerging in the understory. Currently, they perceive these saplings as obstacles to weed and fertilize the coffee plants, and consider that not all the species provide an adequate shade to coffee. In order to change these practices and perceptions, wealthy landlords would have to discover an extra benefit in taking care of trees. Medium coffee farmers have already discovered it. They complement profits from coffee with the frequent extraction of fuel wood and timber. On the basis of this motivation, they protect a wider variety of species in their coffee plantations. The wealthy farmers might also be motivated to manage their plantations in a similar fashion if they perceive economic benefits from timber and fuel wood exploitation.

Authorities of the Ministry of Natural Resources, along with municipal governments, could encourage coffee farmers in this direction. Farmers usually complain about the difficulties to obtain permits to exploit their forests. National and local governments could facilitate such procedures with the condition that wealthy landowners protect a wider variety of species in their coffee plantations. Authorities and farmers together could elaborate management plans specifying goals and practices that allow forest exploitation and conservation at once.

In the case of peasants, land scarcity is one of the major economic problems preventing forest protection. Since their agricultural parcels are small, they tend to search for other areas where to crop or graze their cattle. If they have access to bushes or forests, they will eventually slash and burn part of them to establish their crops. Peasants from El Pellizco hold 2 or 3 ha for cropping in the flatlands, from which they obtain their food and cash produces. They must cultivate all of their parcels every year to fulfill their fundamental needs, leaving no space for forest fallows. Some of their family members have to look for non-agricultural employment to survive, because their small farms cannot absorb all the family labor. Members of Versailles cooperative manage larger areas for cropping (around 14 ha per family). Some of their parcels are partly forested, but they have begun to burn small areas of young forests for cropping, not allowing the woods to develop. In order to maintain their forests for longer periods, they would have to concentrate their agricultural production and graze lands in small areas, leaving the rest of farm in fallow. They would have to increment their production in a reduced area, probably with the help of agricultural innovations. Hence, forest protection will require peasants to introduce changes in their agricultural techniques too, thus modifying their entire farming systems.

In addition, small peasants would need to invest extra efforts in forest protection and management. The peasant association taking care of El Quebrachal forest has already invested great efforts in fire prevention, which allowed the young

forest to emerge. Although they perceive the benefits of their efforts by collecting fuel wood and rustic timber, not all the association members are motivated to continue protecting the forest. Some of them do not have the means (oxen, cart) to collect fuel wood, and therefore do not obtain any direct benefit from the forest. If they cannot harvest any forest product, they are not likely to participate in fire-fighting activities, plantation of new species or any other task to improve the quality of the forest. The peasant association should therefore be concerned about how to encourage these retired members to become involved in forest management activities again. The association would have to invent a manner for the peasants that cannot collect fuel wood directly to participate and benefit from tree harvesting and trade. They could be, for instance, compensated for their work invested in forest protection with a small proportion of the forest products harvested by the other peasants who do have carts. This and other compensation and collaboration mechanisms among association members might be thought and experimented.

The municipal government of Chichigalpa faces a similar problem regarding the preservation of a forest that does not generate any economic profit at this time. The municipality wants to preserve the 35-ha forest at Las Brisas for educational, scientific and recreational purposes, but lacks the resources to set up the infrastructure and services necessary for the project. In addition, the peasants surrounding this forest patch do not perceive any benefit either, and might be tempted to gather fuel wood or harvest timber in the area without caring about

forest preservation. To implement the preservation project, the municipality needs to be more proactive in searching for financial sources, knocking on the doors of conservation agencies and NGO's. It also needs to involve the local community in the management of this small reserve, training local peasants to serve as field guides and explain the forest features to visitors. They could also work as researchers carrying out observations and small experiments about species ecology.

Lack of ecological and economic knowledge about tree species is a general problem affecting all the forest holders that would like to improve species diversity in their woods. They focus on few species to provide shade for coffee, timber, and cattle food. If they knew that other species could also serve their needs, or even provide new services, they would be more interested in managing a wider variety of species. Many species have the potential to produce timber, although they are not harvested for that purpose. *Brosimum alicastrum*, for example, is an abundant species mainly harvested for fuel wood, even though it could be used for timber and employed in furniture production. *Mastichodendron capiri*, *Guarea glabra*, *Tabebuia rosae*, *Tabebuia crisantha* and many others, have the same potential. They are not harvested for fine timber because local and national markets are very narrow and do not value many useful species. Other uses, such as medicinal properties of tree species, have been little explored and developed. Research and promotion of economic uses of tree species could be an important motivation for

forest owners to protect other species and become more curious about their ecology and the ways they can be better managed.

