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To the Graduate Council:

I am submitting herewith a thesis written by Rachel Marie Clement entitled "3000 years of human-vegetation interaction near the Las Cruces biological station in southwestern Costa Rica : paleoecological evidence from Laguna Zoncho." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

Sally P. Horn, Major Professor

We have read this thesis and recommend its acceptance:

Ken Orvis, Carol Harden

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a thesis written by Rachel Marie Clement entitled "3000 Years of Human-Vegetation Interaction Near the Las Cruces Biological Station in Southwestern Costa Rica: Paleoecological Evidence from Laguna Zoncho." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

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Dr. Sally P. Horn, Major Professor

We have read this thesis
and recommend its acceptance.

Carol Harden

[illegible signature]

Accepted for the Council:

[signature]

Associate Vice Chancellor
and Dean of The Graduate School

3000 YEARS OF HUMAN-VEGETATION INTERACTION NEAR THE LAS CRUCES BIOLOGICAL STATION IN SOUTHWESTERN COSTA RICA: PALEOECOLOGICAL EVIDENCE FROM LAGUNA ZONCHO

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Rachel Marie Clement

May 1999

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DEDICATION

This thesis is dedicated to my husband

Brian James Clement

for his unending support and encouragement

ACKNOWLEDGEMENTS

I would like to thank my major professor and advisor, Dr. Sally P. Horn, for her continued interest in and enthusiasm about my thesis research. Dr. Horn's commitment to her graduate students is truly exceptional, and it made my time at the University of Tennessee both successful and enjoyable. I would also like to thank Ph.D. student Lisa Kennedy for her support and friendship throughout my thesis research. I sought Lisa's advice in almost all aspects of my research, from laboratory technique to manuscript edits to hosing down the research vehicle, and I am exceedingly grateful for her assistance.

I would also like to thank the other members of my thesis committee, Dr. Ken Orvis and Dr. Carol Harden. I truly enjoyed classes that Dr. Orvis taught, where he exposed me to new ideas and made me stretch for comprehension of those concepts. Dr. Harden was my example of how to be committed to many different aspects of the department, while still retaining professionalism and enjoyment of the discipline.

I am grateful to land-owners Gail Hewson and Michelle Cloud, who allowed us to retrieve a core from Laguna Zoncho. I am also grateful for the contributions of Maureen Sanchez, who examined Zoncho archaeology; Brandon League, who helped Dr. Horn and Lisa core Laguna Zoncho; and Luis Diego Gómez, who shared knowledge of the recent history of the lake and identified plants we found there. I would also like to thank Mario and Jóse at the Las Cruces Biological Station for towing us out of the mud during a research expedition.

I need to thank my husband, Brian Clement, for his willingness to move far from home to give me the opportunity to do my research with Dr. Horn. I am truly grateful for his continued support. I would also like to thank my parents, Cliff and Jeri Kurtz, and my siblings, Jason, Renae, and Debby, for their constant encouragement and large phone bills. Their gifts of love and friendship are invaluable.

This research was supported by a graduate teaching assistantship from the University of Tennessee and a grant to R.L. Sanford, Jr. and S. Horn from The A.W. Mellon Foundation.

ABSTRACT

There is growing evidence that prehistoric indigenous groups affected tropical forests of Costa Rica. Costa Rica has a diverse array of tropical forest communities and the severity and extent of human impacts in these sites are not well understood. There are some studies that have helped elucidate these impacts. Sediment cores from Lagunas Bonilla and Bonillita show over 2600 years of forest disturbance and maize cultivation on the shores of the lakes. Studies at La Selva Biological Station reveal that this lowland tropical rainforest reserve was also subject to prehistoric forest clearance and maize cultivation.

In this thesis, I analyze a 5.9 meter sediment core from Laguna Zoncho in southwestern Costa Rica. The analysis of this sediment core from a previously unstudied location in Costa Rica provides insight into how indigenous groups affected vegetation at mid-elevations (1190 m). This sediment core records 3000 years of environmental history and provides more evidence to support the concept that indigenous groups altered the landscape. Laguna Zoncho is only 2 km from the Las Cruces Biological Station, so the results of this study are relevant for understanding the extent of past human disturbance that the Las Cruces Forest may have experienced. The archaeology of this region of Costa Rica is less well understood than in other parts of Central America, and this study contributes to a better general understanding of the timing of indigenous occupation.

The presence of the pollen of *Zea mays* throughout the entire length of the sediment core is evidence of 3000 years of human occupation at Laguna Zoncho. This

finding complements and extends some limited prior archaeological work. Finding evidence of human-induced vegetation disturbance in a sediment core from a lake with archaeological sites is not surprising. What is of more interest is the timing, length, and apparent intensity of the human disturbance. Pollen percentages of forest species and disturbance taxa fluctuate dramatically down the core, representing various periods of intense human disturbance and regrowth of mature forest. Changing abundance of charcoal in the sediment core points to variations in the fire regime, which may reflect changes in climate as well as human activities.

Human disturbance is widespread on the Las Cruces landscape today, with coffee fields and pasture having replaced much of the forest that existed a scant 50 years ago. When Italians settled this part of the Costa Rican frontier, they found evidence of indigenous agricultural fields. Continuous indigenous occupation of Laguna Zoncho may have continued well into the twentieth century. Based on the pollen and charcoal evidence of forest clearance and burning at Laguna Zoncho, I suggest that the current clearing of the forest is a cycle of human presence in an already altered landscape.

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CHAPTER 1

INTRODUCTION

The concept of 'noble savages' living in harmony with their surroundings is sometimes still associated with tropical rainforests (Juarez 1994). However, an increasing body of evidence indicates that indigenous groups did alter their natural environment, at times in dramatic ways.. Some researchers estimate that over 40% of Latin American forests are secondary due to human clearing, and that much of the rest has been modified in some way (Denevan 1992a). Recently, research has begun to focus on the timing, nature, and degree of prehistoric human impacts on tropical ecosystems.

This thesis reconstructs the history of human-vegetation dynamics at a site in southwestern Costa Rica through the analysis of lake sediments. The site is located only a few kilometers from the Las Cruces Biological Station, a research area operated by the Organization for Tropical Studies that contains one of the last intact premontane rain forests in Costa Rica. The landscape surrounding the biological station is highly altered today. Documenting the impacts of prehistoric human disturbance on forests in the Las Cruces area provides an important perspective for understanding the modern biology of the reserve and modern effects of humans on the landscape in the wider Las Cruces area.

Paleoecological analyses of sediment records from lakes and swamps often yield the only available long-term records of human-environment interaction (Whitmore *et al.* 1996). Changes in percentages of pollen grains of forest and disturbance taxa, fern spores, and the abundance of charcoal can provide evidence of the history of vegetation, fire, and human land use in areas adjacent to the core site. Lake sediment analyses can also provide evidence of changes in climate and of natural environmental disturbances such as volcanic eruptions.

The lack of archaeological research at undisturbed sites in southwestern Costa Rica (the Diquís archaeological region) makes deciphering prehistoric impacts on vegetation a challenge. In many instances, even sites with good archaeological preservation have no ^{14}C dating of the stratigraphy and thus only relative chronological control, based on artifact styles. Archaeological studies in the area sometimes reveal what types of crops were grown and what type of food was harvested from the forest. But archaeological studies cannot reveal how prehistoric groups cultivated their crops or how they affected the vegetation in general.

In this thesis, I use paleoecological analysis to interpret the history of human impacts on the landscape surrounding Laguna Zoncho. The 5.9 m sediment core recovered from Laguna Zoncho provides the first lacustrine paleoecological record from southwestern Costa Rica and the only such record from mid (1000-2000 m) elevation anywhere in the country. I interpret the results of pollen and charcoal analysis of the Laguna Zoncho core in light of the archaeological record to consider the ways in which indigenous groups altered the landscape by fire and cultivation. I also compare the Laguna Zoncho record with paleoecological records from other parts of Costa Rica and with records from other sites in Central America.

I address the following questions in this thesis. Is there evidence in the sediment record of prehistoric human presence at Laguna Zoncho? Do the sediments reveal differences in human activity after the Spanish Conquest? Are changes in the fire regime evident? Do the sediments contain evidence of prehistoric cultivation? How does this record of prehistoric human disturbance relate to other paleoecological studies around the region? Is there evidence of climatic variability preserved in the pollen and charcoal profiles?

This thesis is divided into six chapters. Chapter 2 gives an account of the physical and human geography of Laguna Zoncho and its surroundings. Chapter 3 describes the methods with which I acquired and analyzed the Laguna Zoncho sediment core. Chapter 4 presents the results of the AMS radiocarbon dating, as well as the pollen, charcoal, and fern spore results. In chapter 5, I discuss these results in the context of the broader concept of prehistoric/historic land use change, and in Chapter 6, I make general conclusions about the evidence of human impacts on the environment preserved in the Laguna Zoncho record.

CHAPTER 2

ENVIRONMENTAL AND CULTURAL SETTING

Environmental Setting

Laguna Zoncho is a small lake in the Fila Costeña of southwestern Costa Rica (Figure 2.1). It is located at an elevation of 1190 meters on the extreme eastern edge of the range, overlooking the Çoto Brus Valley, and 1 km from the town of San Vito. The Las Cruces Biological Station, a research station operated by the Organization for Tropical Studies, is located 2 km to the south of Laguna Zoncho.

The Fila Costeña is a complex coastal range that includes both folded sedimentary and volcanic rock (Hall 1985). The transverse Faralla Fault, which runs the length of the Fila Costeña, caused catastrophic earthquakes in 1904 and 1941 (Hall 1985). This fault is the western boundary between the Fila Costeña and the Coto Brus Valley. The Coto Brus Valley is part of the Terraba Trough, a geologic formation made up of Tertiary and Quaternary sedimentary rocks and volcanic dikes. The boundary between the trough and the Cordillera de Talamanca is a subparallel fault, with the trough as the downthrown block (Castillo Muñoz 1983). Figure 2.2 is a topographic profile that shows the relationship between the Cordillera de Talamanca, the Coto Brus Valley, and the Fila Costeña. The elevation of the Coto Brus Valley ranges from 100-1000 m. Most of the depression is undulating, with slopes of 10-30 percent, and flat land restricted to the valley floors and small river terraces (Hall 1985). The Coto Brus river, after which the valley is named, is a tributary of the Rio Grande de Terraba, which has a watershed of over 5000 square kilometers (Hartshorn *et al.* 1982).

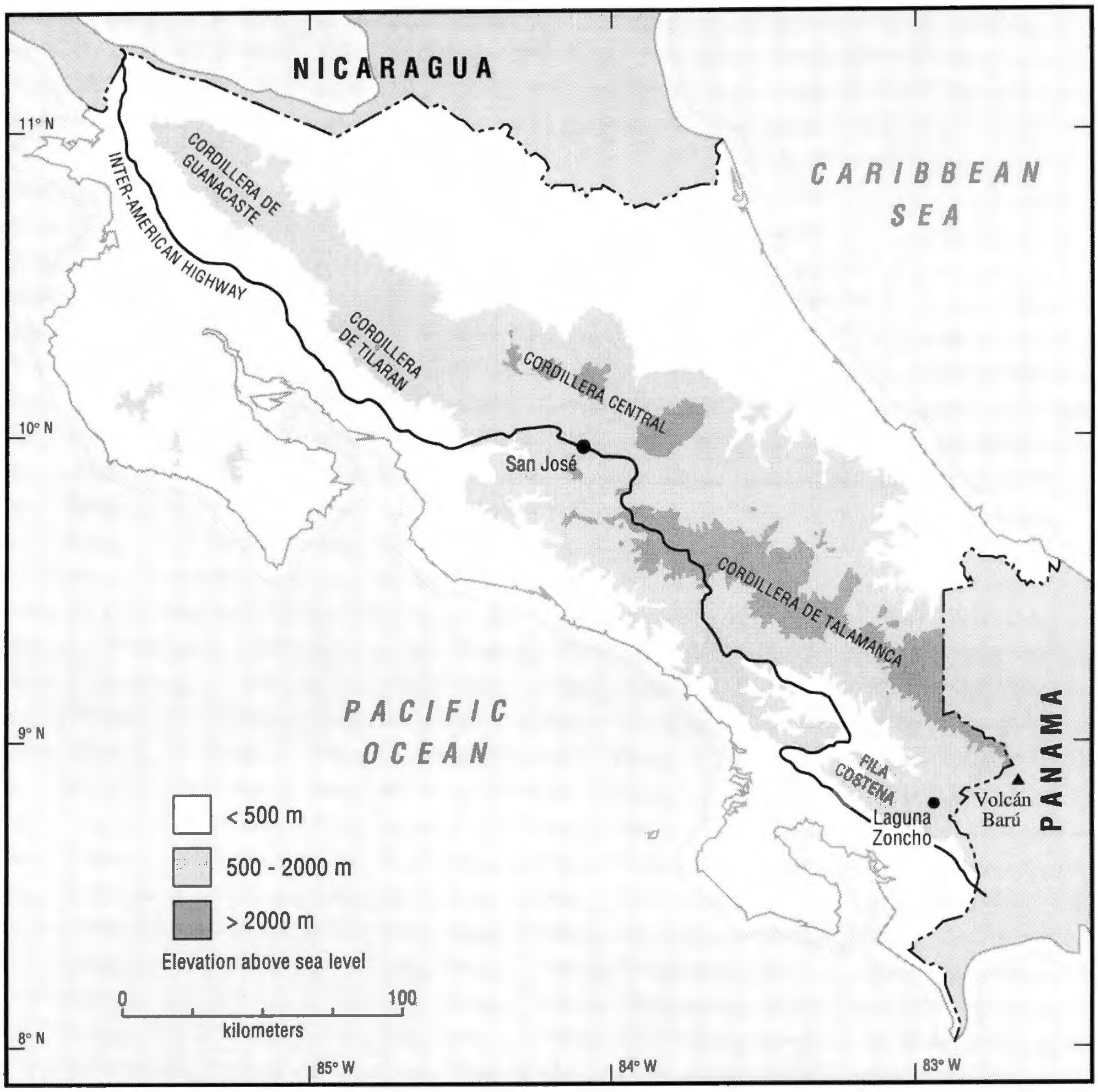

Figure 2.1. Location of Laguna Zoncho in the Fila Costeña of Southern Costa Rica.

