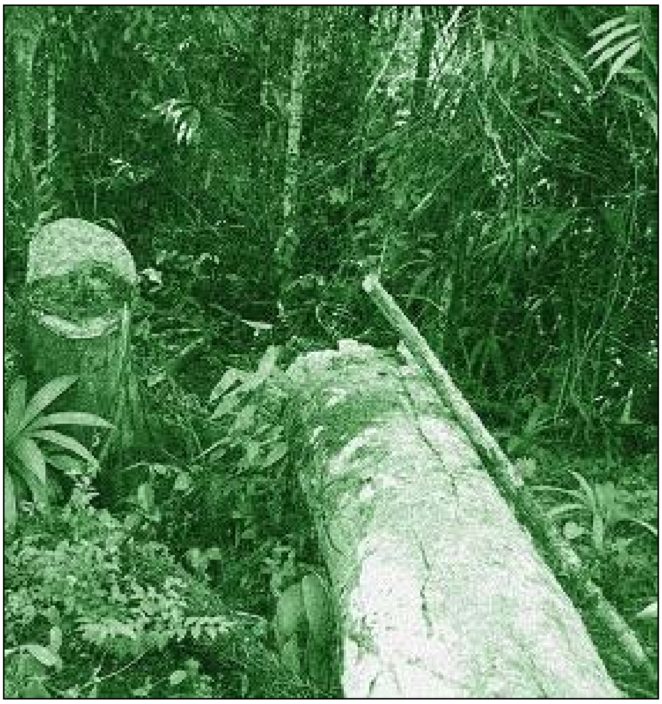

Effects of Certified Logging on Wildlife in Community and Industrial Forest Concessions of Northern Guatemala

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MONITORING ECOLOGICAL INTEGRITY OF THE MAYA BIOSPHERE RESERVE, PETÉN, GUATEMALA

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Introduction

Selective logging has been proposed as a potentially sustainable land-use practice in the Neotropics. Such harvests leave the forest canopy and structure relatively intact, while providing substantial income to harvesters. Since only a small proportion of Neotropical forests will ever be maintained in parks and preserves, sustainable forest management may be the most promising means to protect large tracts of contiguous forest and biological diversity. This is especially true in developing countries incapable of financing and managing parks within a framework of classic strict protection.

In order for sustainable management to be an effective conservation strategy, managed areas must sustain: 1) viable populations of economically valuable species (timber or non-timber) and 2) ecological integrity (Whitacre *et al.* 1992). Managers commonly monitor the effects of harvests on economically valuable species because their future income depends upon it. However, ecological side effects of "sustainable" harvests have been vastly understudied.

Ecological monitoring is a requisite for certification by organizations such as the Forest Stewardship Council (FSC) and can serve as evidence of responsible forest management, thereby attracting higher market prices for timber. In some areas, such as High Conservation Value Forests (HCVF), certification and monitoring may be required by national legislation (Steve Gretzinger, pers. comm.). Monitoring allows immediate feedback as to the adequacy of forest management and helps determine the driving factors behind unacceptable ecological impacts.

This study examines the short-term ecological impacts of certified logging in the Maya Biosphere Reserve in Northern Guatemala. Because several independent forest managers with different management practices were logging simultaneously in a relatively homogeneous area, this study was also able to compare management alternatives and determine their effects on ecological integrity. Furthermore, this study sets a baseline for long-term monitoring of logging impacts.

Maya Biosphere Reserve

The Maya Biosphere Reserve (MBR) was established in 1990 in order to protect two million hectares of subtropical moist forest and savannah in the Petén, Guatemala. The Maya Forest is the largest contiguous tropical forest north of the Amazon and harbors high levels of biodiversity and endemism. However, this biological reservoir has recently become imperiled. For over thirty years, the population of the Petén has increased nine percent per year for a variety of political and socioeconomic reasons (Fort and Grandia 1999). Before designation of the reserve, slash-and-burn agriculture and logging threatened to destroy the entire forest in less than thirty years (Sader 1999). The goal of the Maya Biosphere Reserve is to prevent such destruction by balancing economic activity and conservation.

The reserve is divided into three zones (Figure 1). The Core Zone, covering 36% of the reserve, consists of National Parks and Biotopes. It is reserved for scientific investigation and low impact tourism. The Multiple Use Zone, covering 40% of the reserve, links the National Parks and Biotopes. This zone is an 848,440-hectare "extractive reserve" in which only sustainable, minimally damaging land uses are allowed. The Buffer Zone, covering 24% of the reserve, forms a band fifteen kilometers wide along the entire southern border of the reserve.

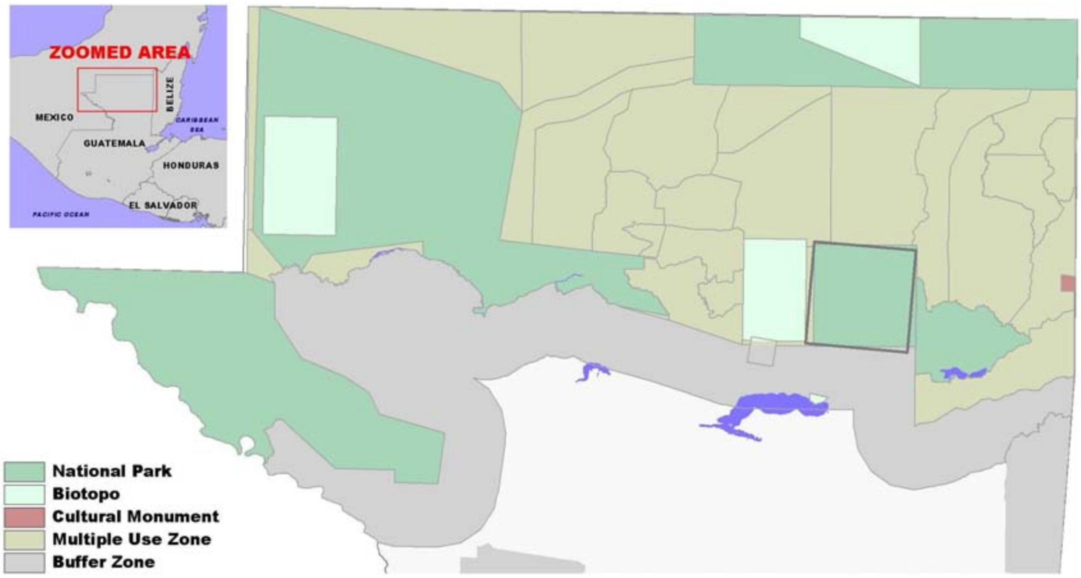

Figure 1. The Maya Biosphere Reserve, Petén, Guatemala.

In the Maya Biosphere Reserve, the core areas are distributed mainly around the reserve's periphery, contrary to the ideal biosphere reserve design. This means that the Multiple Use Zone must function as the *de facto* heart of the reserve in terms of maintaining large-scale ecological processes. The long-term success of the Maya Biosphere Reserve depends intimately on conservation of the Multiple Use Zone and its constituent forest concessions.

Forest Concessions in the Maya Biosphere Reserve

As mandated in the "Agreement on Socioeconomic Aspects and the Agrarian Situation" of Guatemala's 1996 Peace Accords, extraction rights to timber and non-timber forest products are designated by the *Consejo Nacional de Areas Protegidas* (CONAP) through forest concessions. Currently, there are 14 concessions, ranging from approximately 25,000 hectares to 83,000 hectares, and covering nearly 800,000 hectares in the Multiple Use Zone of the Maya Biosphere Reserve. All concessions are required by CONAP to maintain certification, or "green seals", for timber and non-timber forest product extraction. Currently all concessions are certified by Smartwood, part of the Forest Stewardship Council (FSC).

There are several reasons that forest concessions are a potentially viable conservation strategy in the Maya Biosphere Reserve. First, traditional management is failing. A variety of factors have coalesced recently in the Maya Forest that place unprecedented pressure on forest resources. Poverty, ethnic displacement, population increases, special interests, immigration to rural areas, lawlessness, corruption, and institutional weaknesses have combined to create the highest deforestation rate in Central America The average rate of deforestation in Southern Mexico and Central America in the 1980's was 1.5% per year, while some parts of the Maya Forest were deforested at a rate of greater than 3% per year (Sader 1999). Laguna del Tigre and Sierra del Lacandón National Parks are seriously degraded and threatened despite their status.

Furthermore, community forest concessions promise some benefits that open access harvesting or concessions leased to the highest bidder do not. The first is participation of local people. Local people often have an unmatched understanding of the distribution and life-histories of natural resources, and techniques of sustainable harvesting (Gretzinger 1999). This is especially true with non-timber forest products. Local people also have a long-term commitment to the sustainable use of resources within their region. Local people must ensure that production continues into the future and are more likely to defend their concessions against exploitation from outsiders. This is true not only because of long-term commitment, but also because concessionaires are often held responsible for the quality of their resources (Dugelby 1999). Protected area agencies may fine concessionaires or rescind their extraction contracts for violations of regulations.

Despite the many benefits of community forest concessions, there are also several drawbacks. Tamale *et al.* (1995) listed the following major constraints facing local participation in forestry: land tenure insecurity, lack of control over forest resources, lack of reliable markets, lack of appropriate technologies, long rotation periods, competition with other land uses, and bureaucratic adamancy.

In the Maya Biosphere Reserve, a few of these factors are especially important. Lack of reliable markets is probably the greatest challenge. Political instability, devaluation of local currencies, lack of managerial organization and experience, and changing prices on international markets can cause an economically viable operation to collapse. There is also a large bias in market demand toward a few valuable species. Furthermore, communities rarely have the capital to buy equipment such as sawmills and tractors. In every successfully established community concession in the Maya Biosphere Reserve, at least one non-governmental organization (NGO) has provided technical and/or financial assistance to the community with international aid. It is still not clear whether the community concessions will be able to persist without outside support.

Logging Studies in the Maya Biosphere Reserve

Beginning in 1995, the Peregrine Fund started a project entitled "Effects of Logging on Neotropical Bird and Tree Community Composition" (Schulze and Whitacre 1996). Using Tikal National Park as an unlogged control and adjacent logged forests north and south of the park, they compared forest bird community composition. Birds were mist-netted and surveyed using point counts in each treatment. Of 135 total captured species, 68 were captured in sufficient numbers to allow comparisons of abundances.