In summary, the main challenges for species diversity conservation in the fragmented forests of the Reserve have to do with social and management problems:

1. Social problems refer to socioeconomic differences among forest holders in terms of their access to lands and the resources to cultivate them. Small peasants, very limited in their access to lands, continue putting pressure over the remaining forest patches to transform them into agricultural lands. Wealthy and medium coffee farmers, in contrast, maintain large forest patches in their properties, but modifying species composition notably. These socioeconomic differences are deeply rooted in society and are very difficult to reduce unless structural changes, such as a land reform, are undertaken.
2. Management problems appear when landowners modify their forests without maintaining species diversity. This is particularly the case of wealthy coffee farmers, who concentrate in the management of few tree species selected to provide coffee shade. Such management obstacles can be overcome by motivating the landowners to make concrete profits from a wider variety of species, and are easier to solve than structural social problems.

VI. Conclusions

In the second half of the 20th century, a clear process of forest shrinkage and fragmentation has taken place in the flanks of the Chonco, San Cristóbal and Casitas volcanoes in Western Nicaragua. A Nature Reserve was established in the area in 1983 with the aim of protecting the forest remnants and holding back the agricultural pressure coming from the lowlands. Deforestation has nonetheless continued beyond the Reserve boundaries, driven by an unequal social structure in which small peasants are expelled from the lowlands due to the expansion of large entrepreneurial agriculture and extensive cattle ranching. Forest remnants in the Reserve are preserved thanks to the existence of coffee farmers who protect the woods within their properties, along with other minor experiences of forest protection carried out by small peasants and the municipal government of Chichigalpa.

Relying solely on legislative and administrative measures has proven insufficient to protect forests if local actors are not involved in forest management. It is crucial for any conservation strategy to understand and promote forest management by local landowners, since they can assure forest protection more effectively. The findings of this research indicate that human practices substantially influence species richness and composition of forest remnants. Moderate human-made disturbances might enhance species diversity, as it occurs in the case of certain coffee farmers who thin their forests to make room for coffee plantations.

By thinning their forests, they create opportunities for a wide variety of early and late successional species to populate the patch. Excessive elimination of species, conversely, hinders species diversity. Few species are left in coffee plantations when the landowners decide to radically change forest composition, eliminating most of the late successional species of the original forest to be replaced with species carefully chosen for the good of coffee. Late successional species are also absent from young forests developed from agricultural fallow in peasant's parcels. In such cases, forest management innovations are necessary to improve species richness. The main factor to ignite innovative changes is forest owner's economic motivation to obtain concrete benefits from trees.

After considering these social and technical problems regarding the management of forest remnants in a small Nature Reserve, I would like to recommend some general elements for future conservation strategies involving local actors in forest management:

1. Promote forest management by peasant communities in the volcano flanks, following the example of communal forest management carried out by peasants from "El Pellizco" community. There might be other forested or shrub areas in the Reserve that do not have any specific owner, falling under the category of national lands. The Ministry of National Resources and the Environment (MARENA), in agreement with municipal governments, could designate nearby peasant communities to manage,

protect and benefit from those forests. A legal frame should be provided to support such agreements, so peasants like those at El Pellizco can have legal instruments to claim usufruct rights on the forest they protect.

2. Facilitate the development of intermediate and late successional species in young forests managed by peasants. Pioneers, and a few intermediate species, dominate young forests as El Quebrachal and other nearby patches. Late successional species might not be able to develop easily, because of the lack of seed sources in close areas. Therefore, the enrichment of these young forests with seeds and plants of late successional species might be necessary. Peasants can be motivated to work on forest enrichment with the aim of obtaining better quality timber in the future.
3. Manage the agricultural matrix in the lowlands to promote forest recovery. There are scattered minute forest emerging in the agricultural fields beyond the Reserve boundaries, which could be improved and expanded through involving peasants from the lowlands in reforestation and forest management.
4. Promote the management of a wider diversity of tree species in coffee plantations, motivating landowners to protect saplings of species regenerating in the understory. National and local authorities could involve farmers in management plans allowing them to exploit their forests for timber, fuel wood and other goods, but assuring the management practices

to develop new trees. Such management plans should be elaborated with farmers' participation and adapted to their forest management goals.

5. Develop research and experimentation on species use, to increase economic benefits from the management of species diversity. A project in this direction could be to set up a small woodworking workshop to experiment with the use of non-traditional timber species. Research about other uses of species, such as medicinal applications, is another field of investigation worthy to promote.
6. Increase our knowledge on species ecology and its management applications. There is very little understanding about the ecology of dry tropical forest species, which limits our ability to manage complex forests with a mixture of early and late successional species. Inhabitants of the Reserve could contribute to increase our ecological knowledge of species by systematically observing where and how species grow. Their observations can serve as start points for further scientific research involving thorough forest samples. The small forest administered by the municipality of Chichigalpa for conservation purposes is an excellent place to develop such research.

All these recommendations are suggestions that should be discussed and, if viable, implemented with the participation of the forest owners in the Reserve.

They are the ones who can really practice forest conservation in a small Nature Reserve set up in a poor country where the State does not have the resources to protect forests. In particular, the involvement of small peasants in forest management is critical to stabilize and revert the forest fragmentation trend and, at the same time, empower these traditionally marginalized actors and build a more equitable local society.

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Appendix: Database containing row data