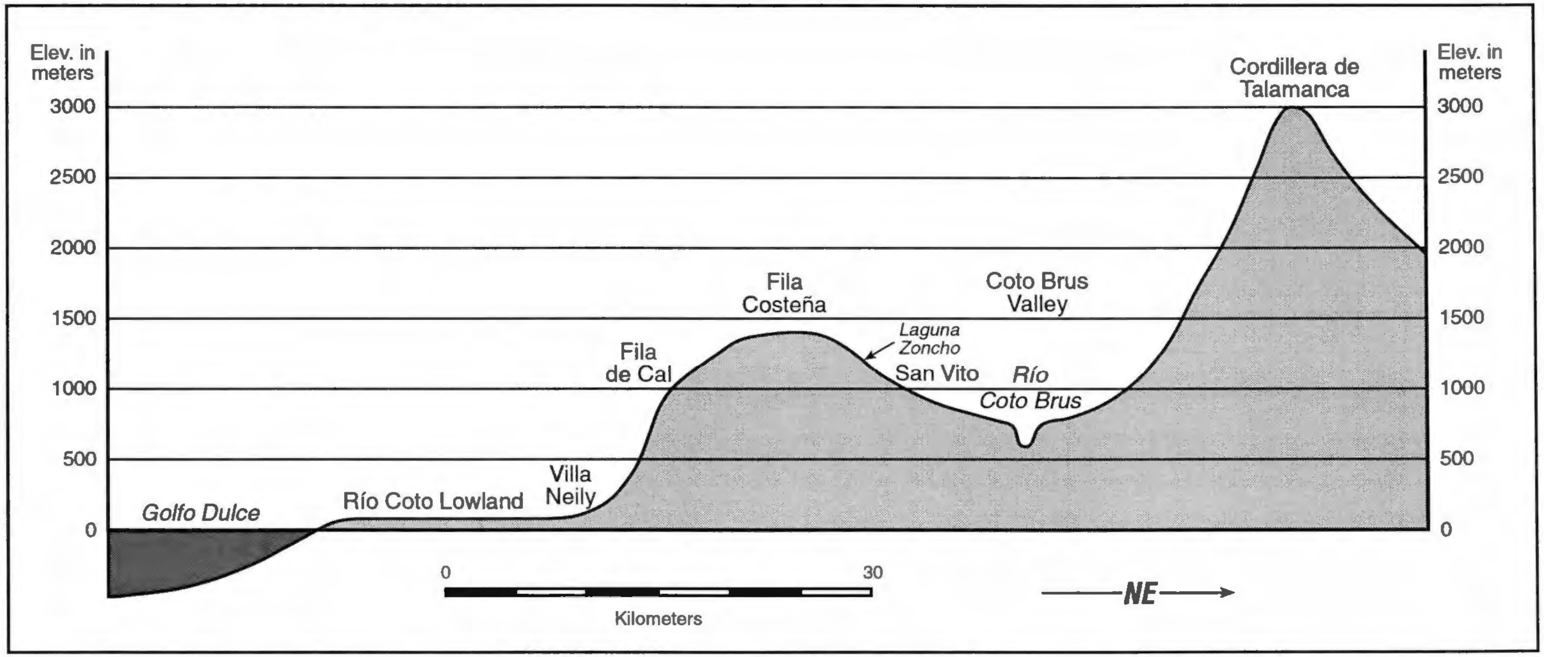

Figure 2.2. Topographic Profile from Golfo Dulce to the Continental Divide. Adapted from Masing, 1964.

While there are old volcanic landforms in the Las Cruces area, the only active Quaternary volcano in the region is Volcán Barú (K. Johnson, pers. comm. 1998), located 35 km east of Laguna Zoncho in Panama. Two of the most recent eruptions occurred about 1350 yr BP (Linares *et al.* 1975) and about 650 yr BP (Stewart 1978) and possibly had impacts on the people and vegetation near Laguna Zoncho.

Soils in the Fila Costeña and the Coto Brus Valley are andepts derived from volcanic ash. Soils at Laguna Zoncho and in the Coto Brus Valley are well-drained and rich in organic material (Vasquez Morera 1983).

Although Costa Rica lies in the Northeast Tradewind belt, weak, equatorial westerlies dominate on the Pacific slope (Hall 1985). Estimated precipitation in the Laguna Zoncho area is 3000 - 4000 mm per year (Coen 1983), with the maximum rainfall on record as 5728 mm in 1960 (Masing 1964). Rainfall differs between the wet and dry seasons (Figure 2.3). The Fila Costeña receives slightly more precipitation (≥4000 mm, estimated from Coen 1983), due to its higher elevation. January to March are generally the only dry months of the entire year in this area (Hall 1985). Although the average monthly temperature does not range more than a few degrees from 21° C (Figure 2.3), the daily temperature range may exceed 10° C. In 1961, for example, the average daily high was 27.3° C and the average low was 16.1° C. Masing (1964) reported that between 1952 and 1962, the extreme high in San Vito was 37.2° C, and the extreme low was 13.8° C.

The area surrounding Laguna Zoncho falls within the Tropical Premontane Wet Forest, warm-wet transition life zone, according to the Holdridge classification (Hartshorn *et al.* 1982). The Holdridge Life Zone classification is a climate classification system, but it is commonly used in Costa Rica for vegetation classification (Hall 1985). That is, mature

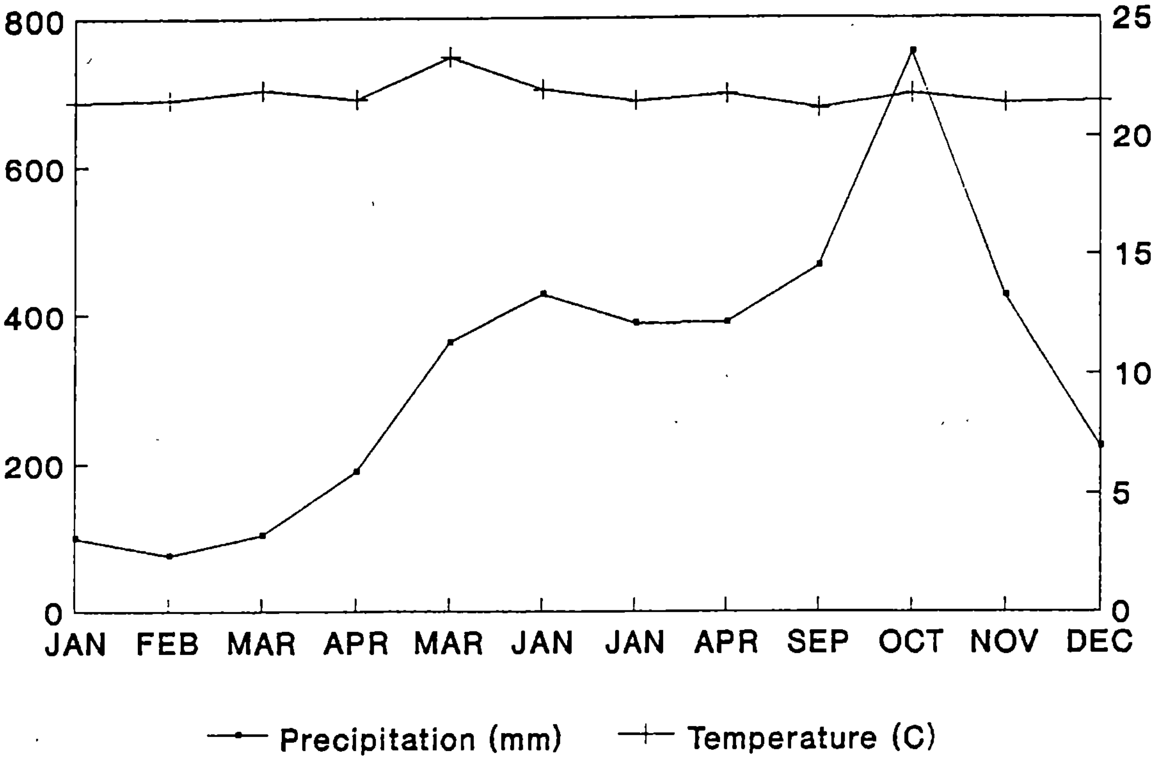

Figure 2.3. Monthly Rainfall and Average Monthly Temperature in San Vito de Java, 1962. Adapted from Masing, 1964.

forests within a given life zone are named according to the life zone designation. Hartshorn (1983) describes Tropical Premontane Wet Forest as an evergreen forest that is intermediate in height with two or three strata and a very dense sub-canopy and understory. The shrub layer is also dense with the ground nearly completely covered with ferns and broad leaved herbs. The forest at the Las Cruces Biological Station, on the northern slope of the Fila Costeña, is the last intact remnant of the Tropical Premontane Wet Forest that once covered the entire upper Coto Brus Valley (Hartshorn 1983). Tropical Premontane Rain Forest occurs in the higher elevations of the Fila Costeña. The modern landscape is highly altered by agriculture and cattle grazing.

The Coto Brus Valley is the only location in southern Costa Rica with savannas or grasslands that predate European settlement. Their origin is controversial. Some researchers hypothesize that indigenous groups overused the area for crops, burned it in the dry season, and did not allow the forest to regenerate (Hall 1985). In contrast, Barrantes (1965) argues that the three month dry season from January to April led to natural savannas in this area.

Figure 2.4 is a sketch map of the landscape immediately surrounding Laguna Zoncho. The complex topography of the surrounding area can be seen in Figure 2.5. There are two fairly steep slopes on opposite banks that retain forest, whereas the other sides of the lake are planted with various species of trees and herbs. A farmer and his family have a house and yard on the northeastern slope of the lake. On the western slope, a garden of varied tree and herbaceous species has been planted on the Finca de Cantaros. Among the planted trees are two genera of special importance to this study: *Eucalyptus and Pinus*. The earliest occurrence of pollen from these non-native species may provide a means to date the near-surface sediments of the lake (see Chapter 4).

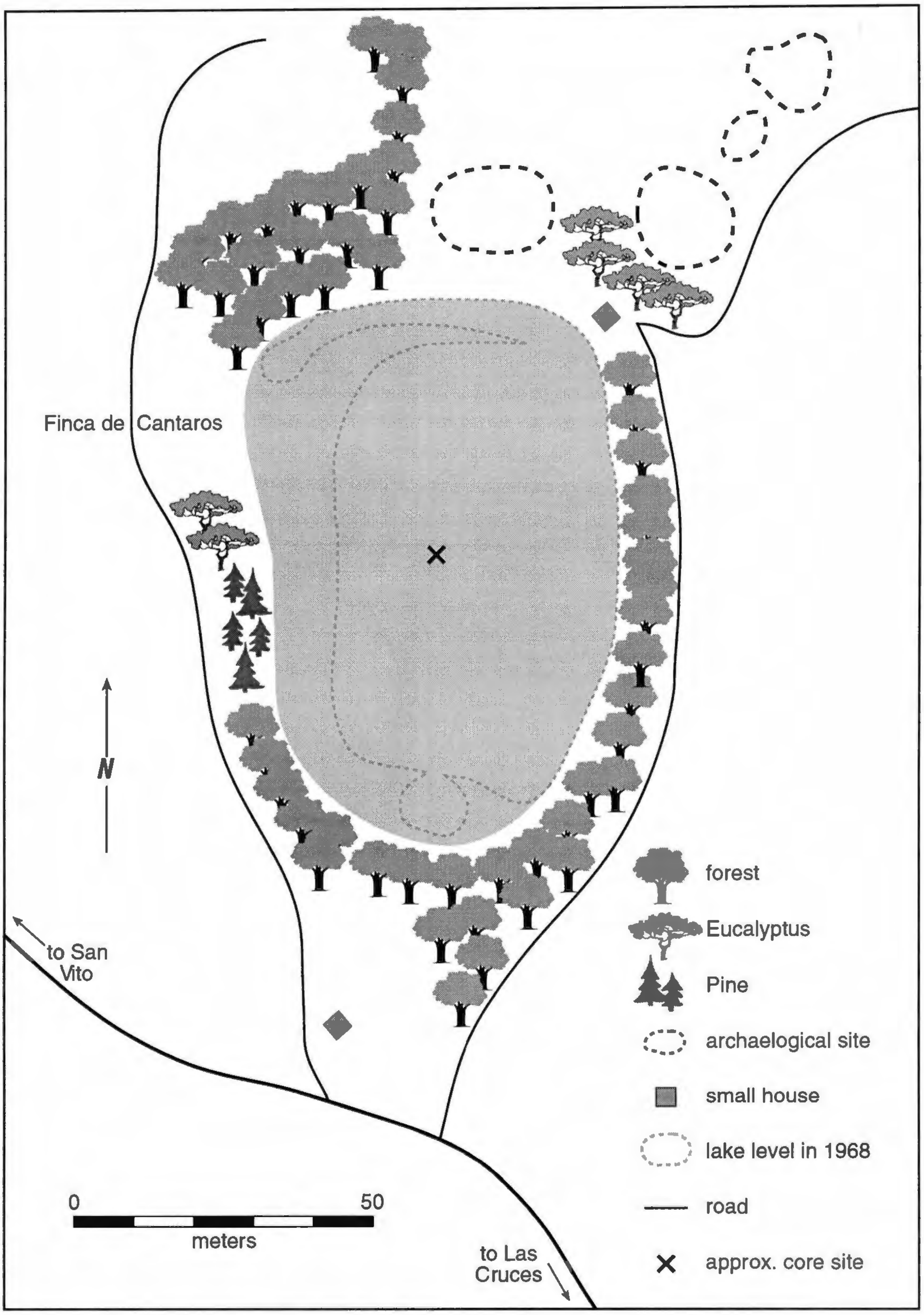

Figure 2.4. Sketch Map of Laguna Zoncho and Surroundings. 1968 lake level inferred from aerial photograph (L-306 R-68).

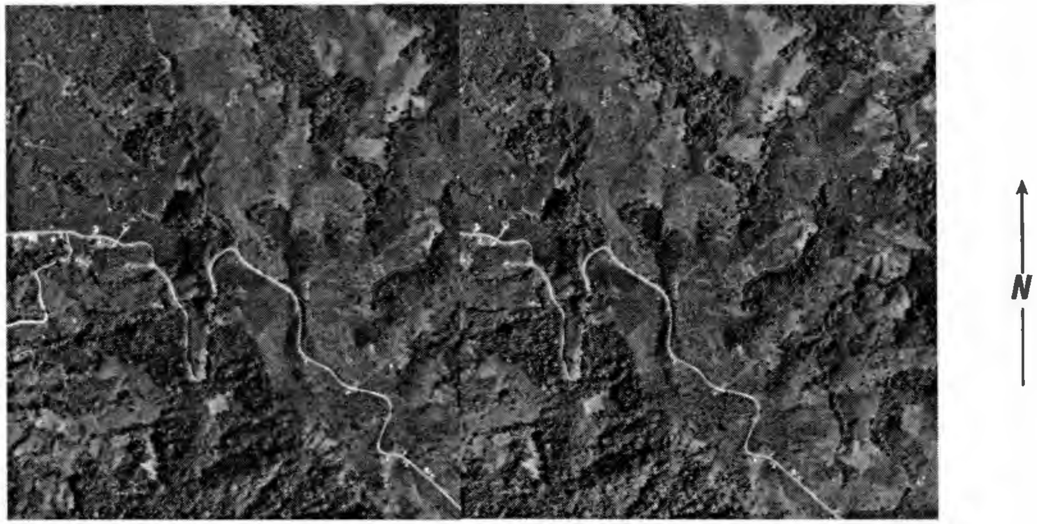

Figure 2.5. Stereo Pair of the Laguna Zoncho Area. Laguna Zoncho is located approximately in the center.

Archaeological Context

Costa Rica can be divided into three archaeological areas of distinct material cultures: the Nicoya Region (northern Costa Rica), the Central Highlands-Atlantic Watershed, and the Diquís Region (the south and the southern Pacific coast) (Stone 1977, Snarskis 1981). The Nicoya region is regarded by many archaeologists as the southernmost extent of Mesoamerican influence, while the rest of Costa Rica is thought to reflect a strong influence of South American cultures (Stone 1977, Hall 1985). Laguna Zoncho is located within the Diquís region, which is the least known archaeologically, with the smallest number of controlled excavations (Snarskis 1981, Hall 1985). The Diquís region of Costa Rica is part of a larger Central American archaeological area called the Greater Chiriquí region, which extends into Panama (Snarskis 1981, Corrales U. *et al.* 1988).