Bird community composition was surprisingly similar in logged and unlogged sites. Of the 135 total species, 97 were found in both forest types. Those that differed were usually rare species, with less than five individuals caught. Twenty-four species were found only in the logged forest. All of them have usually been classified as "second growth" species. Surprisingly, nine "mature forest" species were only found in the logged forest. Three "second growth" species and ten "mature forest" species were unique to the unlogged forest.

Comparisons of the 68 common species showed a small, but significant difference. Ten species showed significant differences between the two treatments. Seven were more common in the logged forest and three were more abundant in unlogged forest. All of these species have specific requirements for feeding or nesting, and are probably responding to structural changes caused by an increased number of gaps in the forest.

In a similar study in the Bethél forest concession, Claudio Méndez compared dung beetles, butterflies, and small mammals in intact forest, selectively logged forest, and cattle pastures (1997). He found significant differences between plots in all three taxa. However, whereas dung beetle diversity and rodent diversity decreased in logged plots, butterfly diversity increased.

A series of nearly 100 permanent plots have been established in order to measure the effects of timber harvests on vegetation. The Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), in conjunction with CONAP, established more than 70 plots (Fundación Naturaleza para la Vida 2000) and Centro Maya established 20 (Sosa 2001). The main focus of this research was to determine the rate of tree regeneration after timber harvests with different liberation treatments. Clear differences were evident. Growth rates for all harvestable species were higher after logging (Fundación Naturaleza para la Vida 2000). This is probably due to increased illumination, which correlated well with diameter growth rates.

Goals of Monitoring the Effects of Timber Extraction

In a participatory threats assessment undertaken in 2001, logging was ranked as the greatest threat to the ecological integrity of the Maya Biosphere Reserve. However, the few studies that had examined logging impacts in the reserve were small scale, site-specific, and gave inconclusive and conflicting results. Furthermore, logging practices had changed since many of the earlier studies were conducted, and certification had since become an important factor in forest management. Therefore, an updated and comprehensive evaluation was necessary.

The study was undertaken in order to achieve the following goals:

- Document the direct and indirect impacts of low-intensity timber harvests on ecological integrity
- Determine the effects of different timber management alternatives on ecological integrity
- Provide forest managers with feedback on current logging practices
- Provide assessments of management practices for certifying organizations
- Develop a baseline for long-term monitoring of logging impacts

Methods

Selection of Treatment Plots

Although some concessions began selectively logging between 1997 and 1999, 2000 was the first year in which a sufficient quantity of logged plots were available to allow for decent replication and across-concession comparisons. Of twelve total concessions that were logged in 2000, ten were selected for sampling based upon logistic feasibility. The ten concessions demonstrate a wide variation in management organization and logging practices (Table 1). Eight concessions are managed by democratic community organizations and two are managed by private industry.

Table 1. Organization and management of concessions included in study

Concession	Industrial/ community	Organization name	Community inside concession?	Number of members	Years of management before 2000
Arbol verde	Community	Árbol Verde	Outside	344	0
Carmelita	Community	Carmelita	Inside	105	3
Río Chanchich	Community	Impulsores Suchitecos	Outside	27	2
Chosquitán	Community	Laborantes del Bosque	Outside	96	0
La Colorada	Community	La Colorada	Inside	40	0
La Gloria	Industrial	Baren Comercial	Outside	N/A (Industrial)	0
La Pasadita	Community	APROLAPA	Inside		3
Paxbán	Industrial	GIBOR	Outside	N/A (Industrial)	0
San Andrés	Community	AFISAP	Outside	178	1
Uaxactún	Community	OMYC	Inside	244	0

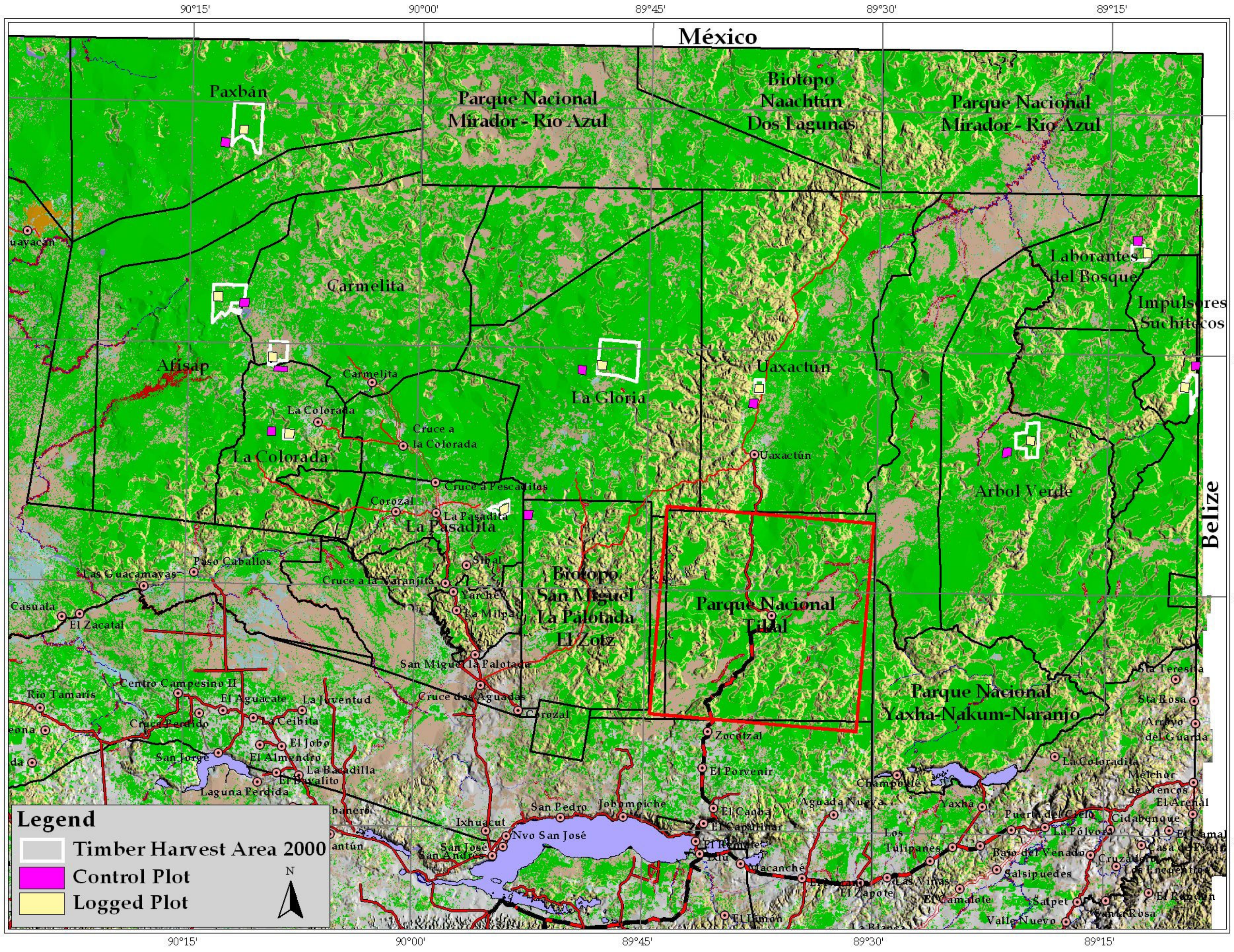

Figure 2. Twenty treatment plots used to examine the ecological effects of timber extraction

In all of the logged areas of 2000, improved logging techniques such as road planning, directed felling, and predominant use of lightweight machinery were employed. However, the methods of road-clearing and post-harvest practices such as road closure and reforestation (enrichment) were very different (Table 2).

Table 2. Forest management in logged area (POA) of 2000

Concession	Liberation of lianas?	Planned roads?	Method of clearing roads	Felling	Method of hauling	Road closed?	Reforestation?
Arbol verde	Not specified	Yes	Not specified	Directed	Skidder	No	No
Carmelita	Yes	Yes	Manually	Directed	Skidder	No	Seed spread experimentally
Río Chanchich	Not specified	Not specified	Chainsaw, skidder	Directed	Skidder	Not specified	Not specified
Chosquitán	Yes	Yes	Manually	Directed	Skidder	Branches placed in road	Not specified
La Colorada	Yes	Yes	Not specified	Directed	Skidder	No	Not specified
La Gloria	Yes	Yes	Not specified	Directed	Skidder	Not specified	Mahogany planted
La Pasadita	Not specified	Yes	Chainsaw, skidder	Directed	Skidder	Closed	No
Paxbán	Not specified	Yes	Heavy machinery	Directed	Skidder	No	Not specified
San Andrés	Yes	Yes	Not specified	Directed	Skidder	No	No
Uaxactún	Yes	Yes	Manually	Directed	Skidder	Branches placed in road	Mahogany planted

The size of logged areas in 2000 varied widely between concessions (Table 3). For some community concessions 2000 was the first year of timber harvests, and therefore they opted to log small, experimental plots, with as few as 110 hectares. The industrial concessions logged areas several times as large as those of community concessions. For example, La Gloria logged 1800 hectares and Paxbán 1450 hectares.

Harvest intensity was greatly limited by the density of marketable species in logged plots (Table 3). In some areas less than one tree was cut per two hectares, while in others more than two trees per hectares were extracted. Volumes extracted ranged from less than one cubic meter per hectare to nearly five cubic meters per hectare, depending upon the number and the average size of harvested trees.

Table 3. Area and intensity of timber extraction

Concession	Arbol verde	Carmelita	Río Chanchich	Chosquitán	La Colorada	La Gloria	La Pasadita	Paxbán	San Andrés	Uaxactún
Hectares	400	423	390	295	110	1800	338	1450	800	150
# Trees	119	917	883	546	110	1139	121	1761	1580	126
Volume	257	1034	1858	1423	283	1811	280	2351	1887	336
Trees/ha	0.30	2.17	2.26	1.85	1.00	0.63	0.36	1.21	1.98	0.84
Volume/ha	0.64	2.44	4.77	4.82	2.57	1.01	0.83	1.62	2.36	2.24
Vol/tree	2.16	1.13	2.10	2.61	2.57	1.59	2.31	1.34	1.19	2.63

In total, 25 tree species were harvested in 2000 (Table 4). By far, four commercial species dominated the harvests: Mahogany (*Swietenia macrophylla*), Santa María (*Calophyllum brasiliense*), Manchiche (*Lonchocarpus castilloi*), and Spanish Cedar (*Cedrela mexicana*). In many cases concessionaires cut fewer trees and species than those permitted by CONAP due to low market prices at the time of felling.