Giant stone spheres are a noteworthy aspect of Diquís archaeology, the largest measuring > 2 m. The time period in which the spheres were created is unknown. Snarskis (1981) suggested that were probably created between 2950 BP - 1450 yr BP, whereas Stone (1977) placed their formation between 1650 BP - 1150 yr BP. The spheres are made from a variety of materials, including granite, andesite, and sedimentary rock (Snarskis 1981). The significance of these spheres is unknown. They have been found in varying alignments in and around cemetery areas, but no definitive pattern has been documented (Snarskis 1981). Some researchers hypothesize that the spheres are a type of cult image (Stone 1977). Several spheres were reportedly found at Laguna Zoncho, one of which (measuring ca. 0.5 m in diameter) is now located in the central park of San Vito (G. Hewson, pers. comm. 1998).

Very little is known about the archaeology of the Diquís region. Snarskis (1981) delineates very tentative archaeological phases, although makes clear that this region is lacking in documented sites. The first phase that Snarskis (1981) documents is the Concepción phase (2250 yr BP) which blends into the Aguas Buenas phase (through 1350 yr BP). During these two phases, earthen mounds of ceremonial significance have been found, but no dwellings have been documented. Maize kernels, beans, palm nuts, and avocado seeds have been recovered from sites in Panama, and similar subsistence agriculture is assumed in the Diquís region (Snarskis 1981). A few small, sedentary communities slowly increased in population and social complexity throughout the Concepción and Aguas Buenas phases (Snarskis 1981). By the time of the Spanish conquest, independent sedentary communities had evolved to villages ruled by "caciques," or chiefs. The exact timing of this transition is uncertain (Snarskis 1981, Hall 1985).

During the Burica, Chiriquí A, and Chiriquí B phases (1450 yr BP - Spanish conquest), important social changes took place in the Diquís region and presumably also near Laguna Zoncho. An increase in South American traditions appears to have taken place in the Burica phase (1350 yr BP – 1000 yr BP). An example of increased southern influence is the presence of a capped phial (a special piece of pottery, normally associated with Colombian cultures) that appears in the Diquís region during this time period. Archaeological sites all three phases (Burica, Chiriquí A, and Chiriquí B) are generally located along the coasts, major rivers, or on terraces above rivers (Snarskis 1981, Hall 1985). Structures associated with this time period include stone platforms, circular house foundations, retaining walls, and cobbled walkways (Snarskis 1981).

Societies were fairly sedentary and waged inter-tribal warfare, practicing head-hunting and sacrificing of captives (Stone 1977, Snarskis 1981). Indigenous groups arranged themselves into small, independent groups for political control and defensive strategy (Snarskis 1981). At the time of Spanish arrival, large, fortified villages and constant warfare among indigenous groups were common. Reasons for war included enslaving the women and the young, capturing the men, whose heads became trophies, and acquiring control of sections of gold-bearing rivers (Fernandez Guardia 1908). In fact, the fort of the Coto (in the present Coto Brus valley) was renowned among the Spanish for being the largest and strongest village. With streams on either side, two layers of fences, and a well-planned layout of the houses on the interior, it was by far the most fortified village of its kind. Each building inside the fort was large enough to hold 400 people, but they usually contained smaller family groups (Fernandez Guardia 1913, Stone 1977).

Assimilation of indigenous groups into Spanish culture was mainly restricted to the localities where the Spanish had firm control (Hall 1985). Many indigenous groups fled to the Cordillera de Talamanca where they retained their culture. Even the indigenous peoples who lived in mission villages were able to maintain their traditional way of life well into the nineteenth, perhaps even into the twentieth, century. In 1800 AD, indigenous peoples were still the dominant group in southern Costa Rica as well as the far northern parts of the country. According to Hall (1985), the population in the south was still 100% indigenous in 1800 AD.

Local Archaeology

There have been several archaeological studies in the Las Cruces area. In one study, several unmarked graves were found in an unnamed archaeological site near San Vito. These were located near what archaeologists thought may be dwellings. The graves may have actually been under a dwelling floor (Laurencich de Minelli and Minelli 1973). In the nearby town of Aguas Buenas, researchers discovered a habitation site about 30 centimeters under the modern soil. The archaeological excavation extended to a depth of 160 cm and covered almost an entire hilltop (Haberland 1955).

Laguna Zoncho has been the site of one published archaeological study. On a hill immediately to the north and east of the lake, four burials were excavated and analyzed (Figure 2.4). At least four types of pottery were found in association with these burials (Laurencich de Minelli and Minelli 1966). Apparently, indigenous groups created new types of pottery, but continued to use older methods, so pottery fragments from several periods were found together (Stone 1977). Gold pieces and a leg from an articulated figurine were among the important archaeological finds at the site (Laurencich de Minelli and Minelli 1966). Other sites in the Diquís region with articulated figurines have been dated to between 3450 and 2950 yr BP (Stone 1977).

One of the important conclusions from the excavation at Laguna Zoncho was that the site was a sacred place among the indigenous peoples who lived there. The archaeological work appeared to indicate several hundred years of intense occupation; however, there was no radiocarbon dating of the site. Laurencich de Minelli and Minelli (1966) suggested that this period of intense occupation occurred from 3000 yr BP – 500 yr BP (Haberland 1955). Based on a significant reduction in artifact abundance, the archaeologists concluded that subsequent occupation of the site, 500 yr BP – present, was much less intensive (Laurencich de Minelli and Minelli 1973).

Field inspection in June 1998 revealed that there has been severe "huaquero" disturbance around Laguna Zoncho. Much of the prehistory of Costa Rica has been forever lost due to the activities of "huaqueros." These collectors and traders plunder tombs in order to retrieve valuable artifacts, including gold objects. This situation is especially severe in the Diquís region and has limited the archaeological findings in that area (Snarskis 1981, Hall 1985).

Indigenous Cultivation and the Origin of Maize

Agriculture is often associated with sedentism and ceramic manufacture (MacNeish 1964, Piperno 1994, Northrop and Horn 1996), so understanding how and when agriculture developed is an important issue in archaeology. In Costa Rica, attention has focused upon when maize first arrived, and from what direction it came. Traditional views assume that maize was first domesticated in the highlands of Mexico and spread southward (MacNeish 1964, Piperno 1994), although the exact timing of domestication and dispersal is under scrutiny (Piperno 1994; Fritz 1994, 1995). Maize is best adapted to periods of sunlight and relative dryness, and in southern Central America, these areas would most likely be middle altitudes and lowlands on the Pacific coast (Linares *et al.* 1975). Linares *et al.* (1975) show evidence of extensive maize cultivation in 2380 yr BP in the Volcán Barú area. They suggest that maize was brought into that region by people from the adjacent lowlands and mid-elevations or from nearby areas via the Pacific coastal plain. This is the first evidence of extensive use of seed culture in the Chiriquí archaeological region, although many archaeologists assume that similar cultivation occurred throughout the area.

Maize and beans are the most important indigenous food crops in Costa Rica today. The Spaniards adopted both crops and they are still widely grown throughout the country (Hall 1985). From Chile to Canada, preColumbian peoples grew about 150 varieties of native maize (MacNeish 1964), which was their most important food plant for millennia (Ludlow-Wiechers *et al.* 1983, Fritz 1995). Some scientists believe that maize was secondary to cassava and pejibaye in Costa Rica (Hall 1985). Another study in northwest Panama indicates that indigenous groups at that site were dependent not only on maize, but on bean agriculture as well (Linares *et al.* 1975). Some other indigenous seed crops include: amaranth, chive, panic grass, sunflower, quinoa, apazote, chocolate, the peanut, and five types of bean. Root crops, such as manioc, have probably been an important crop since cultivation began, but manioc leaves little evidence (Snarskis 1981). Tomato, avocado, pineapple, guava, and papaya are some of the other indigenous food crops grown in the Americas (MacNeish 1964).

Historical Context

Modern European colonization of the Coto Brus Valley came from the north along the Inter-American Highway, which was completed from San José to San Isidro in 1946 (Masing 1964). Although there was a small settlement at Golfito (first occupied around 1874; Trejos 1996), 38 km to the southwest, the Fila Costeña was a major obstacle to colonization of the Coto Brus Valley. There were a few other small towns in the extreme southern portion of Costa Rica, including Cañas Gordas, Aguas Buenas, and Sabalito.

In the late 1940s, the government of Italy contracted with farming families to form an agricultural colony, San Vito de Java, in the Coto Brus Valley of Costa Rica. The primary reason that this area was chosen as a settlement site was that the proposed route of the Inter-American Highway passed through the Coto Brus Valley. Colonization took place in 1952, with the first families arriving in December (Masing 1964). Prior to their arrival, several Italian men worked to clear the forest, arrange for supplies, and devise a way to generate electricity. Forests were more difficult to clear than they had anticipated, and the rainy season more intense, conditions which slowed the settlement of the rest of the colonists. Despite these obstacles, in 1964 San Vito had a population of 485 in town, with an estimated 2,000 more in the rural areas of the settlement. Almost 50% of the inhabitants were Italians, with the rest comprising Costa Ricans, Spaniards, Americans (priests), Yugoslavians (one of whom was the doctor), and English (one of whom was an agronomist) (Masing 1964). Although there are no data as to the population of indigenous groups, natives still lived nearby. In 1962, Masing (1964) observed "bare-footed Indians" among the crowds on the main street of San Vito on the weekends.

The impacts of these colonists on vegetation were intense, although fairly local. Masing (1964) notes that in 1953, "San Vito had become a small island in a vast sea of tropical rainforest." When colonists first arrived, the mostly mature forest had a few patches of young regrowth, which Masing (1964) ascribed to *milpas* (indigenous clearings) that had been abandoned. Routes into San Vito remained impassable for much of the year, so impacts from colonization were limited primarily to local roads. Squatters from Panama were a constant threat to settlers' land because they attempted to claim land that had already been bought. The squatters also altered the forest, as they only had to demonstrate 'improvements' (cutting down the forest) to a parcel of land in order to claim it. No official records were kept of the squatter population near San Vito, so the extent of their impact cannot be determined (Masing 1964).

After 1954, the proposed route of the Inter-American Highway was changed to follow the Pacific coast, a move that perpetuated the relative isolation of San Vito. Primary forests in Coto Brus were reduced from 31660 ha in 1973 to 7577 ha in 1984 (Manger 1992), with coffee cultivation and cattle raising as the major agricultural activities. Land devoted to coffee cultivation nearly doubled between 1964 and 1984 (from 3000 ha to 5980 ha), while land for pasture more than tripled (from 5000 ha to 17984 ha) (Manger 1992). An aerial photograph from 1968 (Instituto Geografico Nacional, L-306 R-68) shows that the land immediately surrounding Laguna Zoncho was cleared much as it is today. At least one large building, and several small ones, stood in the present location of the farm on the northeast slope of the lake. However, unlike the landscape of today, there were extensive coffee plantations surrounding Laguna Zoncho. A map from 1962 indicates that a cemetery is located on the northwest hill that overlooks the lake, although the map does not show whether it is a colonial cemetery or an indigenous one (Masing 1964). This is not the area of the archaeological study, but future study may reveal the presence of indigenous burials in the area. Field inspection in June 1998 did not reveal any indication of a colonial cemetery at the site.

CHAPTER 3

CORE SITE AND METHODS

In March 1997, Dr. Sally Horn and students Lisa Kennedy and Brandon League retrieved a 5.88 m long sediment core from Laguna Zoncho. The core was taken near the center in the deepest part of the lake (water depth 2.3 m). Near-surface sediment (upper 113 cm) was retrieved using a plastic tube fitted with a rubber piston. Deeper sediments were retrieved using a Colinvaux-Vohnout locking piston corer, and returned to the lab at the University of Tennessee still encased in the original 1 m long aluminum coring tubes. The near surface sediments were extruded from the plastic tube in 2 cm sections at the Las Cruces Biological Station. Forty-eight slices, corresponding to 96 cm, were cut and bagged for return to the lab in Tennessee. The coring team may have cut the core into slightly larger than two cm sections, resulting in fewer than expected samples, or the sediment may have settled inside the plastic tube before extrusion. I used the field measurement of 113 cm, and calculated that there was 2.35 cm of sediment per sample.

In the laboratory at the University of Tennessee, Horn, Kennedy, and I opened the aluminum core tubes using a specialized router, and divided each core lengthwise into two halves. We then photographed the cores to record sediment colors and stratigraphy. I examined the cores in the lab and made notes on stratigraphy, texture, and Munsell color. I also noted macroscopic organic fragments and other material in the core, such as large wood fragments and two pieces of pottery.

I sampled the core for pollen analysis and loss on ignition (LOI, Dean 1974) at 16 cm intervals, with 8 cm intervals near the ends of each 1 m core section, and in the uppermost meter of the core. I used 1.2 cm^3 of sediment for pollen analysis and LOI for the upper watery sediments and 0.5 cm^3 for the sediments in the aluminum tubes. I processed the samples using standard procedures (HCl, HF, KOH, acetolysis, safranin stain; Berglund 1986; Appendix A) with the addition of *Lycopodium* spores to enable calculation of pollen concentrations (Stockmarr 1971). The residues were mounted on slides in silicone oil and counted to a minimum of 300 grains per slide, excluding fern spores and indeterminate pollen grains. LOI samples were dried at 100° C and ignited for an hour at 550° C and again at 1000° C (Dean 1974) to measure water content, organic matter, and carbonate content. Samples of charcoal and other plant remains from three depths (120, 247, and 280 cm) were submitted to Beta Analytic Laboratory for Accelerator Mass Spectrometry (AMS) radiocarbon dating.

I identified pollen grains based on examination of reference slides of tropical pollen grains and published keys, photographs, and descriptions (Heusser 1971; Markgraf and D'Antoni 1978; Hooghiemstra 1984; Horn 1985, 1986; Graham 1987; Moore *et al.* 1991; Roubik and Moreno 1991). I identified pollen grains to the lowest possible taxonomic level, but some types had to be grouped because of overlapping morphologies, such as the Melastomataceae and Combretaceae families. These pollen types are very distinctive, with six colpi, but they are nearly identical to each other. There have been attempts to separate them by size, but too much overlap has been found (Hansen 1990, Islebe *et al.* 1996). Another group of pollen that is difficult to separate is the order Urticales (Moraceae, Urticaceae, and Ulmaceae families exclusive of *Ulmus*: Byrne and Horn 1989, Hansen 1990, Northrop 1994, Rodgers 1994, Goman and Byrne 1998, Kennedy 1998). Pollen grains representing this order are small (about 15 μm), diporate to polyporate, and usually psilate or scabrate. I identified several types and grouped others by pore number. The types I distinguished were *Trema*-type, *Celtis*-type, *Ficus*, and *Cecropia*. I identified as *Ficus* only those grains that were oblong (or lozenge-shaped), with the pores on the ends (Horn and Ramirez 1990), as the other morphologies of *Ficus* are indistinguishable from other diporate Urticales. The pollen of *Zea mays* was distinguished from that of other grasses based on grain size and annulus size (see Chapter 4).

I assigned numbers to the unknown pollen grains, described them in detail, and recorded their locations for later reexamination. Following Northrop (1994) and Kennedy (1998), I classified the indeterminate pollen grains using four major categories: corroded, degraded, mechanically damaged, or hidden by detritus. These categories were derived from the more detailed classification of indeterminates by Delcourt and Delcourt (1980), which includes combined characters, such as corroded and mechanically damaged. I used the simpler classification because my indeterminate numbers were so low and multiple damaging factors were rare.

I counted fern spores at every level, and classified them by morphology (monolete and trilete) and exine sculpting (psilate, scabrate, verrucate, coarsely verrucate, echinate, bacculate). I classified charcoal into three size classes based on the longest axis of the fragment: 5 μm - 24 μm, 25 μm - 49 μm, and ≥ 50 μm. Fragments that I identified as charcoal were opaque, black, and angular. I did not count charcoal under 5 μm, as it is too difficult to discriminate between charcoal and other small, angular fragments of material at that size range.

In addition to the slides used for pollen counts, I scanned 3 slides per level to determine the presence or absence of maize pollen. I also scanned 3 slides from 5 levels in the top 12 cm of sediment to determine the presence or absence of the pollen grains of introduced pines and eucalypts.

I entered all of the data into a modified version of the CalPalyn program (Bauer *et al.* 1991). I generated the basic pollen, spore, and charcoal diagrams using CalPalyn and edited the Postscript output to produce the figures included here.

CHAPTER 4

RESULTS

Core Stratigraphy and Chronology

The upper 290 cm of the core are primarily organic, pollen-rich sediments with a possible tephra layer at 98 cm (Table 4.1, Figure 4.1). At 290 cm there is a sharp transition to clay-rich sediments. There is another interval of organic sediment below this clay. However, there is no pollen below 290 cm, neither in the organic nor in the more clay-rich material. A possible tephra layer is located at 363 cm. Another possible tephra layer at 380 divides this organic sediment from the lowest part of the core, which is clay-rich sediment that may predate lake formation. The base of the core appears to be rotted bedrock.

Two ceramic potsherds were found in the core at 192 cm. The largest potsherd measured 5 cm wide and nearly 2 cm thick at its largest dimension. Another potsherd was found in conjunction with the first piece, but it was much smaller, 3 cm wide and 0.5 cm thick.

I submitted organic macrofossils from three levels of the core for AMS radiocarbon dating (Table 4.2). Wood fragments found at 280 cm were submitted to date the base of the pollen-rich section of the core. These fragments yielded a radiocarbon age of 2940 $\pm$ 50 yr BP for this level. Two other levels (120 and 247 cm) were selected for dating based on the results of the pollen analysis. In both cases, there were so few macroscopic remains that a mixture of seeds, leaves, and charcoal was submitted for dating. The results indicate a normal stratigraphic sequence.

Table 4.1. Stratigraphy of the Laguna Zoncho Sediment Core.

Depth(cm)	Visual Description	Munsell Color	Munsell Color Description
Excellent pollen preservation in upper 3 m.			
0-98	Dark organic sediments	10yr 2/2	Very dark brown
98-101	Possible tephra layer, sandy texture	10yr 7/1	Light gray
101-137	Dark organic sediments with clasts from		
	deeper levels	10yr 2/2	Very dark brown
	clasts	2.5y 4/2	Dark grayish brown
137-188	Lighter colored organic sediments	2.5y 4/2	Dark grayish brown
188-193	Potsherd in organic sediments	2.5y 4/2	Dark grayish brown
193-201	Lighter colored organic sediments	2.5y 4/2	Dark grayish brown
201-290	Dark organic sediments	10yr 2/2	Very dark brown
Poor pollen preservation in lower 3 m.			
290-292	Layer of fine particles from possible landslide	10yr 3/1	Very dark gray
292-331	Light colored, sandy soil	10yr 5/2	Grayish brown
331-343	Dark colored, sandy soil	10yr 3/2	Very dark grayish brown
343-363	Dark organic sediments	10yr 2/2	Very dark brown
363-365	Possible tephra layer, fine texture	10yr 3/1	Very dark gray
365-380	Dark organic sediments	10yr 2/2	Very dark brown
380-381	Layer of fine particles from possible landslide	10yr 5/2	Grayish brown
381-567	Inorganic, clay-rich soil	2.5y 5/2	Grayish brown
567-583	Inorganic, clay-rich soil with small minerals	2.5y 5/2	Grayish brown
583-588	Rotted bedrock	10yr 2/2	Very dark brown

Table 4.2. Radiocarbon Determinations on Organic Material from the Laguna Zoncho Sediment Core.

Lab Number	Depth (cm)	Material Dated	$\delta^{13}C$	Uncalibrated ^{14}C Age (^{14}C yr BP)	Calibrated Age cal yr BP	Calibrated Age Range (cal. yr BP) ± 1 σ	Calibrated Age Range (cal yr BP) ± 2 σ
ß-122556	120	M	30.0	540 ± 50	540	552-516 [1]	643-503 [1]
ß-122556	247	M	28.1	2110 ± 50	2060	2139-1994[1]	2298-1944 [1]
ß-115186	280	W	28.1	2940 ± 50	3070	3203-2982 [2]	3248-2941 [2]

All analyses were performed by Beta Analytic Laboratory. Errors estimate 68% (1 σ) and 95% (2 σ) probability. Calibrations were determined using version 3.03 of the CALIB radiocarbon age calibration system (Stuiver and Reimer 1993) and are based on datasets of Stuiver and Pearson (1993) [1] and Pearson and Stuiver (1993) [2].
M = mixed charcoal, seeds, and leaves; W = wood fragments.

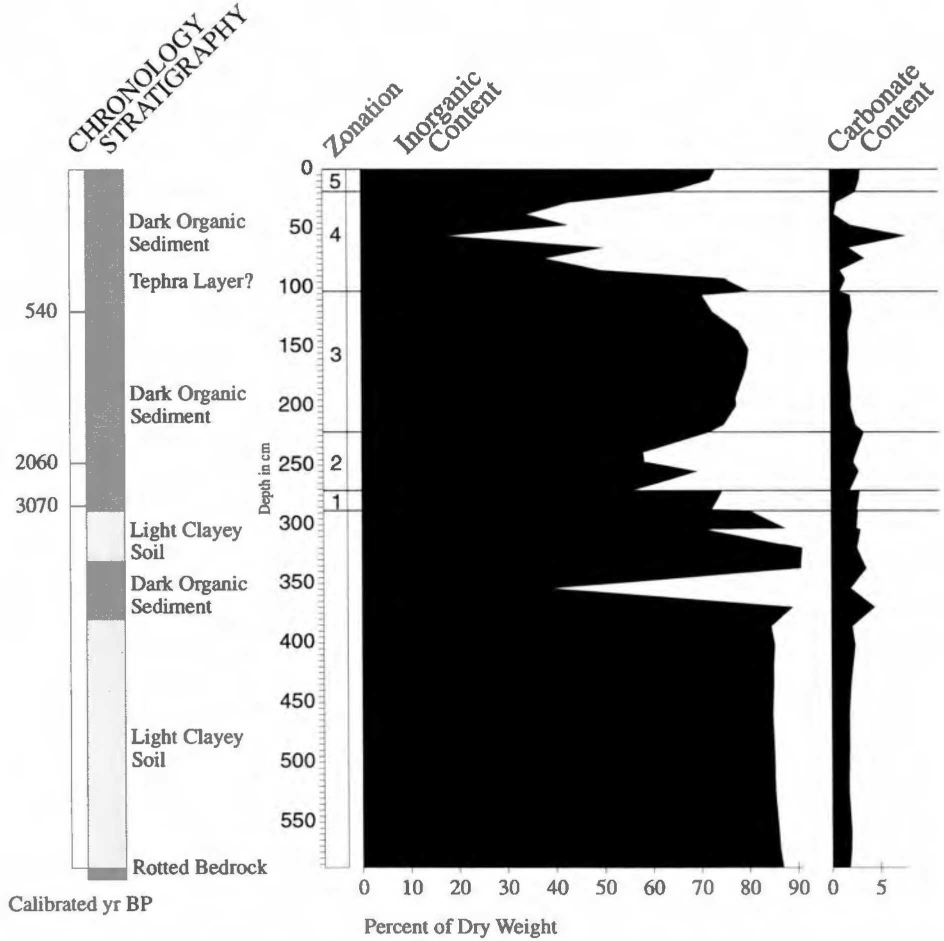

Figure 4.1. Stratigraphy, Inorganic Content, and Carbonate Content of the Entire Laguna Zoncho Sediment Core

I used calibrated calendar dates (cal yr BP: Table 4.2) to determine average rates of sedimentation throughout the pollen-rich part of the core. Sediment in the lowest 33 cm accumulated most slowly (0.03 cm/year). The rate of sedimentation in the middle of the core more than doubled (0.08 cm/year). The topmost sediments have the fastest rate (0.20 cm/year), but these sediments are still quite soft and have yet to compress like the lower sediments.

I was able to estimate the age of near-surface sediments based on the presence of pollen from cultivated pines. There are no native pines in Costa Rica, but several were planted on the shores of Laguna Zoncho. According to former landowner Luis Diego Gómez (pers. comm. 1998), the first pines were planted no more than 40 year ago. Assuming 10 years for the pines to reach maturity and begin pollen production (L. Diego Gómez, pers. comm. 1998), the first pine pollen should have been deposited in 1969 or later. Scanning slides of the topmost sediments resulted in the identification of *Pinus* pollen in only the top 7 cm of the core. This indicates that the 7 cm horizon was deposited no earlier than 1969. Assuming the 7 cm level does correspond to 1969 indicates a sedimentation rate of 7 cm in 30 years, or 0.23 cm/year. This figure corresponds closely to the sedimentation rate of 0.20 cm/year calculated for the upper 1.2 m of the core based on the uppermost radiocarbon date.

I had hoped to be able to do additional "pollen dating" using Eucalyptus pollen. However, pollen grains from exotic eucalypts planted on the shores of Laguna Zoncho proved to be indistinguishable from pollen grains of native genera in the Myrtaceae family.

Pollen preservation was excellent throughout the core except for the lowest counted level (288 cm), in which the preservation was still good, but the indeterminates increased. I identified 54 different types of pollen grains, most to the family level. *Zea mays* pollen

Table 4.3. Presence/Absence of Maize Pollen and the Diameters of the Grains and the Annuli in the Laguna Zoncho Sediment Core.

Depth (cm)	P/A	Grain Diameter (μm)	Annulus Diameter (μm)	Depth (cm)	P/A	Grain Diameter (μm)	Annulus Diameter (μm)
0	+	85	17.5	120	+	75	15
2	+	70	20	136	+	74.5	12.5
5	+	65	11	152	+	72.5	15
7	+	67.5	15	168	+	75	15
9	+	75	12.5	184	+	80	17.5
		70	15			80	15
12	+	105	15			62.5	15
14	-					65	15
19	+	115	15	192	+	67.5	12.5
		72.5	15			97.5	12.5
28	+	90	17.5			87.5	15
38	+	87.5	15			70	17.5
47	-			200	+	75	15
56	+	65	12.5	216	+	72.5	15
		85	15	222	+	65	12.5
66	+	85	12.5			75	15
75	+	65	12.5	239	+	70	17.5
85	-			247	+	75	17
92	+	82.5	15			85	20
94	+	97.5	12.5	255	+	80	15
103	+	65	12.5	271	+	70	17.5
106	+	75	15				

was found in 4 levels in the regular counts. Scanning additional slides (Table 4.3) showed that pollen of this cultigen is actually found in almost every level sampled in the core (only 3 levels lack *Zea mays*).

I also recognized 51 different types of pollen that I was unable to identify. The total percentage of these unknowns (all levels together) was 5.7%. Percentages of unknowns by level varied between 0.7% and 10%. Table 4.4 categorizes the unknowns by exine and aperture types. Increases in unknown pollen types coincide with increases in the pollen of forest taxa and reductions in the pollen of disturbance taxa.

Table 4.4. Percentages of Unknown Pollen Grain Types in the Laguna Zoncho Sediment Core.

Morphology	Psilate	Scabrate	Reticulate	Echinate	Verrucate	Total
Inaperturate	14%	29%	14%	29%	14%	14%
Tricolporate	40%	20%	34%	6%	0%	69%
Periporate	11%	22%	44%	11%	11%	17%
Total	31%	22%	33%	10%	4%	100%

Table 4.5. Percentages of Indeterminate Pollen Grain Types in the Laguna Zoncho Sediment Core.

Type of Deterioration[1]	Description[2]	Highest Percent of Indeterminates (any level)	Percent of Total Indeterminates (all levels)
Mechanical Damage	Grain broken or crumpled	100%	49%
Concealment by Detritus	Grain hidden by mineral or organic debris	69%	28%
Degradation	Exine thinned, fusion of sculptural features, or fusion of structural elements forming the wall layer	79%	16%
Corrosion	Exine locally etched, pitted, or perforated	21%	6%

[1,2] Delcourt and Delcourt 1980

Indeterminate pollen grains were relatively rare in the Laguna Zoncho core. Table 4.5 shows the types of indeterminate pollen grains and their highest (any level) and overall (all levels summed) percentages. The average percentage for indeterminates in all levels is 3.5%. Percentages of indeterminates in any level range between 0% and 7.4%. I excluded the lowest counted level in the core from the above calculations because it had a substantially higher proportion of indeterminate pollen grains (19.8%).

Pollen, Spores, and Charcoal

Figure 4.2 is a summary diagram that includes pollen percentages for forest and disturbance taxa, presence of maize pollen in both regular counts and additional counts, total fern spore percentages, inorganic content of the sediment, and total charcoal abundance. The category of Other Premontane and Montane Taxa include *Quercus*, *Alnus*, *Ulmus*, and *Weinmannia*. The triporate and diporate Urticales groups include all 2- and 3- pored pollen in this order other than *Cecropia*. Pollen percentages are calculated as percent total pollen (excluding indeterminates), while fern spore values are the percent of total pollen plus fern spores. Charcoal abundance in Figure 4.2 is shown as the ratio of total fragments of charcoal counted (all size classes) to total pollen.