Table 4. Volume of timber extracted per species (m^3) (includes timber cut and left in patio)

Scientific Name	Common Name	Arbol verde	Carmelita	Chanchich	Chosquitán	La Colorada	La Gloria	La Pasadita	Paxbán	San Andrés	Uaxactún
Swietenia macrophylla	Caoba, Mahogany	135.0	562.5	569.7	687.1	173.4	1498.6	258.8	1457.7	908.8	118.4
Calophyllum brasiliense	Santa María, Marío	103.0		576.0	88.7		33.9		388.2	31.4	34.6
Lonchocarpus castilloi	Manchiche	9.6	324.0	118.1	46.0		44.9		236.5	405.5	36.3
Cedrela mexicana	Cedro, Spanish Cedar		7.6	69.8	280.4	42.1	155.2	21.3	121.2	384.8	127.1
Bucida buceras	Pucté			287.0	168.2				34.0		
Pseudobombax elliptica	Amapola		132.5				2.9		79.1	115.3	
Vatairea lundellii	Danto			106.8	48.6	67.1					
Dendropanax arboreus	Mano de León	6.3		14.4	38.8		16.4				
Mastichodendron foetidesimum	Tempisque	1.3		42.4	15.5						
Acacia dolichostachya	Jesmó			22.3	16.3		8.5				
Aspidosperma megalocarpon	Malerio Blanco			12.3	3.7		6.0			6.9	7.4
Swietenia panamensis	Chichipate								34.6		
Aspidosperma cruenta	Malerio Colorado			16.9	8.7						7.6
Astronium graveolens	Jobillo				12.6		2.9			15.4	
Swartzia lundelli	Catalox	1.5		8.5	6.8		5.1				
Pouteria amygdalina	Silión						20.7				
Terminalia amazonia	Canxán	0.5			1.3		0.4			11.4	
	Colorín			13.3							
Platymiscium yucataneum	Hormigo		7.0							5.3	
Rehdera penninervia	Sacuché						12.1				
Pithecellobium arboreum	Cola de Coche									2.2	
Metopium brownei	Chechen Negro			0.7			1.2				
	Pupsikil						1.3				
Simira salvadorensis	Saltemuche						1.3				
Cordia sebastena	Cericote									0.3	

Preparation of Treatment Plots

In each logged area, a one square kilometer plot was measured and marked with flagging tape. Straight-line transects were cut on the entire perimeter and five transects (typically North-South) were cut at every 200 meters within the square for access to sampling points. The four corners were marked with large posts, and a section of rebar was driven flush into the soil so that the plots may be identified precisely with a metal detector even well after the wooden corner posts have rotted. Schematic maps including the coordinates of plot corners and the placement of transects are attached as appendices.

During preparation of the logged plot, investigators also characterized slope, soils, drainage, and vegetation type in order to select an ecologically similar control plot. Using Landsat images, potential control areas were selected. Priority was given to control areas close to the harvested area (with at least a 500m buffer), and at similar distances from communities, water bodies, roads, or other extraneous factors that could affect wildlife communities. During extensive field visits, habitat types, soils, and slope were verified for each potential area and the most similar one-kilometer area to the logged plot was selected. In some cases, topography and vegetation classes forced us to use irregularly shaped plots in order to maintain comparability with the logged plots. The control plots were prepared in exactly the same manner as the logged plots.

Sampling Regimen

Investigators worked in two teams of seven people each: two people focused on birds, forest structure, and microclimate; two people focused on butterflies; two people focused on dung beetles; and one person served as a cook and guarded the provisional camps and vehicles during sampling. All investigators working with butterflies and dung beetles also sampled for large vertebrates in the early morning.

Investigators typically sampled for six to eight days per concession per round, depending upon logistical conditions and weather. For all taxa, sampling was alternated daily between the logged and control plots in order to dampen the bias caused by confounding factors such as weather and temperature. Repeated visits to the same sampling points allowed calculation of and increased encounter probability. Investigators began data collection in November 2002 and terminated in April 2004, completing four complete rounds of the ten concessions, and allowing analyses of seasonal and annual trends.

Forest Structure and Composition

In each treatment plot, twenty-five 10 X 10 meter plots were established in order to measure forest structure data. The plots were positioned in a uniform grid at every 200 meters, always at least 100 meters from treatment plot edges. In each plot, the following data were recorded: forest type, type of human disturbance, number of standing dead trees (snags), number of fallen dead trees, average canopy height, maximum canopy height, and presence fruit on ground. Leaf litter depth was measured in the four corners of each plot with a plastic ruler. Percent canopy cover was calculated by taking a hemispherical digital photo using a Nikon Coolpix 950 camera fitted with a Nikon E-8 fisheye lens, and classifying the images with the program Gap Light Analyzer (GLA), Version 2.0 (Frazer *et al.* 1999).

All trees (DBH > 10 cm) within the 10 X 10 meter plot were identified to species. Diameter at breast height and the presence of fruits and flowers was recorded for each tree. In a 1 X 10 meter subplot, the number of seedlings and the number of saplings was also recorded.

A multi-factor MANOVA including treatment type, concession, sampling round, and sampling team was used to compare continuous quantitative data characterizing habitats in the two treatments.

Microclimate

At each of the 25 forest structure plots, microclimate data were also recorded. Soil humidity was measured with a FieldScout TDR 100 soil moisture probe from Spectrum Technologies with 4.8-inch probes. Soil temperature was measured with a Reotemp brand soil thermometer with a 4.8-inch probe. Air temperature, relative humidity, and wind speed were measured with a Kestrel 3000 weather meter.

A multi-factor MANOVA including treatment type, concession, sampling round, and sampling team was used to compare continuous quantitative data characterizing microclimate in the two treatments.

Human Presence

All humans and evidence of recent human activity encountered within the 1-square kilometer study plots was recorded during the entire study period. If possible, the reason for presence was determined. Dogs were also included as a proxy of human influence. A paired T-test was used to compare the number of humans in the two treatments.

Large Vertebrates

In each of the ten logged plots and ten control plots, four parallel 1-kilometer straight line transects were cut at intervals of 200 meters. Transects were cleaned and maintained in order to allow detection of tracks and other sign, and to avoid making noise while walking. Flagging tape was placed at every 25 meters along the transects for accurate distance measurements.

Before sampling, all researchers were trained in a participatory two-day workshop in the Uaxactún forest concession in order to standardize data collection. Investigators practiced estimating perpendicular distances using flagging tape and studied identifying characteristics of confusable species.

Observers sampled transects in the early morning between 5:00 and 9:00 AM – the period in which large vertebrate encounter rates are highest. Observers walked silently at a rate of 1 km per hour, scanning the forest for all large vertebrates and sign. For each observation researchers recorded the type of observation (visual, auditory, track, scat, scratch, fur, feather, or scent), species, number of individuals, position along the transect, and perpendicular distance from the transect.

To estimate vertebrate densities, conventional distance sampling methods were used. Visual observations for species with a sufficient number of observations were entered into the program Distance 4.0 (Thomas *et al.* 2002). In order to best fit detection probability curves, data were transformed into intervals and the most parsimonious detection probability model was selected using Akaike's Information Criterion (AIC).

Birds

The bird community was sampled using10-minute point counts at the same 25 points at which forest structure and microclimate data were sampled. In each team, two highly experienced field assistants sampled 12 or 13 points each daily, recording all visual and auditory observations in a radius of 100 meters. Hand-held recorders were used to later verify unknown or confusing vocalizations. Sampling normally began at sunrise, during peak calling activity, and finished approximately two and a half hours later. All sampling took place between 5:15 and 10:00 AM.

Community dynamics parameters were estimated through mark-recapture methods using the program COMDYN (Hines 1999). Species richness was estimated using Burnham and Overton's jack-knife estimator (1979). For community similarity comparisons, the Morisita-Horn index was used.

Butterflies

We employed three methods for butterfly sampling: Van Someron –Rydon baited traps, visual surveys, and hand netting.

Van Someron –Rydon traps consist of a cylinder of mosquito netting (65 cm high and 25 cm in diameter) supported by two wire loops. The cylinder is completely closed except for a five centimeter opening at the bottom under which a 40 by 40 cm plywood platform is suspended. Bait is placed in the center of the platform, attracting butterflies, which enter through the opening. After feeding, butterflies almost always crawl or fly upward, and thus become trapped.

We placed 25 Van Someron –Rydon traps in each treatment area in a grid at every 200 meters, at a height of 3-5 meters (at the same points used to sample birds, forest structure, and microclimate). A 200-meter distance, several times the distance used in many other trapping studies (Austin et al. 1996, Méndez 1997, Sparrow et al. 1994), was used to assure independence of captures at traps. Through mark-recapture studies with a 100-meter grid, it was determined that butterflies often traveled from one trap to another in less time than it took investigators to walk between traps, possibly biasing capture rates (Radachowsky 2002). Traps were hung from the most suitable tree within 5 meters of the selected points.

We baited each trap with approximately one cup of mashed rotting bananas mixed with beer every other day in the morning check after clearing butterflies, alternating sites each day. Hughes et al. (1998) showed that checking traps after leaving bait out for two days is more efficient than the typical half-day or one-day periods used in most studies. The bait was contained in small (ca. 15 cm diameter), open-topped plastic plates in the center of each trap.

Two people checked one area per day, between 7:00 and 13:00 hours. We removed specimens one by one from the traps, identifying to species. Individuals not easily identified in the field were placed in envelopes for later identification. A voucher specimen of each species and any notable variations within species was collected. For each specimen, we recorded date, trap location, treatment area, time, and weather conditions.

During the 5 km walk required to sample traps, butterflies were also identified on the wing and captured with nets when visual identification was impossible. Investigators maintained a speed of approximately two kilometers per hour, recording all individuals observed and caught. For butterflies captured with nets, we kept a voucher specimen of each species, and recorded date, capture location, treatment area, time, weather conditions, and whether collected.