Additional diagrams present further details of the record. Figure 4.3 shows the rare pollen types. Figure 4.4 shows pollen curves of individual taxa within the order Urticales. In Figure 4.5, total charcoal is plotted on both a wet volume and dry mass basis, and the total charcoal is further broken down into size categories. Charcoal influx (per cm^2/ year) is also shown. Percentages of different fern spore types, and unknown and indeterminate pollen grains, are shown in Figure 4.6, along with organic content as determined by LOI and pollen and spore concentrations. I have divided the record into five intervals or zones, based on the changing percentages of certain pollen types and on the abundance of

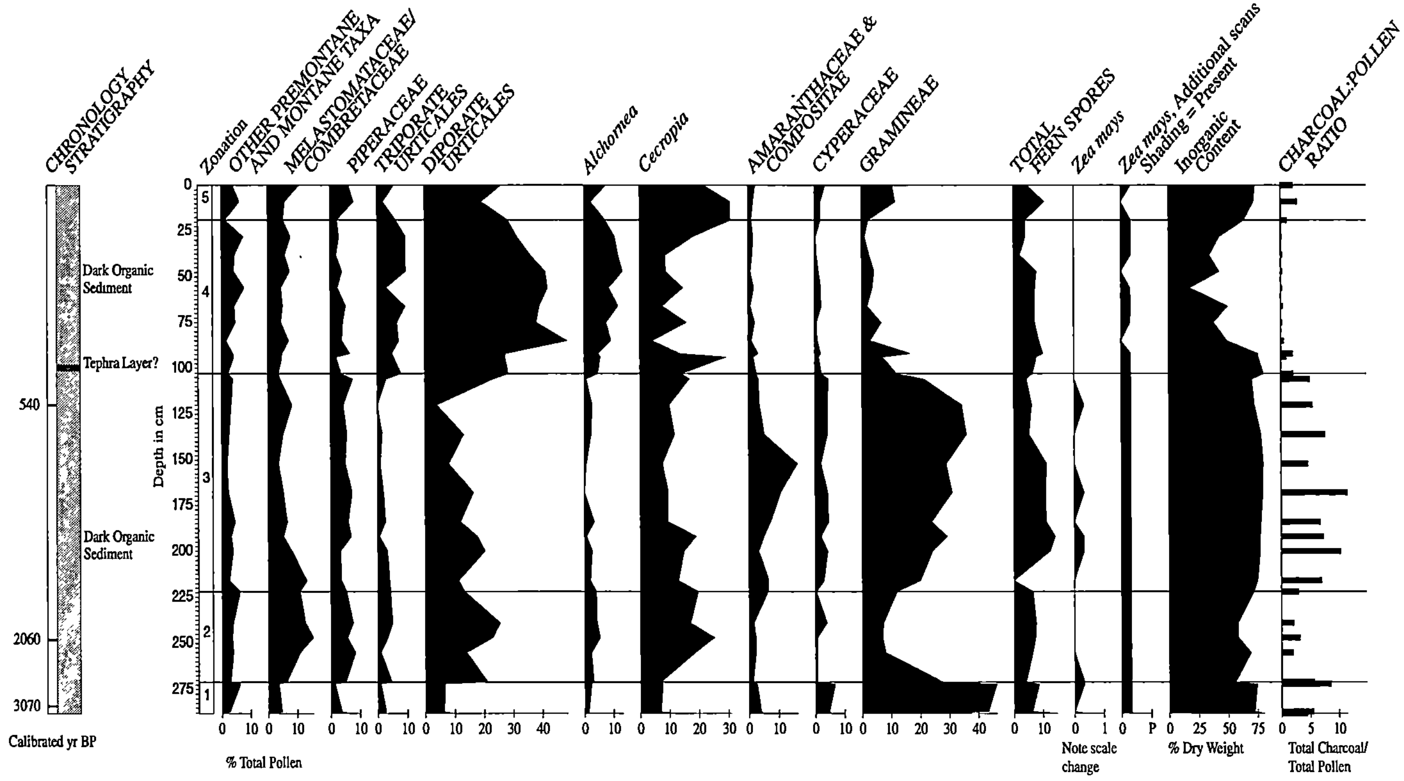

Figure 4.2. Summary Pollen Diagram for the Laguna Zoncho Sediment Core

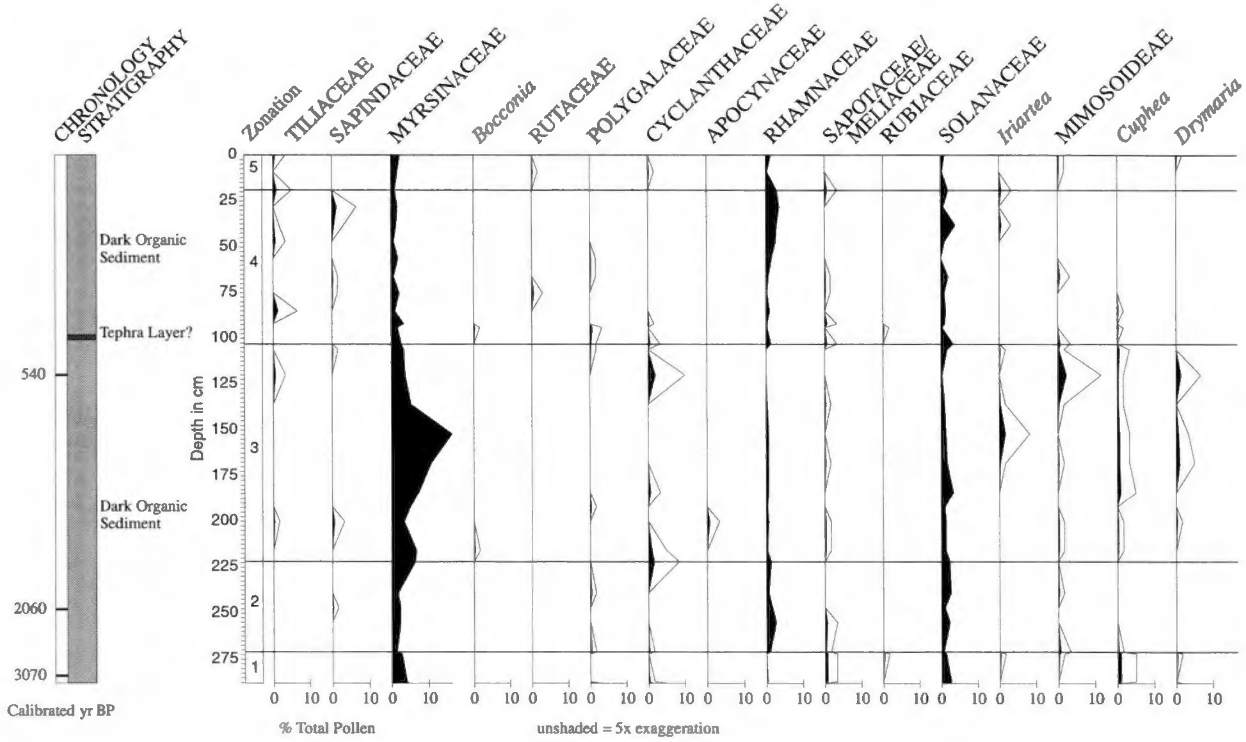

Figure 4.3. Rare Pollen Taxa in the Laguna Zoncho Sediment Core

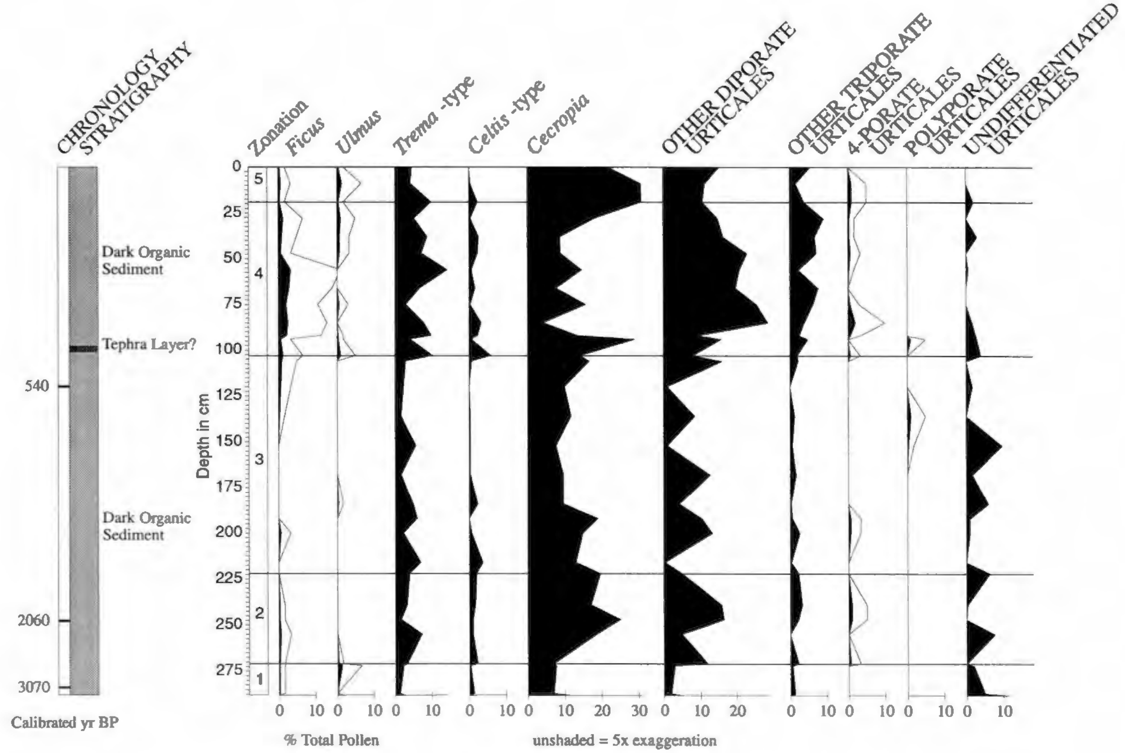

Figure 4.4. Urticales Pollen Percentages in the Laguna Zoncho Sediment Core

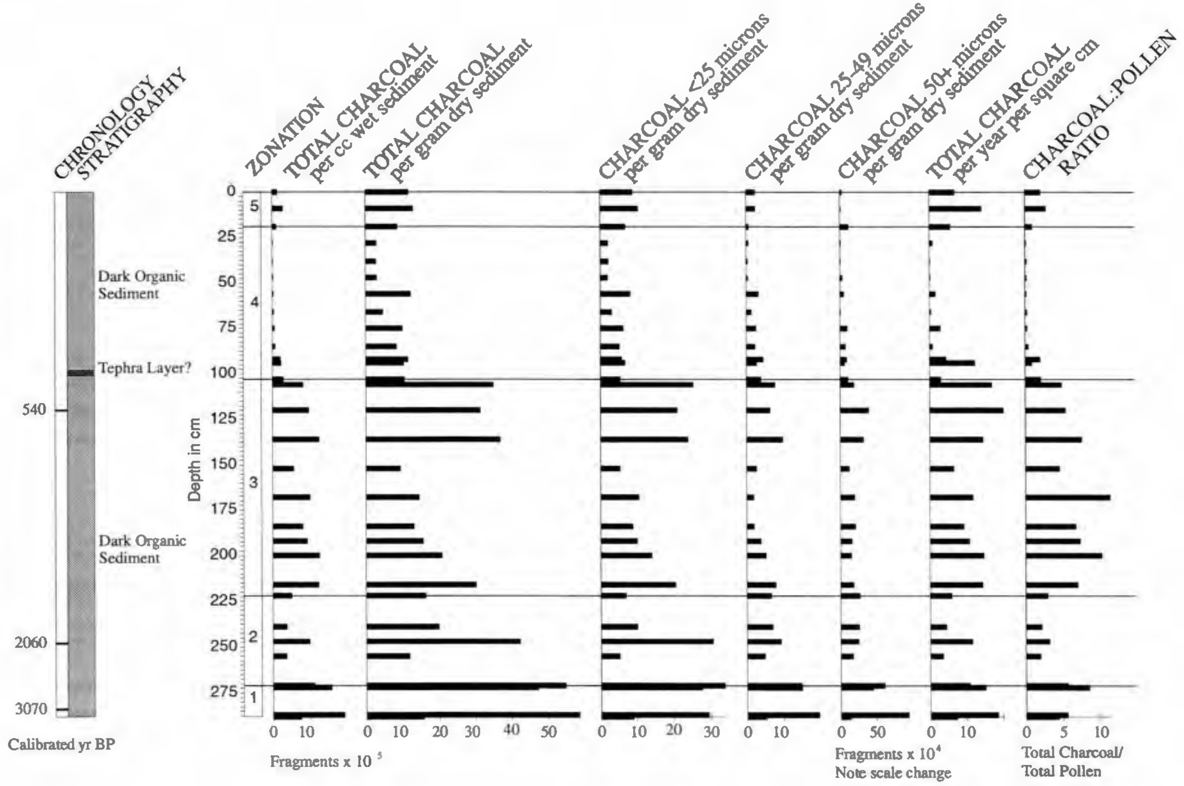

Figure 4.5. Charcoal Diagram for the Laguna Zoncho Sediment Core

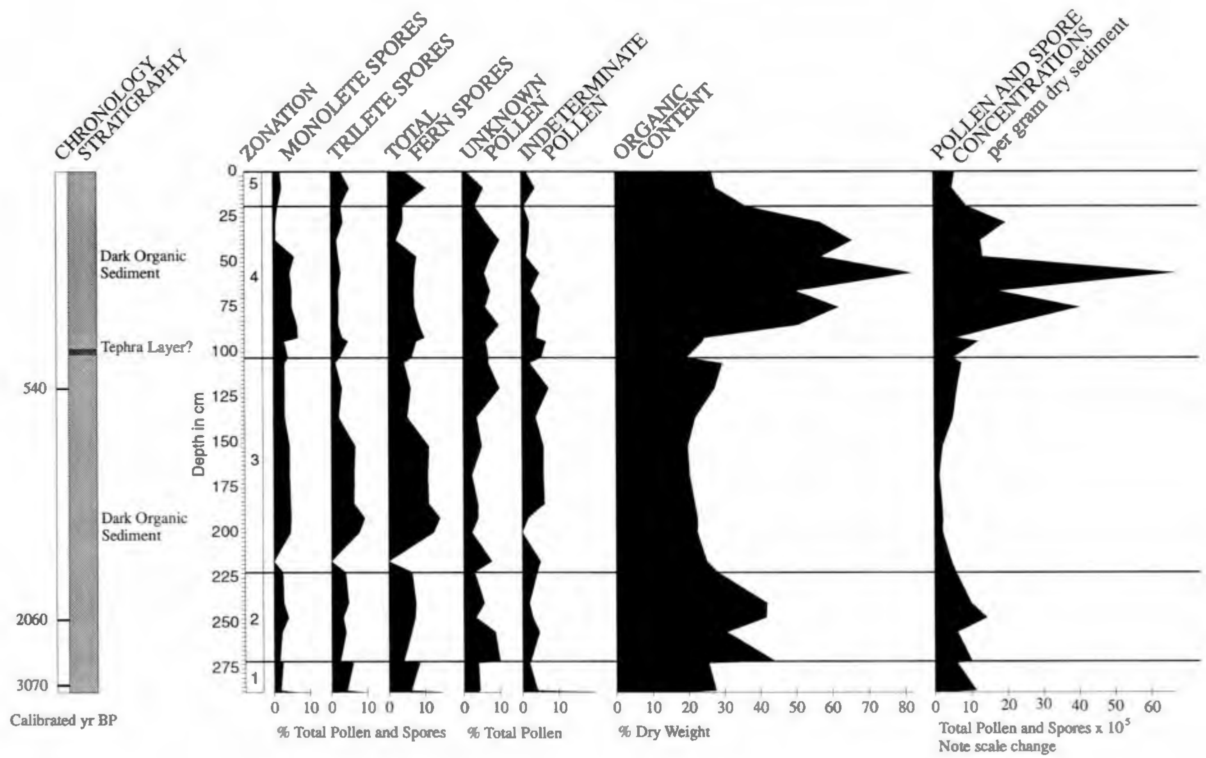

Figure 4.6. Fern Spores, Unknowns, Indeterminates, Organic Content, and Pollen and Spore Concentrations in the Laguna Zoncho Sediment Core

charcoal. I use this zone notation in detailing and discussing the pollen record in this and the following chapters.

I calculated the most abundant pollen types in the entire pollen record by dividing the total pollen grains of a particular taxon by the total pollen grains of all taxa counted. The most abundant grains are Poaceae (17%), *Cecropia* (15%), and diporate Urticales (12%). Within any level, Poaceae pollen is the most abundant at 46%. Pollen types with percentages greater than 10% in any level include *Cecropia* (31%), Urticales diporate (29%), Melastomataceae/Combretaceae (16%), and *Trema*-type (14%).