Devries' guides to butterflies of Costa Rica (1997, 1987) and *Mariposas Mexicanas* (De La Maza 1986) served as primary identification sources. For its invaluable checklist and descriptions and photographs of local species, the description of butterflies of the Tikal vicinity by Austin et al. (1996) was used.

As for birds, community dynamics parameters were estimated through mark-recapture methods using the program COMDYN (Hines 1999). Species richness was estimated using Burnham and Overton's jack-knife estimator (1979). For community similarity comparisons, the Morisita-Horn index was used.

Dung Beetles

To sample dung beetles, we placed 45 baited pitfall traps at intervals of 100 meters along five parallel transects in each treatment plot. Traps consisted of 10 cm diameter Tupperware containers buried so that their lips set flush with the soil. Bait was wrapped in plastic mosquito screening and tied to a stick driven diagonally into the soil so that it overhung the receptacle. The containers were filled with one inch of soapy water. Traps were alternately baited with human dung and meat or fish, depending upon availability.

After 24 hours, traps were checked. All beetles captured per trap were placed in a small bottle with a label describing the date, trap position, treatment type, bait type, and whether the trap or bait had been disturbed. The same protocol was used for traps with no beetles.

Specimens were then transported to a central office where they were identified to species using a stereoscope. A voucher and reference collection was established in the Wildlife Conservation Society office in Flores, Petén.

The program EstimateS (Colwell 1997) was used to estimate species richness and similarity indices.

Results

In this section, I present results of general interest that describe comparisons between logged and unlogged treatments and investigate the underlying reasons for ecological differences. In order to evaluate individual concessions and compare their impacts with those of other concessions, summaries at the level of individual concessions have been attached as appendices. Managers and certifying agencies should first read the general results and conclusions in the main text, and then direct themselves to the corresponding appendices for individual evaluations.

Forest Structure

Several aspects of forest structure differed significantly between logged and unlogged treatments (Table 5). In general, logged areas showed significantly greater canopy openness, a higher density of seedlings, and a higher density of dead fallen trees than unlogged areas. In unlogged areas, canopy height (both mean and maximum) was significantly higher. Leaf litter depth, density of snags, and density of saplings showed no significant differences at the treatment plot level. Results of forest structure parameters are summarized by concession in appendix I.

Table 5. Comparison of forest structure parameters in unlogged and logged areas, ordered by the P-value of a multi-factor manova using concession, round, logging treatment, and team as factors.

Parameter	Control mean	Logged mean	P(F)
Seedlings (<5cm DBH)	**6.6**	**7.9**	**0.000**
Dead fallen trees	**0.8**	**1.0**	**0.000**
Maximum canopy height (m)	**19.2**	**18.4**	**0.000**
Mean canopy height (m)	**13.4**	**12.9**	**0.001**
Canopy Openness (%)	12.7	13.0	0.056
Leaf litter depth (cm)	2.9	3.0	0.211
Saplings (5-10cm DBH)	0.9	0.9	0.494
Dead standing trees	0.4	0.4	0.729

In general, size-class distributions of trees in logged and unlogged treatments are very similar. However, more trees in the 10 - 20 cm DAP size-class and greater than 100 cm DAP were encountered in unlogged areas. Mean density is lower in logged areas for the most heavily harvested size classes (40 cm – 80 cm DAP), although not significantly so.

Table 6. Mean tree density (individuals per hectare) by size-class in unlogged and logged areas. Differences were tested using a multi-factor manova including concession, round, logging treatment, and team as factors.

DAP	Control	Logged	p(F)
10-20	414.35	376.79	0.000
20-30	138.15	144.29	0.307
30-40	46.24	48.45	0.479
40-50	20.91	17.89	0.125
50-60	9.15	8.32	0.547
60-70	4.24	3.58	0.438
70-80	2.12	1.64	0.427
80-90	1.54	1.55	0.983
90-100	0.19	0.39	0.410
>100	0.67	0.10	0.058

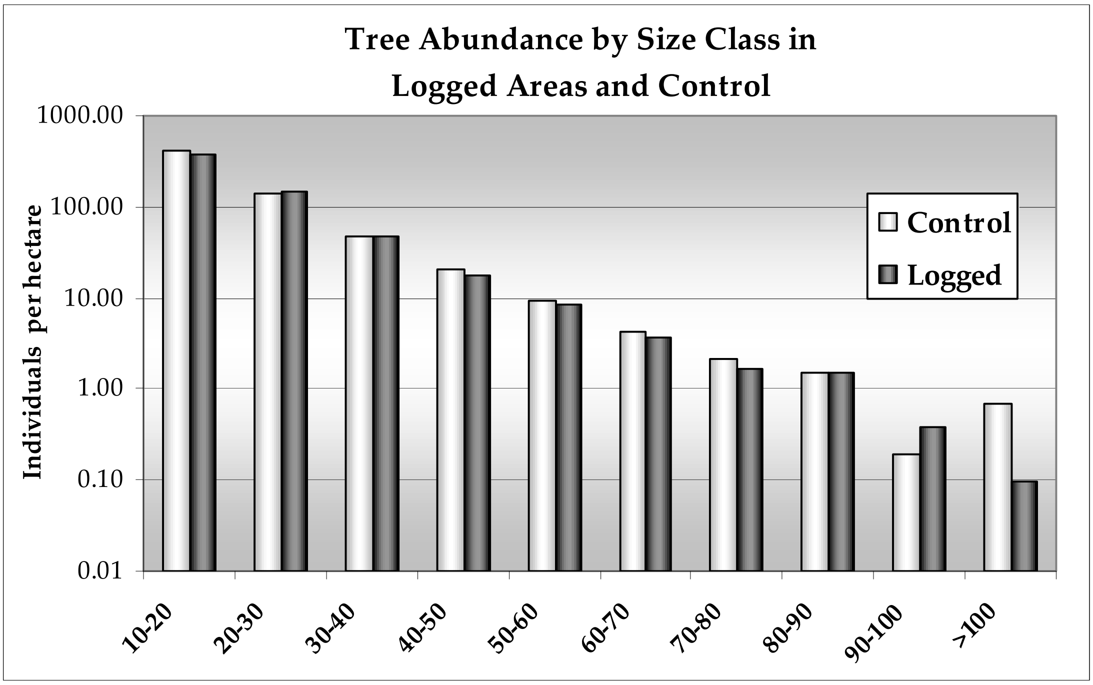

Figure 3. Size-class distribution of trees in logged and unlogged areas. Note that densities are presented on a logarithmic scale.

Microclimate

The results of microclimate measurements suggest that logged areas are warmer and drier than their unlogged counterparts. In logged areas, both air and soil temperature were significantly higher. Mean air humidity was higher in unlogged plots, though not significantly. Results of microclimatic parameters are summarized by concession in appendix II.

Table 7. Comparison of microclimate parameters in unlogged and logged areas, ordered by the P-value of a multi-factor multi-factor manova using concession, round, logging treatment, and team as factors.

Parameter	Control mean	Logged mean	P(F)
Air temperature (degrees F)	**80.6**	**81.6**	**0.003**
Soil temperature (degrees F)	**74.8**	**75.1**	**0.044**
Air humidity (%)	78.1	77.0	0.143
Air speed (km/hr)	0.8	0.9	0.200
Soil humidity (%)	44.4	44.4	0.982

Human Presence

In total, 44 humans and 14 dogs were encountered in treatment plots during the study period. Interestingly, no difference was found between logged and unlogged plots in terms of human presence (p = 0.87), with 23 people encountered in control plots and 21 people in logged plots.

Table 8. Humans and dogs observed during all sampling sessions

Concession	Humans Control	Humans Logged	Total Humans	Total Dogs	Distance to nearest community
La Colorada	8	2	**10**	5	5
Uaxactún	4	7	**11**	2	7
La Pasadita	4	6	**10**	5	11
Carmelita	0	2	**2**	0	20
San Andrés	2	0	**2**	0	25
La Gloria	5	3	**8**	2	31
Paxbán	0	1	**1**	0	48
Chanchich	0	0	**0**	0	50
Arbol verde	0	0	**0**	0	60
Chosquitán	0	0	**0**	0	65
Total	**23**	**21**	**44**	**14**	

Human presence in both logged and unlogged plots shows similar tendencies with relation to distance from communities (Figure 4). In plots closer to communities, human encounter rates were significantly higher than in those far from communities, regardless of treatment type.

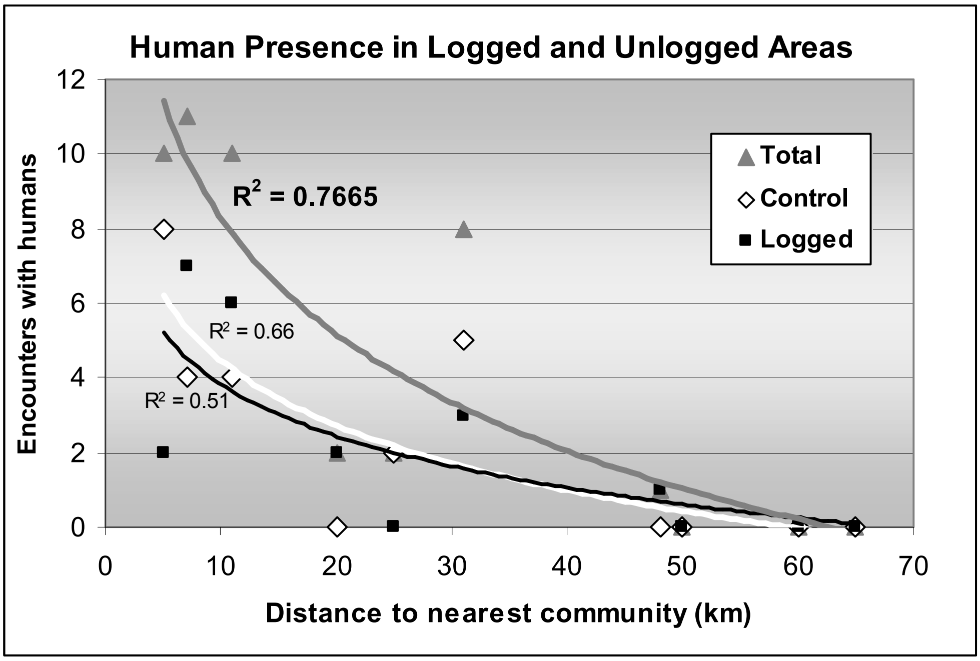

Figure 4. Humans encountered in logged and unlogged areas as a function of distance from communities. Logarithmic regression analysis shows a similarly strong tendency for higher human encounter rates closer to human settlements in both logged and unlogged plots.