Pollen percentages of both forest and disturbance taxa ranged widely. The pollen type that has the highest variation is Poaceae, which ranges between 1% and 46%. Other disturbance indicators that have wide variation include Amaranthaceae (0% - 9%) Asteraceae (0.3% - 8.7%) and Cyperaceae (0.3% - 4.7%). Pollen of forest taxa that have a high variation include Urticales triporate (0% - 9.2%), Piperaceae (1.3% - 7.9%), *Acalypha* (0% - 6.3%), and *Celtis*-type (0% - 6%).

The order Urticales is generally very abundant. In the summary diagram (Figure 4.2), all pollen types of Urticales, other than *Cecropia*, are grouped into diporate or triporate classes. When the different pollen types (*Ficus*, *Celtis*-type, *Trema*-type, triporate, diporate, 4-porate, and polyporate) are broken out of the larger groups, different results are apparent (Figure 4.4). Pollen of *Ficus* and *Ulmus* are most abundant in Zones 4 and 5 (0 - 103 cm). The pollen of the other Urticales types (except polyporate) are also common in this portion of the core, but have higher abundance in different depths of the core. *Trema*-type, *Celtis*-type, triporate, and 4-porate pollen grains have a bimodal distribution. The second area of prevalence of these types in the core is in Zone 2. Pollen of *Cecropia* and other Urticales diporate are found throughout the core at various depths. *Cecropia* pollen is most abundant near the top of the core, but has two additional large peaks at 100 cm and 250 cm, and seven minor peaks. The largest peak of Urticales diporate pollen occurs in Zone 4 at 75 cm, with ten additional peaks throughout the core. The pollen of Urticales polyporate stands out as being rare and occurring during times of high percentages of disturbance taxa pollen in Zone 3.

Figure 4.6 shows the curves for both monolete and trilete fern spores. Trilete fern spores were the most abundant in any level at 9.4% and also had the highest variation (1.3% - 9.4%). Percentages of monolete fern spores range between 1.6% and 7.3%. The maximum percentage of total fern spores in any level was 15%. Peaks of trilete fern spores tend to coincide with peaks in Poaceae pollen, whereas peaks in monolete fern spores appear to coincide with an increase in the pollen of forest taxa (Figure 4.6). Among the spores in the Laguna Zoncho samples was a diversity of exine sculpturing types. Table 4.6 shows both the percentage of monolete or trilete spores for each exine type and the percentage of total spores for different exine types.

Table 4.6. Percentages of Fern Spore Types in the Laguna Zoncho Sediment Core.

Sclerine Type	Monolete	Trilete	Total
Psilate	42%	58%	65%
Coarsely Verrucate	89%	11%	15%
Verrucate	36%	64%	4%
Scabrate	31%	69%	8%
Echinate	52%	48%	3%
Bacculate	60%	40%	1%
Other		100%	4%
Total	47%	53%	100%

Charcoal that measures 5 - 24 μm shows the greatest change throughout the core. The abundance of charcoal of this size ranges from around three million fragments per gram dry sediment in Zone 1 (at the base of the organic sediments) to almost zero in Zone 4. The smallest class size comprises almost 100% of the charcoal total in Zone 5 (0 - 19 cm), but the total charcoal is so low that this is, in fact, the lowest abundance of charcoal fragments represented in the entire core. The middle size class of charcoal (25-49 μm) has a similar shaped curve, but the range is much smaller and the peaks are less pronounced. In Zone 1, the amount of charcoal in the middle size class reaches nearly 2,000,000 fragments per gram dry sediment, which is the highest value reached for this class. There is a fairly constant representation throughout the core except in Zones 4 and 5 where this class is almost nonexistent. The largest charcoal size class (≥ 50 μm) is the least abundant. At the base of the core, one sample contains nearly 1,000,000 fragments of the largest charcoal size class per gram dry sediment. Charcoal fragments decrease in Zone 2 and rise again in Zone 3. All classes fall abruptly in Zone 4 to near zero levels. Low abundance is prevalent throughout Zone 4, but in Zone 5, the small and middle size classes rise again, while large charcoal remains low.

Description of Pollen Zones

In Zone 1 (290 - 272 cm, 3074 - 2829 cal yr BP), comprising the four lowest samples counted in the Laguna Zoncho core, there are high percentages of Poaceae pollen, with lesser amounts of Cyperaceae pollen, and large amounts of charcoal (Figure 4.2). Percentages of *Cecropia*, Urticales, Melastomataceae/Combretaceae, and Piperaceae pollen are low. At the initiation of Zone 2 (272 - 222 cm, 2829 - 1763 cal yr BP), a sharp drop in pollen of Poaceae and Cyperaceae and a decrease in charcoal abundance coincide with a dramatic increase in percentages of forest pollen taxa, such as *Cecropia*, Urticales diporate, Piperaceae, Melastomataceae/Combretaceae and pollen in the Other Premontane and

Montane Taxa group. In Zone 3 (222 - 103 cm, 1763 - 457 cal yr BP), there are increasing amounts of charcoal, Poaceae pollen, and Amaranthaceae and Asteraceae pollen. There is a gradual drop in forest taxa pollen, such as Urticales diporate and Melastomataceae/ Combretaceae. Pollen of *Cecropia* and Cyperaceae stay relatively constant throughout Zone 3. At the boundary of Zones 3 and 4 (103 cm, 457 cal yr BP) a sudden decrease in Poaceae pollen coincides with a major increase in Urticales pollen and is followed immediately by a large peak in *Cecropia* pollen. Pollen of Poaceae, Cyperaceae, Amaranthaceae and Asteraceae, and charcoal abundance, remain low throughout Zone 4. In this section of the core, *Alchornea* pollen reaches its highest value, as does pollen of Other Premontane and Montane taxa. Two gaps occur in the distribution of *Zea mays* pollen. In Zone 5 (0 - 19 cm, c. AD 1902 - 1997), there is a decrease in all pollen of forest taxa, while Poaceae pollen and charcoal rise. Cyperaceae pollen and Amaranthaceae and Asteraceae pollen remain at low levels, with one sample (14 cm) lacking *Zea mays*.

In general, increases in the pollen of forest taxa coincide with an increase in organic content, an increase in the percentage of unknowns, and decreases in total pollen concentration.

Maize Pollen

Maize pollen is generally present throughout the Laguna Zoncho core. I did not tally *Lycopodium* controls as I scanned additional slides for maize pollen, so I was unable to calculate pollen percentages. The pollen grains measured 62.5 μm to 115 μm in maximum dimension (Table 4.3). Several different diameter measurements have been used to determine *Zea mays* pollen. Tsukada and Rowley (1964) state that most preColumbian maize pollen ranges in size from 60 - 85 μm. However, they also cite cases where the combined ranges at several sites were 55 - 115.7 μm. Ludlow-Wiechers *et al.* (1983) show that the diameters of pollen grains from Mexican races of maize measure 69.8 - 84.4 μm. All of the Laguna Zoncho maize pollen falls within the larger range. Measuring the annulus is another way to determine maize pollen from other *Zea* species. The annulus of maize can range from 11 - 22 μm (Ludlow-Wiechers *et al.* 1983), and all of the maize grains at Laguna Zoncho are within this range. The main concern about identification of maize pollen is that it overlaps with teosinte pollen in both grain and annulus diameters. As Whitehead and Langham (1965) describe, it is nearly impossible to distinguish one from the other. However, Irwin and Barghoorn (1965) state that in areas where teosinte does not naturally occur, the identification of maize in the pollen record should prove relatively easy. Since there is no evidence that wild teosinte ever occurred in southern Costa Rica, this problem is not an issue in the Laguna Zoncho pollen record.

CHAPTER 5

DISCUSSION

The pollen record of Laguna Zoncho indicates that humans have altered the landscape around the lake for at least the last 3000 years. Maize pollen occurs nearly continuously throughout the record. This finding, together with the fluctuations in the pollen of disturbance and forest taxa, probably reflects continuous occupation since lake formation. Abundant charcoal in the sediment supports the idea of relatively high populations and frequent anthropogenic burning throughout the region. In this chapter, I discuss how the history of human activity and natural disturbances, such as tectonic activity and climatic shifts, may be reflected in the pollen and charcoal profiles of Laguna Zoncho.

Stratigraphy, Lake Formation, and Sedimentation Rates

The sediment record of Laguna Zoncho contains an upper pollen-rich section and a lower section that contains little or no pollen. The base of the core appears to be rotted bedrock that predates lake formation. The pollen-poor section above the rotted bedrock is mainly inorganic sediment that may be colluvial in part. There is a section of darker, more organic material that was probably deposited in a wet environment – possibly a swamp or lake. However, there is little or no pollen preserved in this organic section, probably due to later drying and oxidation. This pollen-poor organic layer is overlain by a 50 cm thick section of more inorganic material that appears to be a soil profile. There are filled cracks in this material that support the interpretation of drying. The lowest occurrence of pollen in countable quantities (288 cm) corresponds with a change from inorganic soil to more organic sediment. This material was probably deposited in a lake or wetland. I interpret this beginning of organic sedimentation at 288 cm to mark the formation of the modern lake that took place about 3000 radiocarbon years ago.

The formation of the basin that holds modern Laguna Zoncho was likely the result of tectonic activity, mass wasting, or a combination of the two (K. Orvis and S. Horn, pers. comm. 1998). Analysis of aerial photographs (Instituto Geografico Nacional, L-308 R-38, Instituto Geografico Nacional, 16FEB92 0641) show linear scarps likely associated with the major fault that runs along the Fila Costeña, and Laguna Zoncho's basin may have formed from en echelon faulting parallel to the main scarp east of San Vito. The basin may alternatively be defined by two small faults (parallel to each other and the larger fault), with the basin itself a downdropped area in between. Mass wasting events, perhaps triggered by earthquakes along faults in the area, could also explain the presence of the basin. Analysis of the aerial photographs reveals a number of examples of probable mass wasting events (landslides and/or slumps) in the Laguna Zoncho area. There may have been a deep rotational slump to the northwest of the entire scarp. As the area around the lake dropped, ancestral drainage (which would have been to the east) would have been blocked, and the lake would have formed. Another possibility is that a more local landslide from the large hill to the southeast blocked an eastward-draining valley. The landslide would have come from the northwest slope of that hill, filling in the drainage between the large hill and the hill where the archaeological sites are located (northeast of the lake; Figure 2.4).

From the abundance of well-preserved pollen and generally high organic content of the sediments, I suggest that Laguna Zoncho has had water continuously since 3070 cal yr BP. Lake levels have varied in historic time (Figure 2.4), and likely in prehistory, but the basin seems to have never dried up. In all discussion that follows, I will refer to the upper, pollen-rich half of the sediment core as the 'core,' as that is the only section that I analyzed for changes in pollen, spores, and charcoal abundance.

Sedimentation rates calculated from the AMS dates on the Zoncho core are consistent with expectations from the literature. Many tropical sediment records show that as the pollen of disturbance taxa increases, sedimentation rates also increase, possibly due to increased erosion after deforestation (Leyden 1987, Northrop 1994, Roosevelt *et al.* 1996). In Laguna Zoncho, sedimentation rates increase when pollen of forest taxa declines and pollen of disturbance taxa and charcoal fragments increase.

Different Taxa and Their Implications

The plants represented by pollen grains and spores in the Laguna Zoncho sediments include taxa with differing habitat requirements. The mid-elevation location of Laguna Zoncho puts the lake near the upper elevational limit of some lowland plant taxa, and the lower elevational limit of some montane plant taxa. The record includes pollen types that suggest more open, disturbed ground, and others that are common in more mature forests.

My interpretation of the ecological significance of different pollen types in the Laguna Zoncho record is based on knowledge of the habitat requirements of the plant taxa represented (Standley 1937 – 1938, Gentry 1993), on known relationships between modern pollen rain and vegetation in Costa Rica (Rodgers and Horn 1996), and on previous paleoecological research in Costa Rica and elsewhere in the Latin American tropics (Brown 1985; Binford *et al.* 1987; Leyden 1987; Byrne and Horn 1989; Bush and Colinvaux 1990, 1994; Northrop 1994; Hansen and Rodbell 1995; Islebe *et al.* 1996; Northrop and Horn 1996; Kennedy and Horn 1997; Goman and Byrne 1998; Kennedy 1998).

A particularly important task in the case of the Laguna Zoncho core is identifying taxa that may relate to disturbance. In a naturally forested landscape, the pollen of herbaceous plants may indicate disturbance. Many researchers consider that high percentages of the pollen of *Poaceae*, Chenopodiaceae, Amaranthaceae, and Asteraceae also demonstrate high levels of human disturbance, possibly related to cultivation (Brown 1985, Leyden 1987, Byrne and Horn 1989, Islebe *et al.* 1996, Hansen and Rodbell 1995, Northrop and Horn 1996). The most relied upon indicator of cultivation is the pollen of *Zea mays*, which is distinguishable from related grasses. Manioc pollen is also distinctive, but it is rarely preserved.

Peaks in *Cecropia* pollen have often been associated with increased disturbance, both human and natural (Standley 1937 - 1938; Leyden 1987; Bush and Colinvaux 1990, 1994; Gentry 1993; Northrop and Horn 1996; Kennedy 1998). At Laguna Zoncho, a decrease in the pollen of *Cecropia* indicates either the presence of a more mature forest or suppression of forest regrowth. I do not include *Cecropia* when referring to disturbance taxa, however, because in order to have regrowth, cleared areas must be abandoned. *Trema* (and sometimes Melastomataceae; Leyden 1987) is often associated with forest regrowth, as well (Binford *et al.* 1987, Northrop and Horn 1996).

Previous pollen studies in the American tropics have identified different species as indicative of montane forest cover. These differences relate to regional floristic differences as well as differences in the elevations of the forests under study. In montane forests of southern Mexico, indicative pollen taxa include *Myrsine*, *Weinmannia*, Piperaceae, *Quercus*, and *Alnus* (Goman and Byrne 1998). Pollen spectra from wet montane forests of northern Peru include all of the above other than *Quercus*, which does not occur naturally in Peru, along with *Podocarpus*, Urticales, *Acalypha*, *Alchornea*, and Ulmaceae (Hansen and Rodbell 1995). In Costa Rica, Rodgers and Horn (1996) found that Melastomataceae/ Combretaceae, Urticales diporate, *Weinmannia*, and *Myrica* are most common in premontane rain forests, while in montane rain forest, Urticales diporate, *Quercus*, *Myrica*, *Weinmannia*, and *Alnus* dominate.

At Laguna Zoncho, the disturbance taxa include Poaceae, Amaranthaceae, and Asteraceae. I include *Alnus*, *Quercus*, *Podocarpus*, and Diporate Urticales as forest taxa. I also consider Melastomataceae, *Alchornea*, and *Acalypha* to be indicators of forest presence, not only based on previous studies, but on how the downcore changes compare to changes in other pollen percentages of forest taxa.

3000 Years of Human Disturbance around Laguna Zoncho: Evidence from the Pollen Record

The five pollen zones in the Zoncho core suggest major changes in vegetation and land use over the 3000 year period spanned by the record. Three thousand years ago (Zone 1), fire may have been an important mechanism of vegetation disturbance around Laguna Zoncho. Charcoal at this level (288 cm) is 2.5 times more abundant than at other sites studied in Costa Rica (Northrop 1993, Kennedy 1998). Poaceae pollen comprises nearly half of the total pollen, while forest taxa represent less than 25% (Figure 4.2). In an area covered in prehistory by premontane wet forest (Masing 1964), this level of disturbance is noteworthy. While changes in climate could influence fire activity, the presence of *Zea mays* pollen in the lowest level of the pollen record suggests that the charcoal is likely derived from anthropogenic burning. The presence of maize indicates human habitation of this site because maize requires human cultivation (Fearn and Liu 1995, Northrop and Horn 1996).

Stratigraphic evidence from Laguna Zoncho indicates human presence throughout the entire 3000 year period spanned by the pollen diagram, but the intensity of human impact appears to have varied over time. The seemingly high impact from humans in Zone 1 (the basal pollen zone) continues for about 300 years (3070 - 2830 cal yr BP; Figure 4.2). In Zone 2 (2830 - 1760 yr BP), Poaceae pollen decreases sharply and pollen of forest taxa increases, suggesting a decrease in human impact. Fires appear to have decreased, as the charcoal total is also much lower. The cause of these changes from Zone 1 to Zone 2 is unknown. One possibility is that the human population near Laguna Zoncho decreased, perhaps owing to natural disturbances, climate shifts, disease, or warfare. The archaeological evidence does not provide any clues, as the archaeological record does not extend back this far in either the archaeological site at Laguna Zoncho or the Diquís region as a whole.

Another possible explanation for the changes in the lower part of the record would be changes in subsistence patterns. Perhaps the transition from a highly disturbed landscape to one with more forest cover was the result of different people inhabiting the site. Perhaps one culture left the area, and was shortly replaced by a different culture. In this case, vegetation may have been influenced differently as a result of variation in food-gathering techniques. For example, northern cultures, such as the Maya, were strongly maize-dependent (Ludlow-Wiechers *et al.* 1983, Fritz 1995). Southern cultures, however, were known to have harvested many foods from the forest, such as tubers and fruits. As previously mentioned in Chapter 2, the peoples known from the Diquís region were influenced more by southern cultures starting around 1450 yr BP (Snarskis 1981). The assumption is that earlier people were also tied to southern cultures, but since we know so little of these people, it cannot be determined how they were culturally influenced. Different subsistence strategies could affect vegetation, and hence, the pollen record, in different ways. The sediment record alone cannot adequately explain the cause of forest regrowth in Zone 2, which lasted around 900 years (2830 – 1760 cal yr BP). Further archaeological study may help resolve this mystery.

At around 1800 cal yr BP (Zone 3, 222 cm) fluctuations in pollen percentages again indicate changing human activity around Laguna Zoncho, with increases in pollen of disturbance taxa and decreases in pollen of forest taxa (Figure 4.2). Throughout Zone 3, pollen percentages of Amaranthaceae and Asteraceae, often indicators of agricultural disturbance (Brown 1985, Rue 1987, Northrop and Horn 1996), rise dramatically while pollen of forest taxa is reduced to less than 30%. The low percentages of *Cecropia* pollen in this Zone may be due to the establishment of permanent fields. Denevan (1992b) suggests that clearing the rainforest with stone implements was so difficult that permanent fields were created. This may also explain why the percentage of the pollen of forest taxa continually declines throughout this period. A major peak in sedimentary charcoal may also suggest increasing human activity, and help explain the decrease in forest taxa pollen.

An increase in South American traditions took place at around 1800 cal yr BP in the archaeological record, which may indicate an increased population of those same people. It is impossible to infer human population density from the pollen record, but archaeological evidence from Laguna Zoncho suggests that indigenous peoples flourished at the lake until the time of Spanish conquest (Laurencich de Minelli and Minelli 1966). Based on the pollen record, this period of increased disturbance lasts for 1300 years (1760 - 460 cal yr BP), more than 30% of the entire time span of the core.

In Zone 4 (460 – 50 cal yr BP or AD 1490 - 1900), pollen of disturbance taxa (Poaceae, Amaranthaceae and Asteraceae) again decline while pollen of forest taxa increase (Figure 4.2). These changes may represent abandonment of the Laguna Zoncho area, or at least a reduction in cultivation at the site. Another notable change near this level (85 cm) is the first absence of *Zea mays* pollen from the pollen record.

The significance of the first break in *Zea mays* pollen is uncertain. The absence of *Zea mays* pollen at this level does not necessarily mean that the plant was not still being cultivated at Laguna Zoncho. Maize pollen is large and heavy and research has suggested that most of the pollen stays within 60 m of the plant that produces it (Raynor *et al.* 1972).

It is possible that only maize that is planted on the lakeshore is close enough for pollen deposition in the lake (Islebe *et al.* 1996), and maize fields far from the lakeshore may not contribute to the sediment record. Sediment cores from other paleoecological research sites in Costa Rica have shown wide variation in maize pollen percentages. Maize comprised <1 to 4% of total pollen in a core from Laguna Bonillita (Atlantic lowlands; Northrop and Horn 1996). Northrop and Horn (1996) interpreted the pollen data to indicate a limited area of cultivation because evidence of extensive forest clearance was lacking. Sediments from the Cantarrana Swamp at the La Selva Biological Station also document maize cultivation in the Atlantic lowlands (Kennedy and Horn 1997). Pollen percentages for *Zea mays* were not calculated at this site, but levels were clearly lower in the Cantarrana Swamp at La Selva than they were at Laguna Bonillita (Kennedy 1998). Although maize pollen percentages were not calculated for the Laguna Zoncho pollen record, the evidence of major forest clearance suggests that maize cultivation was extensive.

Throughout Zone 4 (460 – 50 cal yr BP or AD 1490 - 1900), the pollen percentage of forest taxa remains high, while pollen percentages of disturbance taxa stay low. Although the pollen of disturbance taxa are at their lowest percentages (Figure 4.2), the presence of *Zea mays* pollen indicates continued human activity at Laguna Zoncho. As at Laguna Bonillita, low levels of pollen percentages of disturbance taxa, in conjunction with the presence of maize, may indicate that maize was being cultivated right along the lakeshore, where extensive forest clearance is not required (Northrop and Horn 1996).

The decrease in disturbance taxa and the increase in forest in Zone 4 probably reflects decreasing populations around Laguna Zoncho. The decrease may be related to cultural changes and/or volcanic activity. The lower boundary of Zone 4 coincides with the Spanish conquest, as well as a time of increased warfare among the indigenous peoples (Stone 1977, Snarskis 1981). Indigenous warfare may have indirectly reduced the human impact on the forest. As mentioned earlier, warring indigenous groups took women and children as slaves and killed the men, taking their heads as trophies (Stone 1977, Snarskis 1981). To protect men, women, and children from attack, movement outside of confined villages may have been reduced. Population also may have declined due to disease spread by Spanish explorers, or because indigenous peoples abandoned the area to avoid the possibility of slavery.

Another possible impetus for depopulation, specific to the Laguna Zoncho and Las Cruces area, may have been a major eruption of Volcán Barú. At 92 cm (about 400 cal yr BP) in Zone 4, there is a layer of coarse sediment that is suspected to be tephra from Volcán Barú in nearby Panama. Kathleen Johnson of the University of New Orleans, who is studying the eruptive history of Barú, is currently examining this material to check this hypothesis. If this layer in the sediment core does mark a major eruption, it may help to explain the changes in the pollen record. Linares *et al.* (1975) hypothesize that an eruption at around 1350 yr BP resulted in almost complete abandonment of an archaeological site near the volcano in Panama. Perhaps this latest eruption (400 cal yr BP) caused near-abandonment of Laguna Zoncho similar to the abandonment Linares *et al.* (1975) describe in Panama. The tephra layer in the Laguna Zoncho sediments coincides with increases in pollen percentages of *Cecropia* and forest taxa pollen and decreases of Poaceae pollen, which, taken together, may indicate abandonment of the area.

The most recent changes in the pollen record (Zone 5, 0 - 19 cm, AD 1902 – 1997) are likely related to the settlement of the Italian colony, San Vito de Java. As mentioned in Chapter 2, the Italians found evidence of indigenous peoples in the form of *milpas* (land cleared for planting crops) which had partially regenerated to forest. The Italians must have settled within a decade or two of the time of indigenous occupation, as the maize pollen indicates only a brief gap during this time period. In Zone 5, the cultivation of maize may have changed from indigenous people the Italians who adopted maize as a subsistence food crop (Hall 1985). Italians and others settled in this region and substantially cleared and burned forests and used the land for grazing cattle or producing coffee. By 1968, Laguna Zoncho was almost entirely surrounded by coffee fields, as documented by an aerial photograph taken that year (Instituto Geografico Nacional, L-306 R-68).

Changes in the Fire Regime

The charcoal stratigraphy of the Laguna Zoncho core reveals major shifts in the fire regime during the past 3000 years. Because there is clear evidence of human occupation (maize pollen grains) at the base of the core, I cannot determine fire regimes under 'pristine' conditions. But changes in charcoal abundance reveal changes in fire activity associated with human subsistence strategies, human population, climate variability, or some combination of factors.

Under present-day climate, wildfires in undisturbed tropical evergreen rainforests are nearly impossible. Kauffman *et al.* (1988) have studied the combustibility of the evergreen rainforest in the Venezuelan Amazon. They found that the fuel load and fuel chemistry are adequate for combustion, but that the microclimate of the rainforest suppresses fire. In order for fires to occur, the relative humidity must be 65% or lower, a level of humidity that a closed canopy forest may experience for less than one day a year. As the forest is disturbed and/or cleared, fire frequencies increase. On the Pacific slope of Costa Rica, the seasonality is much greater than in the Venezuelan forests, so the lower humidity may be attainable during the dry season. In general, an increase in human disturbance is likely to dramatically increase the likelihood of fires, and hence, an increase in the abundance of charcoal in lake sediments. Uhl *et al.* (1988) list four main reasons why this is true: 1) human activity generally involves fire in one aspect or another, 2) forest cutting for any purpose leaves slash on the ground and thus increases fuel load, 3) opening the forest canopy allows fuels to quickly dry to the ignition point, and 4) deforestation, at the basin-wide level, can change overall climatic patterns, altering evapotranspiration, precipitation, and relative humidity in such ways that fires become easier to sustain.

Charcoal fragments remain an important clue to fire history but their interpretation is not always straightforward. The factors that control size distributions of charcoal assemblages are complex and not well understood (MacDonald *et al.* 1991, Millspaugh and Whitlock 1995, Earle *et al.* 1996). Charcoal particles of macroscopic size (visible to the naked eye), such as the pieces included in the upper two AMS radiocarbon samples from the Laguna Zoncho core, cannot be transported very far by wind and so indicate local fires. However, microscopic charcoal particles on pollen slides may signal distant as well as local fires. Some researchers interpret small microscopic charcoal as indicating non-local fires (Clark 1988; MacDonald *et al.* 1991; Clark and Royall 1995a, 1995b; Earle *et al.* 1996), but small charcoal can also be produced by local fires or derived from the breaking up of large pieces as they move into a lake basin, or during pollen processing. Lakes without a recent fire history may still retain charcoal in the sediment (MacDonald *et al.* 1991, Earle *et al.* 1996). This may indicate that there is a large amount of 'background' charcoal from far-distant sites, or it could represent charcoal deposited in the lake by erosion and overland flow long after the period of burning ended. As the Laguna Zoncho area is a region of high rainfall (3000 - 4000 mm/year), it is important to consider overland flow as a source of charcoal.

One problem in comparing charcoal data from different areas is that methods of charcoal analysis are not standardized. Different researchers use different measurement techniques and different size classes. However, Clark and Hussey (1996) found consistent patterns in charcoal abundance along vegetation and climate gradients despite the potential biases introduced by different methods. That is, differences in methodology were not sufficient to obscure spatial patterns.

Charcoal fragments greater than 60 μm in maximum dimension are typically not suspended at normal surface wind speeds (Clark and Royall 1995b), but smaller particles can be wind-borne. The fact that the charcoal in the Laguna Zoncho core is mostly less than 50 μm might suggest that most of the charcoal present represents regional rather than local burning. However, as mentioned above, the fact that smaller charcoal can be dispersed long distances does not necessarily mean that it has been. Although the proportion of larger (≥ 50 μm) microscopic charcoal in the Laguna Zoncho record is relatively low, the absolute abundance of charcoal in this larger size range is in fact greater than the total abundance of charcoal in other studies. For example, Northrop (1994) shows that all but six levels in both Bonilla and Bonillita sediment cores have fewer than 200,000 charcoal fragments per gram dry sediment. In the Cantarrana Swamp at La Selva Biological Station, the charcoal total is never above 200,000 fragments per gram dry sediment (Kennedy 1998). The large charcoal (≥ 50 μm) alone in the Laguna Zoncho core ranges from nearly 1,000,000 fragments per gram dry sediment in Zone 1 to around 200,000 in Zones 2 and 3. The large charcoal generally disappears from the record in Zones 4 and 5, but the entire charcoal abundance drops sharply in these zones. This abundance of charcoal supports the scenario of large amounts of local burning, perhaps in conjunction with regional burning.

Horn and Sanford (1992 and unpublished) found dates on soil charcoal beneath rainforest in the Atlantic lowlands of Costa Rica (La Selva Biological Station) to cluster at 2430 yr BP and 1180 - 1110 yr BP. They suggest that these time periods may have been periods of more frequent rain forest fires, perhaps facilitated by drought episodes. Charcoal lenses in lake sediment from the Chirripó páramo in the Cordillera de Talamanca may reflect drought-induced, lower lake stands at the same time. The period of abundant charcoal in the Laguna Zoncho core encompasses the burning intervals identified by Horn and Sanford (1992). This may indicate that increasing in burning at Laguna Zoncho was due to a drier climate as well as human activity. However, it is very difficult to separate out possible climate changes at Laguna Zoncho given the extensive human disturbance.

Indicators of Climate Change in the Pollen and Sediment Records

Where there is evidence of human disturbance in the pollen record, any climate changes that occurred over that same time period are often masked (Brown 1985, Leyden 1987, Hansen 1990, Hansen and Rodbell 1995, Hodell *et al.* 1995, Haberyan and Horn 1999). This may be the case at Laguna Zoncho, where evidence of human activity is apparent as early as the formation of the lake.

The Laguna Zoncho sediment core spans time periods in which episodes of drier climate are thought to have occurred in Central America and the Caribbean. Curtis *et al.* (1996) identified three periods of different precipitation regimes based on oxygen isotope profiles derived from the measurement of $\delta^{18}O$ in monospecific ostracods and gastropods in a 6.3 m sediment core (that represented the last 3500 years) from Laguna Punta, Mexico. These periods were: 3400 - 1800 yr BP, a relatively wet period; 1800 - 900 yr BP, dry; and 900 yr BP to present, shift towards a wetter period. A similar study at Lake Chichancanab, Mexico indicated that the driest period in the middle Holocene was between 1300 - 1100 yr BP (Hodell *et al.* 1995). Piperno and Becker (1996) documented major fire events in the Amazon during this period. Changes in the pollen and charcoal record at Laguna Zoncho do correspond to some degree with the 1300 – 1100 yr BP time period. Relatively dry periods may result in an increase in fire frequency and disturbance taxa and a decline in forest species. The relatively dry period of 1800 - 900 yr BP matches up fairly well with Zone 3 and an increase in Poaceae pollen, a decrease in the pollen of forest taxa, and an increase in charcoal fragments. This is the period of most intense human activity at Laguna Zoncho, and there could have been interplay between human activity and climate. Drier climate may have allowed for more frequent burning by agriculturists, and may have increased the possibility that human-set fires would escape into non-cultivated areas. Additionally, a drier climate may have been more favorable for maize cultivation, possibly leading to the expansion of cultivated areas.