Large Vertebrates

Encounter Rates and Density

In total, more than 20 species and 5700 observations of large vertebrates were recorded on the 1087 kilometers of transects sampled during the study period. By far, the most commonly observed species was the spider monkey (*Ateles geoffroyi*), followed by Depp's squirrel (*Sciurus deppei*), the crested guan (*Penelope purpurascens*), chachalaca (*Ortalis vetula*), great curassow (*Crax rubra*), mantled howler monkey (*Alouatta pigra*), spotted wood-quail (*Odontophorus guttatus*), coati (*Nasua narica*), great tinamou (*Tinamus major*), agouti (*Dasyprocta punctata*), ocellated turkey (*Meleagris ocellata*), brocket deer (*Mazama americana*), and thicket tinamou (*Crypturellus cinnamomeus*). Rank abundance of species encountered is shown in figure 5.

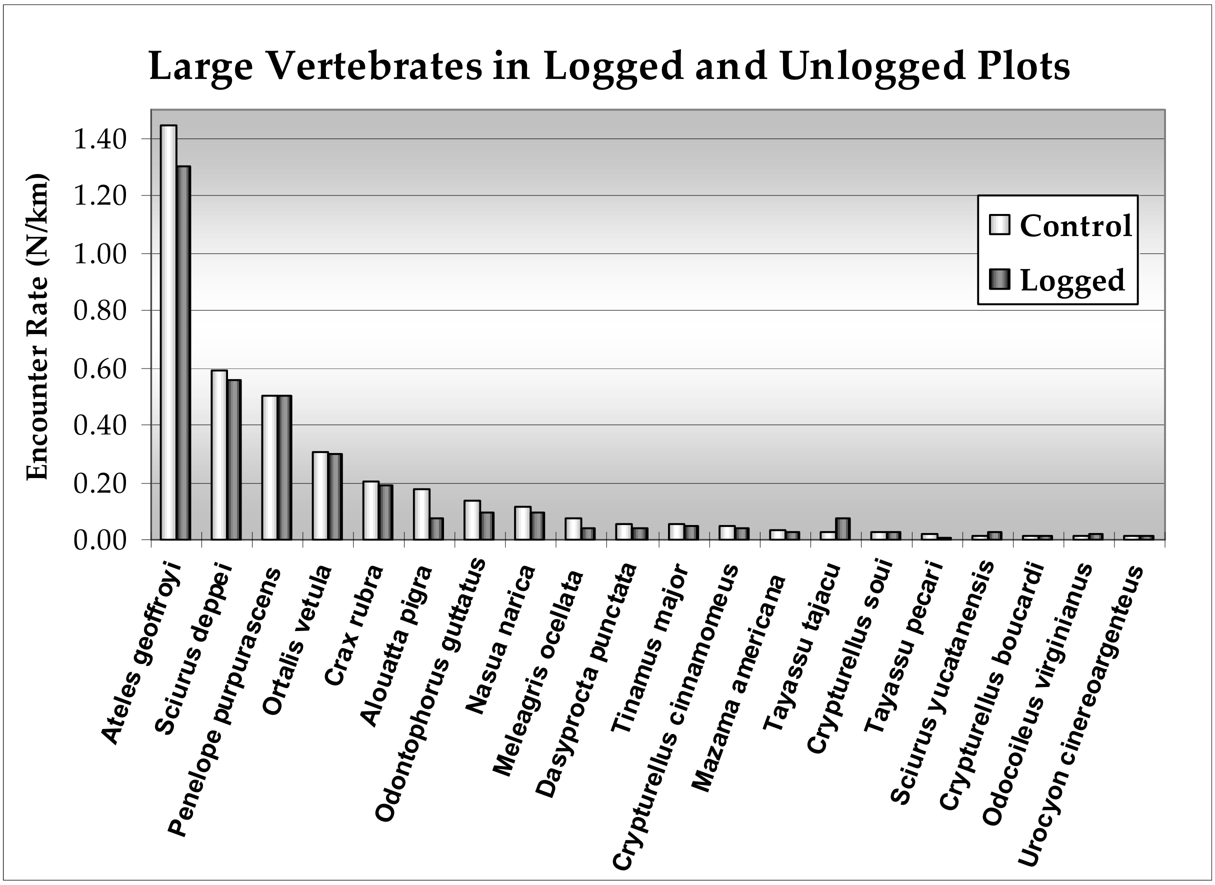

Figure 5. Rank abundance distribution of large vertebrates sampled with straight line transects

Encounter rates and density point estimates for the 12 most commonly observed species are given in table 9. Of the more than 20 species of large vertebrates sampled with transects, only the mantled howler monkey (*Alouatta pigra*) demonstrated significantly lower encounter rates in logged areas ($p = 0.004$). Density estimates for howler monkeys are 5.67 individuals per km^2 in unlogged plots and 3.38 individuals per km^2 in logged areas. Whether density differences are due to the effects of logging or other confounding factors should be further examined.

Table 9. Encounter rates and density estimates for the 12 most commonly observed species sampled with straight line transects

Species	Treatment	Number of Obser-vations	Distance Sampled (km)	Encounter rate (n/km)	D Point Estimate (n/km^2)	Mean Cluster Size
Alouatta pigra	control	24	528	0.05	5.67	3.47
	logged	14	527	0.03	3.38	3.47
Ateles geoffroyi	control	213	528	0.40	42.68	3.74
	logged	198	527	0.35	37.65	3.74
Crax rubra	control	72	528	0.14	4.55	1.45
	logged	69	527	0.13	4.13	1.45
Crypturellus cinnamomeus	control	26	528	0.05	2.50	1.02
	logged	23	527	0.04	2.13	1.02
Dasyprocta punctata	control	26	528	0.05	1.77	1.11
	logged	20	527	0.04	1.43	1.11
Mazama americana	control	17	528	0.03	0.85	1.05
	logged	12	527	0.02	0.57	1.05
Meleagris ocellata	control	14	528	0.03	1.65	2.20
	logged	12	527	0.02	1.31	2.20
Nasua narica	control	14	528	0.03	2.08	2.62
	logged	15	527	0.03	2.15	2.62
Ortalis vetula	control	64	528	0.12	10.17	2.53
	logged	67	527	0.13	11.28	2.53
Penelope purpurascens	control	126	528	0.25	12.31	2.18
	logged	145	527	0.27	13.71	2.18
Sciurus deppei	control	287	528	0.54	31.11	1.14
	logged	245	527	0.47	26.54	1.14
Tinamus major	control	28	528	0.05	1.82	1.12
	logged	25	527	0.05	1.67	1.12

Human Access and Game Species

For the purpose of analyses, the crested guan, great curassow, and brocket deer were included as game species. Human access explains nearly 80% of the variation in game species density in unlogged areas ($p = 0.0006$) (Figure 6). However, access shows no significant relationship with game species density in logged areas ($p = 0.43$) and explains only eight percent of the variance. This suggests that other factors than access may play a more important role in determining game species densities in logging treatments.

Figure 7 examines the difference between game species density in paired logged and unlogged plots as a function of human access. Interestingly, in areas with low human access, fewer game species were encountered in logged areas than in unlogged areas. In areas with high human access, more game species were found in logged areas than paired control plots.

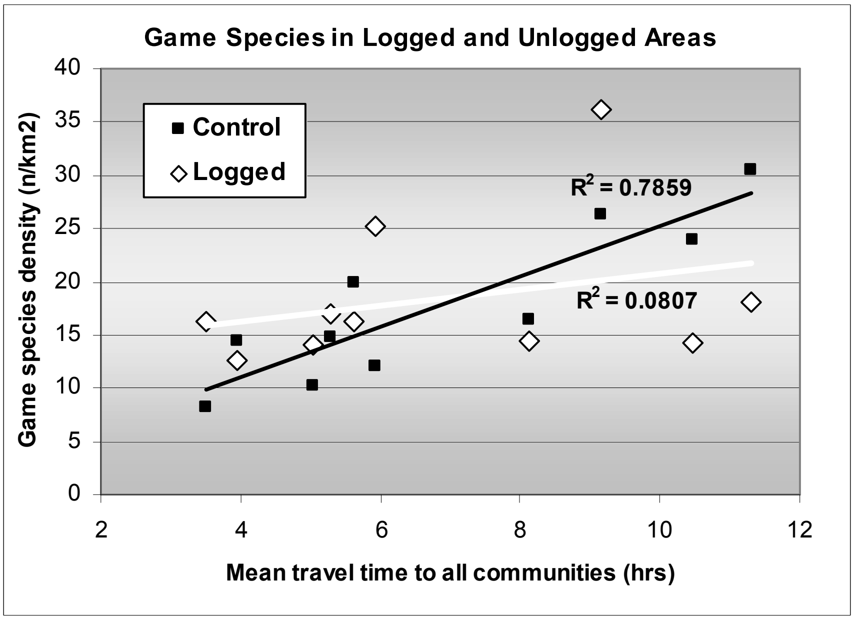

Figure 6. Game species density in logged and unlogged areas as a function of human access. Note that in unlogged areas, access explains most of the variation in density while in logged areas other factors are probably more important.

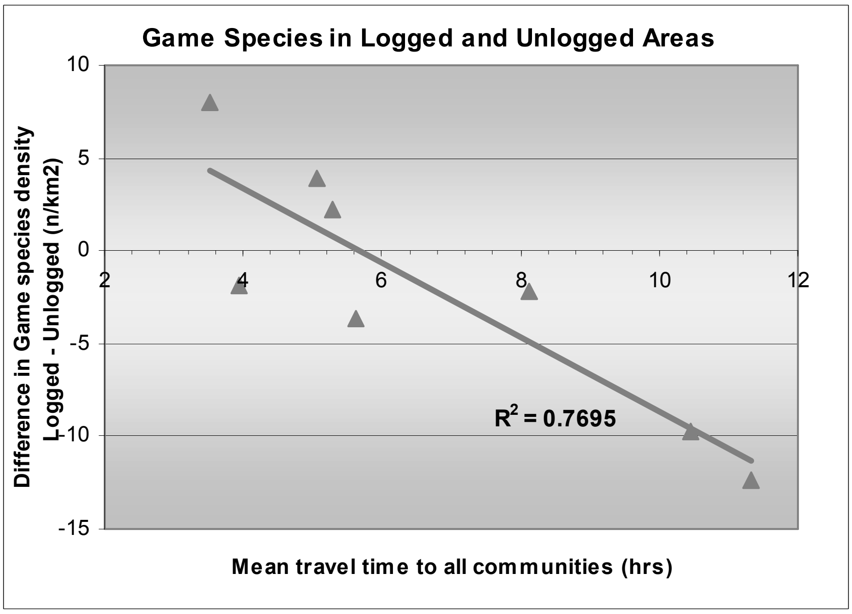

Figure 7. Difference in game species density between unlogged and logged areas as a function of human access. Note that near communities differences tend to be positive while far from communities differences tend to be negative.

Birds

Species Richness

In total, 99,713 observations of 224 species were recorded during the study period. Generally, species richness was greater in logged areas than in unlogged areas ($p = 0.059$). Only in the concession of La Gloria did species richness in the unlogged plot surpass that of the logged area. The mean bootstrap richness estimate per concession across all sampling sessions is shown in figure 8.

Species richness in the logged plots is especially higher than unlogged plots in forest types that are structurally homogeneous and have few natural disturbances, such as those sampled in Arbol Verde, Uaxactún, and La Pasadita. Logging may add heterogeneity in such closed forests, allowing the entry of edge specialists. Species richness summaries by concession and by sampling round are included in appendix III.

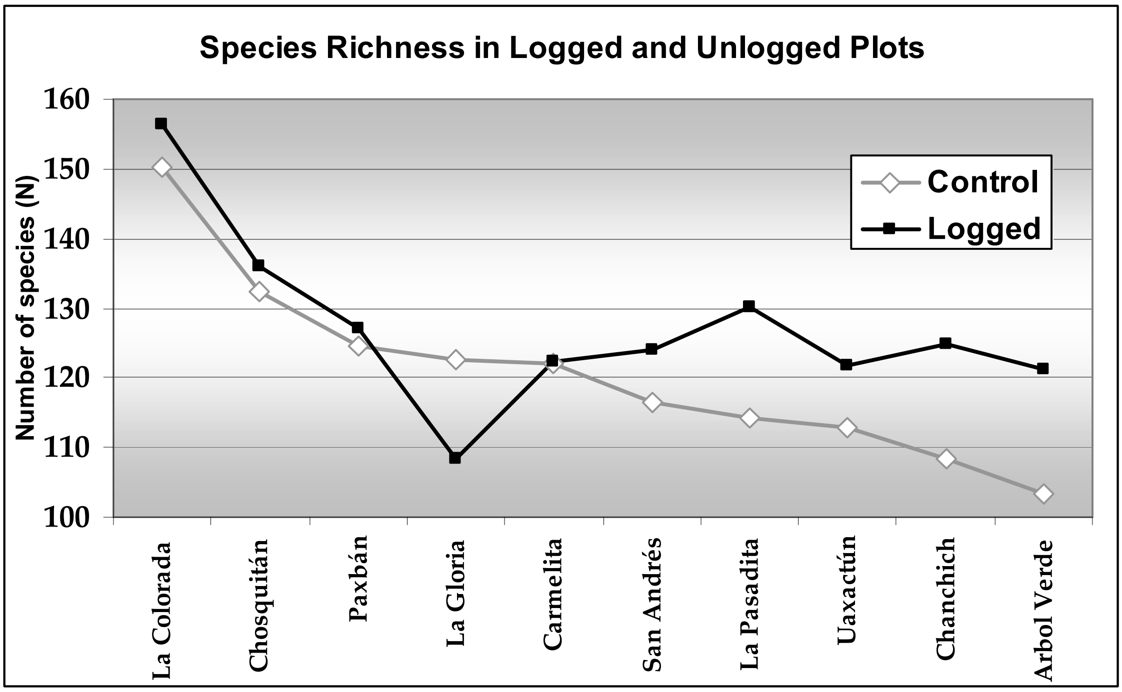

Figure 8. Estimated number of bird species in logged and unlogged areas for each concession

Similarity of Communities

Phi, the proportion of species in the unlogged plot that were also encountered in the logged plot, ranged from 0.96 in La Colorada to 0.90 in La Pasadita (Figure 9). Gamma, the proportion of species in the logged plot that were also encountered in the unlogged plot, ranged from 0.96 in La Gloria to 0.90 in San Andrés and La Pasadita. That phi and gamma have similar values suggests no strong directional tendencies in the number of shared species between treatment plots. If logging were causing the exclusion of species, one would expect higher gamma values than phi values. Phi and gamma summaries by concession and by sampling round are included in appendix III.

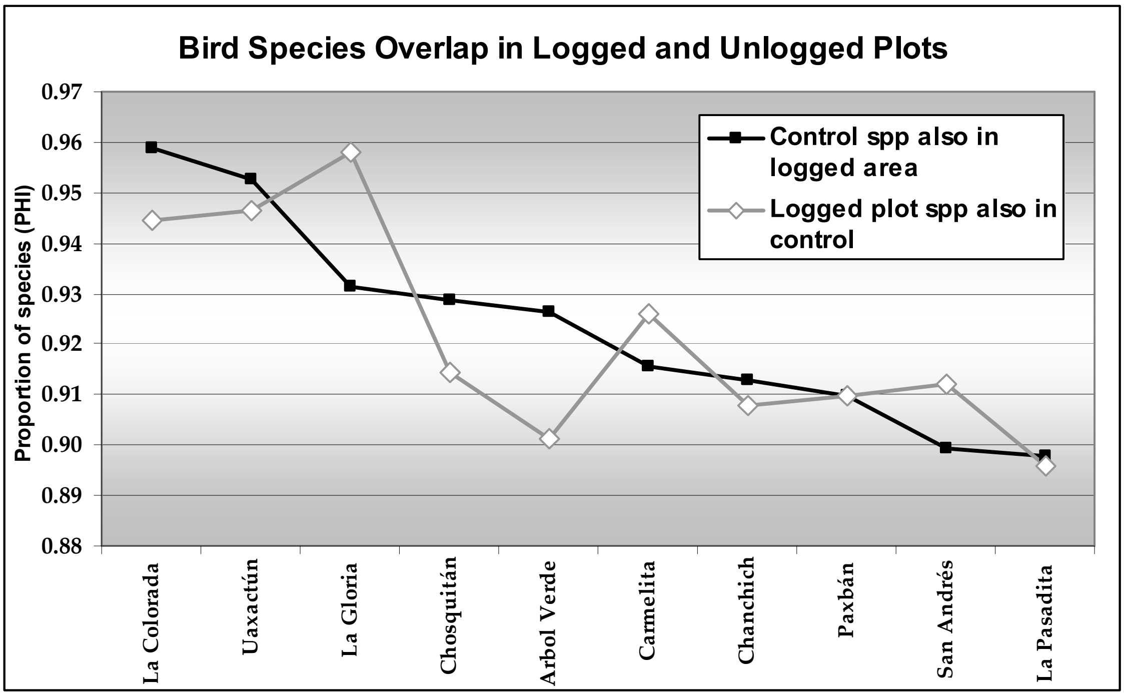

Figure 9. Proportion of species overlap between logged and unlogged plots in ten forest concessions.

The Morisita-Horn similarity index compares both species richness and relative abundance of species between samples. Encounter rates varied considerably between field investigators, causing a bias in similarity estimates between teams. Therefore, similarity indices are calculated separately for both field teams, and ANOVAs also include sampling team as a factor.

Figure 10 shows community similarity values between logged and unlogged plots for each team. For team 1, whose encounter rate was significantly higher, similarity indices ranged from 0.91 to 0.95. For team 2, similarity index values ranged from 0.81 to 0.91. Interestingly, the rank order of similarity values is very different between teams.

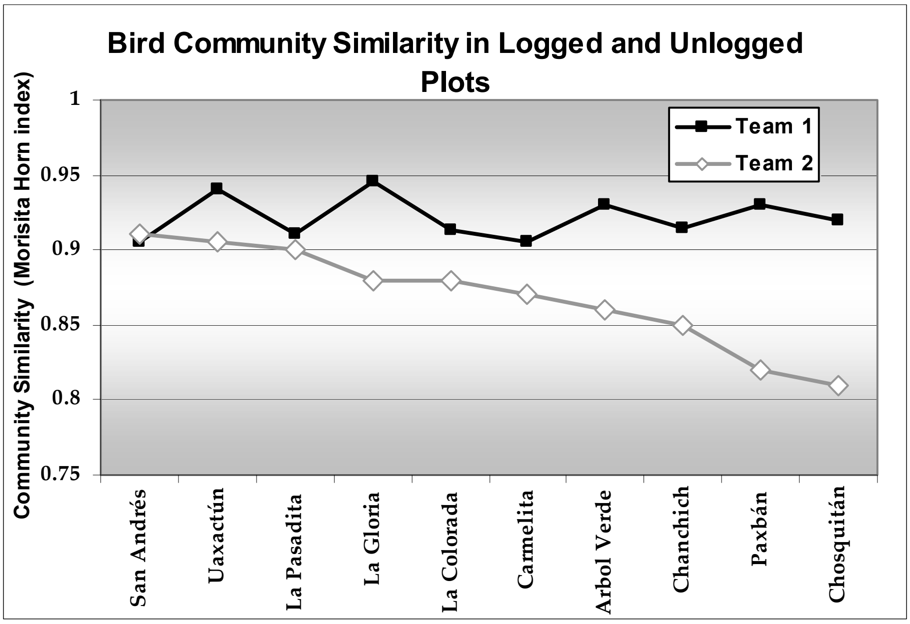

Figure 10. Morisita-Horn community similarity between logged and unlogged plots for each sampling team. Values for teams differ significantly due to a bias in the number of individuals recorded.