Other stratigraphic indicators of climate change may exist in the Laguna Zoncho record. Increases in the pollen of Cyperaceae (sedges) may indicate lower lake levels that are possibly related to drier climate conditions (Northrop 1994, Kennedy 1998). Aerial photos reveal historic changes in lake level (Figure 2.4); perhaps the lake level has also fluctuated over a longer time span. At Laguna Zoncho, the highest percentage of Cyperaceae pollen occurs in Zone 3, which would appear consistent with hypothesized drought intervals in the circum-Carribean region. However, the sedge pollen could instead relate to human disturbance during this interval of intensive agricultural activity.

In the lowlands of Panama, Bush and Colinvaux (1994) considered an increase in fern spores to indicate local aridity. Peaks in fern spore percentages, Poaceae pollen, and charcoal abundance at Laguna Bonillita were interpreted to represent a period of drier climate around 1377 and 1151 yr BP (Northrop 1994). At Laguna Zoncho, however, fern spores show only minor peaks during the time of major human disturbance (Zone 3; Figure 4.2). Fern spores are dispersed in large numbers and can travel over long distances in open landscapes (Gentry and Dodson 1987), so the minor peaks in fern spores during major peaks in Poaceae may simply indicate that fern spores could travel to the lake more easily due to the reduction in forest extent. Interpretation of fern spores is complicated because fern spores of a given morphology may represent species from mature forests as well as early colonizers of disturbed areas.

The lack of especially strong evidence of aridity at Laguna Zoncho during the two dry periods documented from other parts of the circum-Caribbean region (Curtis *et al.* 1996, Hodell *et al.* 1995) may have alternative explanations. Perhaps aridity was less pronounced, or absent in the Laguna Zoncho area, or the period of aridity was different. The mechanisms that created dry conditions at Laguna Punta in Mexico (Curtis *et al.* 1996) may have not affected Laguna Zoncho or affected the lake in a different way. The paleoclimate of the area is not well understood. Certain climatological conditions, such as the shifting of the North American high pressure cell, must occur for drier periods to persist in Mexico (Curtis et al. 1996). Hodell *et al.* (1995) state that the evidence of a drier climate may indicate local aridity instead of a widespread event. Conditions that would lead to aridity in Mexico, whether local or regional, may only pertain to the northern Caribbean, the Gulf of Mexico, and the adjacent mainland. As the Cordillera de Talamanca lies between these regions and Laguna Zoncho, climatological cycles may affect Laguna Zoncho differently.

Perhaps one indicator of a fairly consistent climate regime is that the lake has not dried to the point of oxidizing sediments during the past 3000 years. The lake measures 2.3 m deep, there is no apparent inlet, and the geology of the landscape would not indicate a groundwater source. Therefore, in order for the lake to stay wet, there could not be any significant dry periods. The material below the pollen-rich sediments may, however, indicate past droughts. The fact that the organic layer between 343 and 380 cm does not contain preserved pollen, and is overlain by a soil that shows cracking (and is also pollen-poor) suggests a dry period sometime prior to 3000 yr BP. This drying may also be the result of headward erosion, which may have drained an earlier lake. AMS radiocarbon dating of the organic macrofossils in these layers could help construct the timing of this event.

CHAPTER 6

CONCLUSION

The most interesting, and most important, conclusion from this study is that Laguna Zoncho has been affected by humans for over 3000 years. Whatever the interpretation of the downcore fluctuations in the pollen and charcoal spectra, the continuous presence of *Zea mays* pollen documents that Laguna Zoncho was a habitation site. It appears, however, that after 2500 years of increased levels of clearing and burning, the forest regenerated, with high levels of forest taxa pollen in the pollen record. Forest regrowth and only small-scale maize cultivation, perhaps by just a few families, characterized the Laguna Zoncho watershed from AD 1490 to Italian settlement in AD 1952. It is because of this 450 year period of regrowth that the Italian colonists had to contend with mature rain forest when they first arrived to carve San Vito de Java out of the Costa Rican frontier (Masing 1964). On this level, the concept of the noble savage living in harmony with the environment may have some merit; the paleoecological record reveals hundreds of years of indigenous presence after the Spanish Conquest in which the forest remained intact. The long period of apparently widespread intact forest may be the result, however, of the decimation of native populations by the Spanish. When indigenous populations were at their peak, prior to Conquest, the sediment record suggests that vegetation was substantially disturbed and fire was heavily used.

Another important finding, based on the presence of *Zea mays* in the sediment record, is that indigenous habitation of Laguna Zoncho was generally uninterrupted until this century. In the Las Cruces areas, all of the premontane rain forest was cut down and converted to coffee fields and pasture in less than 50 years. However, knowing that indigenous groups practiced widespread forest clearance and burning, the current clearing of the forest may be viewed as just another cycle of human presence in a long-altered landscape. This human presence in the Laguna Zoncho watershed will continue, as the two owners of the lake plan to establish a botanical garden and build new homes.

In combination with the pollen, the charcoal record of Laguna Zoncho is strong evidence of prehistoric human activity around the lake. While it is clear that there were shifts in the fire regime, the mechanism behind these shifts can only be speculated upon. One possibility is that high variability in charcoal abundance results from changing levels of human activity; abundant charcoal coincides with high percentages of disturbance taxa and low percentages of forest taxa. Because it is easier to burn second-growth forest on sites previously cleared, these intense burning periods may have resulted from the reburning of sites. In this scenario, climate may not have been an important factor. However, periods of increased burning shown by the Laguna Zoncho sediment record generally correlate with the drier periods in Central America proposed by Curtis *et al.* (1996). Burning by indigenous groups may have been assisted by drier climate. However, since Laguna Zoncho has not dried up in the past 3000 years, any dry period that did occur could not have been severe.

The Las Cruces Biological Station is only 2 km from the shores of Laguna Zoncho, and was very likely affected by the human activity revealed in this sediment record. The only remaining intact Premontane Wet Forest, found at the Las Cruces Reserve, has probably been altered significantly in the past 3000 years. Ceramic artifacts have been found at the Las Cruces Biological Reserve (L. Diego Gómez, pers. comm. 1998) and soil cores from the Las Cruces Forest contain abundant charcoal (Horn and Sanford 1998). Ongoing study of soil charcoal will reveal more about the extent and timing of past fires in the Las Cruces Reserve. In July 1998, Horn, Kennedy, and I recovered a sediment core from the Gamboa wetland, located near the upper boundary of the Las Cruces Biological

Station. With R.L. Sanford Jr. and students, we also took several soil cores from the forest that is immediately east of the Gamboa wetland. Future analyses of charcoal in these soil and sediment cores will help further elucidate local and regional impacts of indigenous populations in the area.

The Laguna Zoncho sediment record is a new paleo-record for Costa Rica. Interpretation of the profiles of pollen grains, fern spores, charcoal fragments, and tephra layers preserved in the lake sediments contributes to the overall understanding of both natural processes and indigenous impacts near the Las Cruces Biological Station and over the wider region. Results from the Laguna Zoncho study and the companion studies in the Las Cruces Reserve and at Laguna Gamboa will complement planned future archaeological work in the area.

Future paleoecological research in Costa Rica would benefit from additional study of pollen grains and fern spore types and morphologies and the ecology of the taxa that produce them. Additional work on sedimentary charcoal would also be useful. Most previous work on sedimentary charcoal has been conducted in temperate areas. A better understanding of how charcoal is transported and deposited in tropical areas is needed to increase the accuracy of charcoal analysis in these sites. Future paleoecological research in the mid-elevations of Costa Rica would also benefit from detailed analysis of contemporary vegetation and pollen rain in the Premontane Wet Forest.

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APPENDICES

APPENDIX A

POLLEN PROCESSING SCHEDULE

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POLLEN PROCESSING SCHEDULE

I used this schedule to extract pollen from the Laguna Zoncho sediment core. The process was developed by Dr. Sally Horn and John C. Rodgers, III (following Berglund 1986). It takes about 5 hours to complete on 6 samples.

1. Place 0.5 cc wet sediment in preweighed, 15 ml polypropylene centrifuge tubes and reweigh.
2. Add 1 *Lycopodium* tablet (13,500 spores) to each tube.
3. Add a few ml 10% HCl, and let reaction proceed; slowly fill tubes until there is about 10 ml in each tube. Stir well, and place in hot water bath for 3 minutes. Remove from bath, centrifuge for 2 minutes, and decant.
4. Add 10 ml hot distilled water to each tube, stir, centrifuge for 2 minutes and decant. Repeat for a total of two washes.
5. Add about 10 ml 5% KOH, stir, and place in boiling bath for 10 minutes, stirring after 5 minutes. Remove from bath and stir again. Centrifuge 2 minutes and decant.
6. Wash 4 times with hot distilled water. Centrifuge for 2 minutes each time. Decant after each centrifuge.
7. Fill tubes about half way with distilled water, stir, and pour through 125 μm mesh screen, collecting liquid in a labeled beaker underneath. Wash out material remaining in test tube with more distilled water. Wash screen with a powerful jet of distilled water.
8. Centrifuge down material in beaker by repeatedly pouring beaker contents into correct tube, centrifuging for 2 minutes, and decanting.

9. Add 8 ml of 52% HF and stir. Place tubes in boiling bath for 20 minutes, stirring after 10 minutes. Centrifuge 2 minutes and decant.

10. Add 10 ml hot Alconox solution to each tube. Stir well and let sit for 5 minutes, centrifuge and decant. (Alconox solution is made by dissolving 2.5 cc Alconox detergent powder in 1000 ml distilled water).

11. Add about 12 ml hot distilled water to each tube, so top of water comes close to top of tube. Stir, centrifuge for 2 minutes, and decant. Check top of tubes for an oily residue after decanting the hot water. If present, remove carefully with a bit of clean paper towel. Also at this time, examine the tubes to see if they still contain silica. If silica is still present, repeat steps 9 - 11. Assuming that no samples need retreatment with HF, continue washing with hot distilled water as above for a total of 3 washes.

12. Add 10 ml of glacial acetic acid, stir, centrifuge for 2 minutes, and decant.

13. Make acetolysis mixture by mixing together 9 parts acetic anhydride and 1 part concentrated sulfuric acid. Add about 8 ml to each tube and stir. Place in boiling bath for 5 minutes, stirring after 2.5 minutes. Centrifuge for two minutes and decant.

14. Add 10 ml glacial acetic acid, stir, centrifuge for 2 minutes, and decant.

15. Wash with hot distilled water, centrifuge, and decant.

16. Add 10 ml 5% KOH, stir, and heat in vigorously boiling bath for 5 minutes, stirring after 2.5 minutes. Centrifuge for 2 minutes and decant.

17. Add 10 ml hot distilled water, centrifuge for 2 minutes, and decant for a total of 3 washes.

18. After decanting last water wash, use a vortex mixer for 20 seconds to mix sediment in tube.

19. Add one drop 1% safranin stain to each tube. Use vortex mixer for 10 seconds. Add distilled water to make 10 ml. Stir, centrifuge for 2 minutes, and decant.

20. Add a few ml TBA, vortex for 20 seconds. Fill to 10 ml with TBA, stir, centrifuge for 2 minutes, and decant.

21. Add 10 ml TBA, stir, centrifuge 2 minutes, and decant.

22. Agitate samples using the vortex mixer to mix the microfossils with the TBA left in the tubes. Carefully transfer the liquid to clean, labeled glass vials. Centrifuge down vials and decant.

23. Add several drops of silicone oil (2000 cs viscosity) to each vial. Stir with a clean toothpick.

24. Place uncorked samples in a dust-free cabinet to let the residual TBA evaporate.

25. Stir again after one hour, adding more silicone oil if necessary.

26. Check the samples after 24 hours; if there is no alcohol smell, cap the samples.

APPENDIX B

SELECTED PLANT SPECIES KNOWN TO OCCUR AT LAGUNA ZONCHO AND THE LAS CRUCES BIOLOGICAL STATION

APPENDIX B

SELECTED PLANT SPECIES KNOWN TO OCCUR AT LAGUNA ZONCHO AND THE LAS CRUCES BIOLOGICAL STATION

Selected Aquatics and Herbs noted at Laguna Zoncho in July 1998
Identifications by Luis Diego Gómez and Lisa Kennedy.

Aquatics

Apiaceae	*Hydrocotyle*
Amaranthaceae	*Iresine*
Polygonaceae	*Polygonum punctatum*

Herbs

Onagraceae	*Ludwigia*
Lythraceae	*Cuphea* sp.
Poaceae	*Coix*
Euphorbiaceae	*Chamaesyce*
Rubiaceae	*Borreria*
Rubiaceae	*Richardia*
Lamiaceae	*Salvia*
Asteraceae	*Pseudelephautopis*

Selected Tree Species at the Las Cruces Biological Station
Modified from Sanabria (1992) by Luis Diego Gómez.

Anacardiaceae	*Anacardium excelsum*
Bignoniaceae	*Tabebuia chrysantha*
Bombacaceae	*Ceiba pentandra*
Bombacaceae	*Ochroma lagopus*
Combretaceae	*Terminalia amazonia*
Cunoniaceae	*Weinmannia* sp.
Euphorbiaceae	*Heironyma alchorneoides*
Fagaceae	*Quercus* sp.
Clusiaceae	*Rheedia edulis*
Clusiaceae	*Symphonia globulifera*
Lauraceae	*Persea* sp.
Meliaceae	*Cedrela touduzii*
Meliaceae	*Cedrela mexicana*
Myristicaceae	*Dialbacethera cootoba*
Myristicaceae	*Virola sebifera*
Olacaceae	*Minquartia guianensis*
Sterculiaceae	*Guazuma ulmifolia*
Theaceae	*Laplacea* sp.
Tiliaceae	*Goethalsia meiantha*
Tiliaceae	*Luehea seemanni*
Verbenaceae	*Vitex cooperi*

Vita

Vita

Rachel Marie Kurtz was born in Brookings, South Dakota on October 3, 1974. She attended school in Elkton, South Dakota until 1984. Her family moved to California for three years and then returned to the Brookings area, where Rachel attended Brookings High School, graduating in 1992. Rachel attended South Dakota State University, also in Brookings, where she pursued a Bachelor of Science degree in geography. Rachel graduated from South Dakota State University and married Brian James Clement in May 1996. Her degree in geography incorporated many of Rachel's interests, including environmental science, human - environment interactions, and remote sensing.

Rachel has been involved extensively with Gamma Theta Upsilon, the international geography honor society. She has held leadership roles in local chapters and has participated in Executive Board meetings as the student representative. She has been the recipient of the Geography Alumni scholarship and the Moriarty scholarship, both from the Geography Department at South Dakota State University. Rachel was also awarded the Outstanding Service Award in 1995.

While at the University of Tennessee, Rachel worked as a Teaching Assistant for introductory physical geography. Her thesis work was supported by a grant from The A.W. Mellon Foundation, and she received her Master of Science degree from the University of Tennessee in May 1999. She presented her thesis research at the annual meeting of the Association of American Geographers in Honolulu, Hawaii in 1999. She hopes to pursue biogeographical research and plans to begin a Ph.D. program in the near future.