Ten bird species were encountered at significantly lower rates in logged areas than in unlogged areas (Table 10). Of these, nine are resident breeders and one is a winter visitor; seven are forest generalists, two are edge specialists, and one is a forest interior obligate; five are omnivores, four are insectivores, and one is a frugivore; five are lower-canopy foragers, four are aerial salliers, and one is a bark prober; six are understory nesters, two are cavity nesters, and one is a canopy nester. None of the species are on CITES or IUCN lists, although *Lipaugus unirufus* is on the CONAP red list and *Lanio aurantius* is endemic to the Maya Forest. It is worth noting that although differences are statistically significant, declines in encounter rates are mostly less than 25%.

Table 10. Species with significantly lower encounter rates in logged areas according to a multiple-factor ANOVA with concession, team, round, and treatment as factors.

Scientific Name	Common Name	Nombre Común	enc rate control	enc rate logged	p(F)
Columba nigrirostris	Short-billed pigeon	Paloma piquinegra	0.2	0.17	0.01
Lipaugus unirufus	Rufous pija	Piha rufa	0.024	0.0157	0.04
Piaya cayana	Squirrel cuckoo	Cuco ardilla	0.15	0.13	0.03
Mniotilta varia	Black-and-white warbler	Chipe trepador	0.06	0.04	0.05
Eucometis penicillata	Grey-headed tanager	Tángara cabecigris	0.18	0.12	0.00
Lanio aurantius	Black-throated shrike-tanager	Tángara-lanio gorjiinegro	0.25	0.2	0.00
Trogon collaris	Collared trogon	Trogon collarejo	0.11	0.09	0.01
Trogon violaceus	Violaceous trogon	Trogon violáceo	0.17	0.15	0.04
Mionectes oleaginus	Ochre-bellied flycatcher	Mosquero vientre-ocre	0.09	0.06	0.00
Oncostoma cinereigulare	Northern bentbill	Picocurvo norteño	0.43	0.38	0.00

Seven bird species were encountered at significantly higher rates in logged areas than in unlogged areas (Table 11). Of these, six are resident breeders and one is a winter visitor; five are forest generalists, and two are edge specialists; three are omnivores, two are insectivores, one is a frugivore, and one is a seed-eater; three are lower-canopy foragers, two are upper canopy foragers, one is a ground gleaner, and one is a bark prober; three are understory nesters, two are cavity nesters, and one is a canopy nester. *Aratinga nana* is listed in CITES appendix II and on CONAP's red list, and *Arremonops chloronotus* is endemic to the Maya Forest.

Table 11. Species with significantly higher encounter rates in logged areas according to a multiple-factor ANOVA with concession, team, round, and treatment as factors.

Scientific Name	Common Name	Nombre Común	enc rate control	enc rate logged	p(F)
Aratinga nana astec	Aztec parakeet	Perico pechisucio	0.3	0.46	0.00
Arremonops chloronotus	Green-backed sparrow	Gorrión dorsiverde	0.2	0.29	0.00
Cyanocorax yncas	Green jay	Chara verde	0.01	0.02	0.04
Dumetella carolinensis	Grey catbird	Pájaro-gato gris	0.25	0.32	0.00
Habia rubica	Red-crowned ant-tanager	Tángara-hormiguera coronirroja	0.03	0.04	0.01
Melanerpes aurifrons	Golden-fronted woodpecker	Carpintero frentidorado	0.06	0.08	0.05
Myiopagis viridicata	Greenish elaenia	Elenia verdosa	0	0.01	0.03

Temporal Variation

More than forty species of migratory birds were sampled in treatment plots. The presence or absence of these species can temporally affect species richness and community similarity.

Figure 11 shows altLambda, an estimator for the relative species richness in logged areas as compared with unlogged areas. Sampling sessions one and four occurred in the winter, when migratory birds are present in Guatemala, while sessions two and three occurred during the summer, when there are no migratory birds. Species richness is especially higher in logged areas during sessions one and four, suggesting a relatively more important influx of migratory species in logged areas than in unlogged areas. Among residents, as indicated during sessions two and three, species richness is nearly even (altLambda close to one) in logged and unlogged plots.

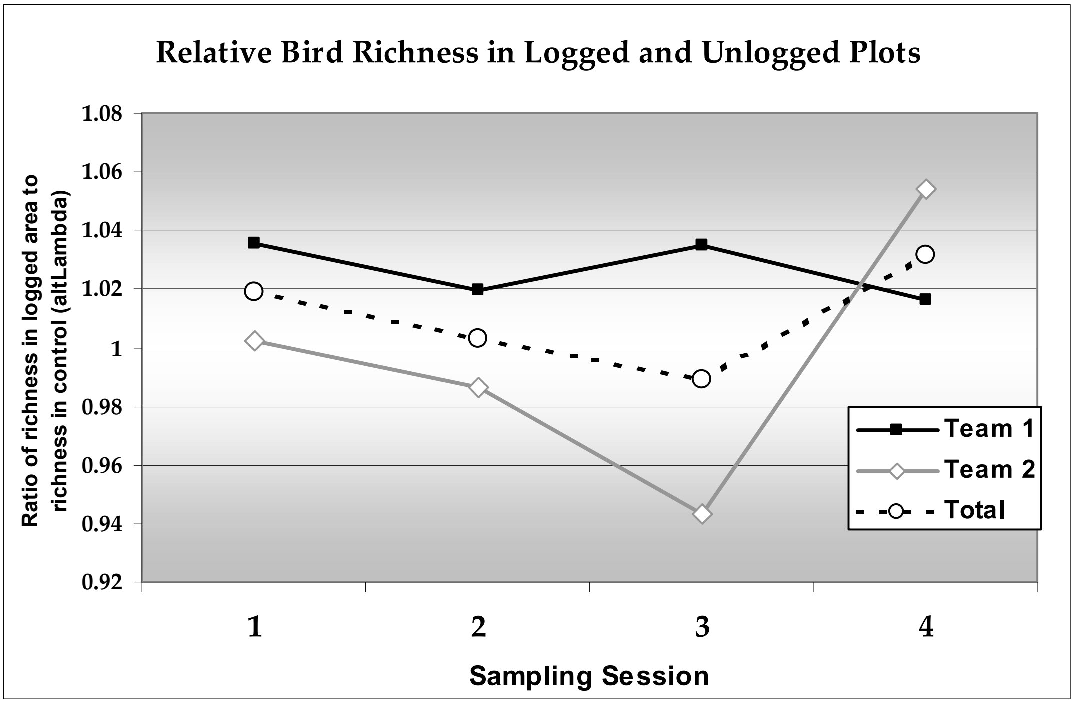

Figure 11. Relative species richness in logged versus unlogged plots, as estimated by altLambda

When relative abundance is taken into account, as in the Morisita-Horn index, community similarity appears relatively stable over time. The mean similarity index value across all ten concessions shows a slight, though insignificant increase over the study period. This may reflect vegetation regeneration during the one-year study period.

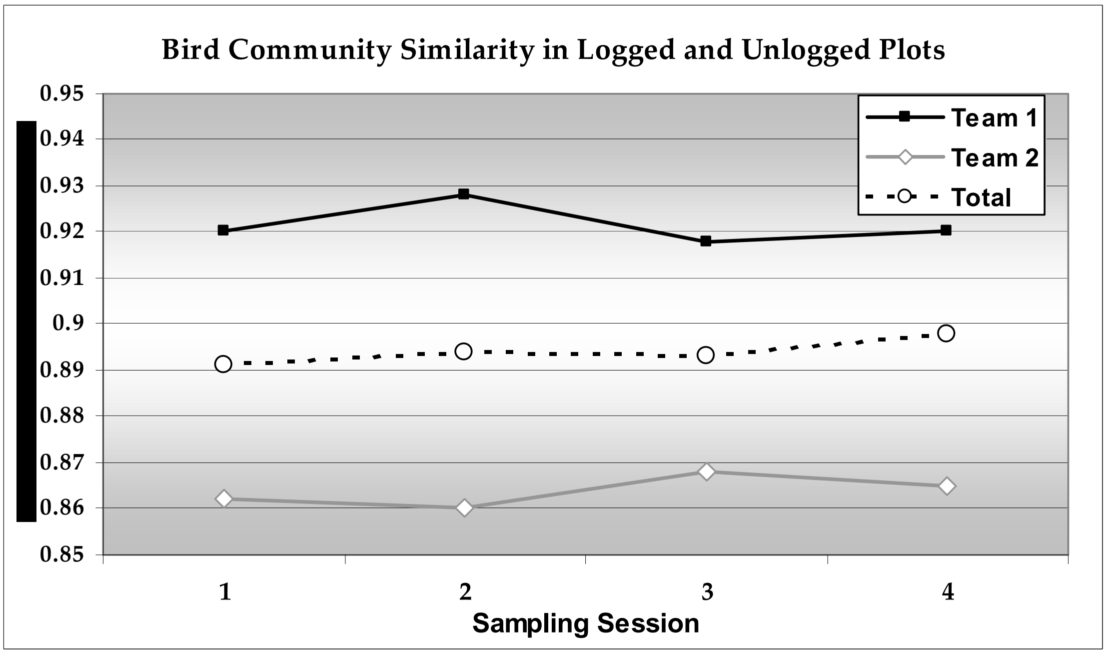

Figure 12. Morisita-Horn community similarity index over time

Ecological Explanations for Community Differences

Neither the number of individuals nor species of birds showed significant differences between logged and unlogged areas in terms of primary habitat preference. In logged areas, two more species of open habitat specialists were encountered, while in unlogged areas two more generalist species were encountered. The same number of forest-interior obligate species was encountered in logged and unlogged plots.

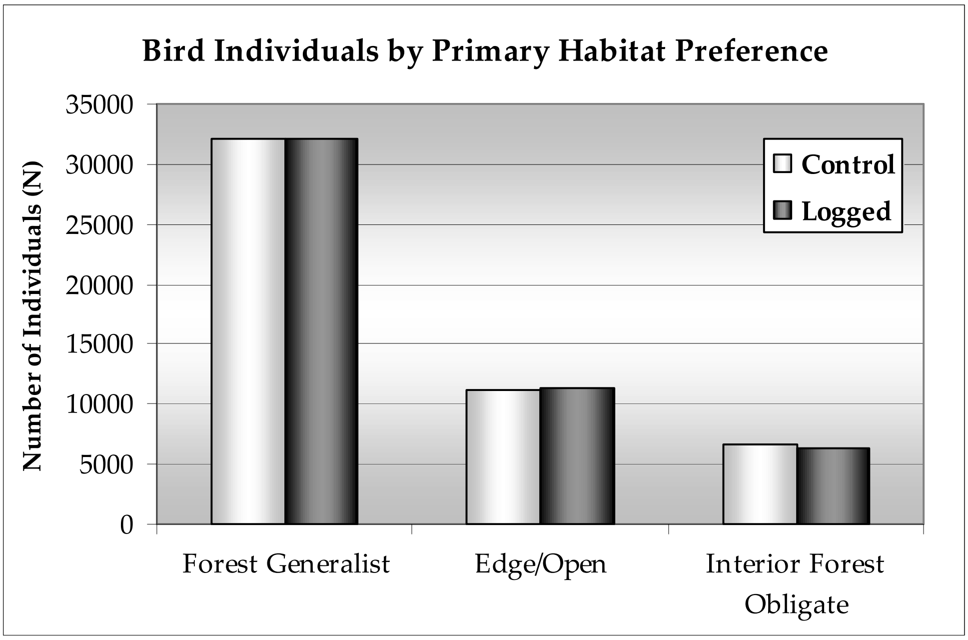

Figure 13. Total number of birds encountered in logged and unlogged plots per habitat specialist guild

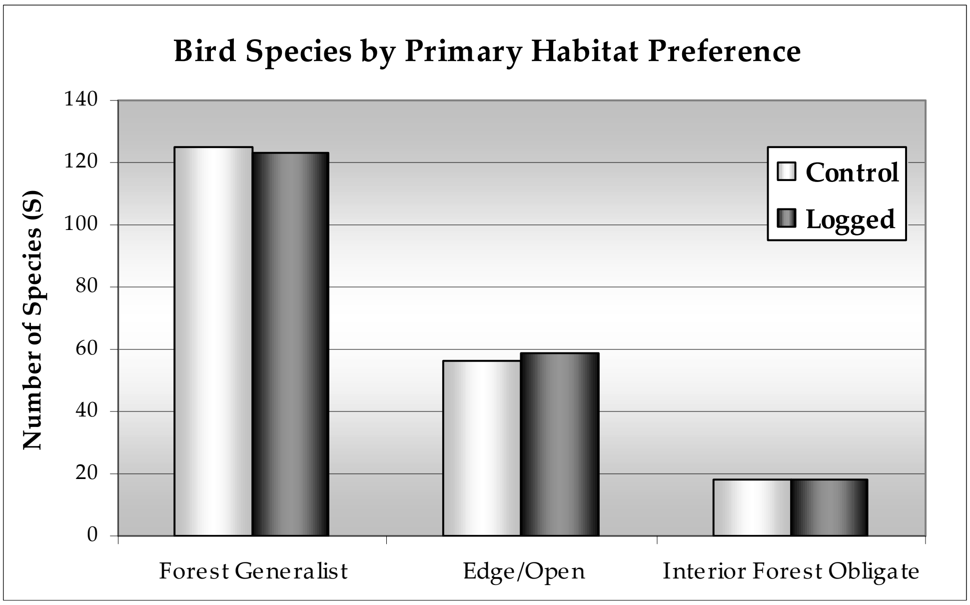

Figure 14. Number of bird species encountered in logged and unlogged plots per habitat specialist guild

Interestingly, patterns of bird richness and abundance react differently in logged and unlogged areas with respect to trophic level (Figures 15, 16). In logged areas, more insectivorous species but fewer insectivorous individuals were encountered; fewer frugivorous species but more frugivorous individuals were encountered. To some degree, these differences may reflect the increase in habitat heterogeneity, but varying responses in food resource availability in logged areas.

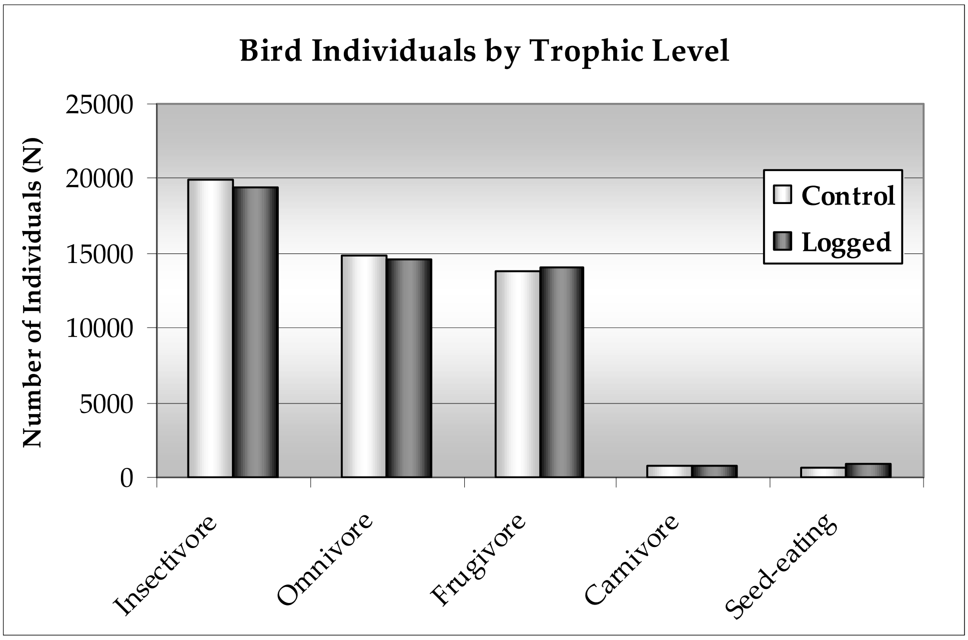

Figure 15. Total number of birds encountered in logged and unlogged plots per trophic level guild

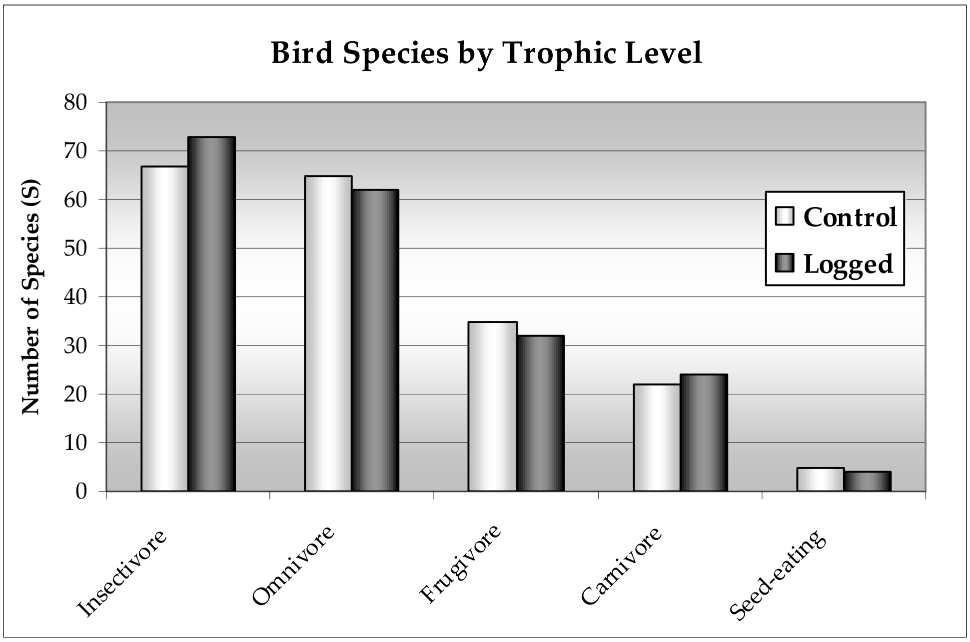

Figure 16. Number of bird species encountered in logged and unlogged plots per trophic level guild

Very minor differences were observed in terms of bird foraging behavior in logged and unlogged plots (Figures 17, 18). In logged plots, more species of bark-probers, soaring hunters, and lower canopy foragers, and fewer species of ground-gleaners and upper canopy foragers were encountered.

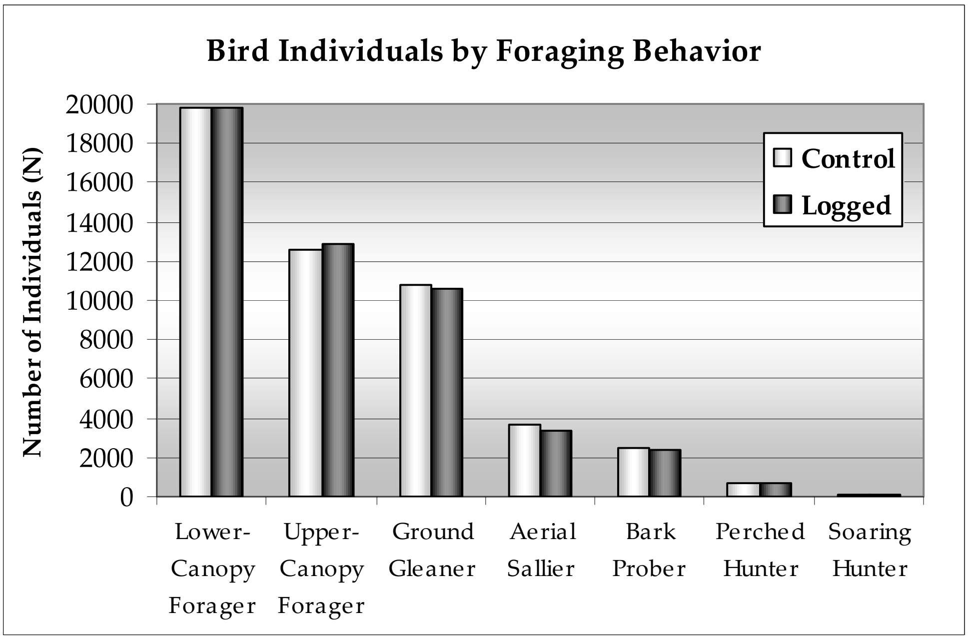

Figure 17. Total number of birds encountered in logged and unlogged plots per foraging behaviour guild

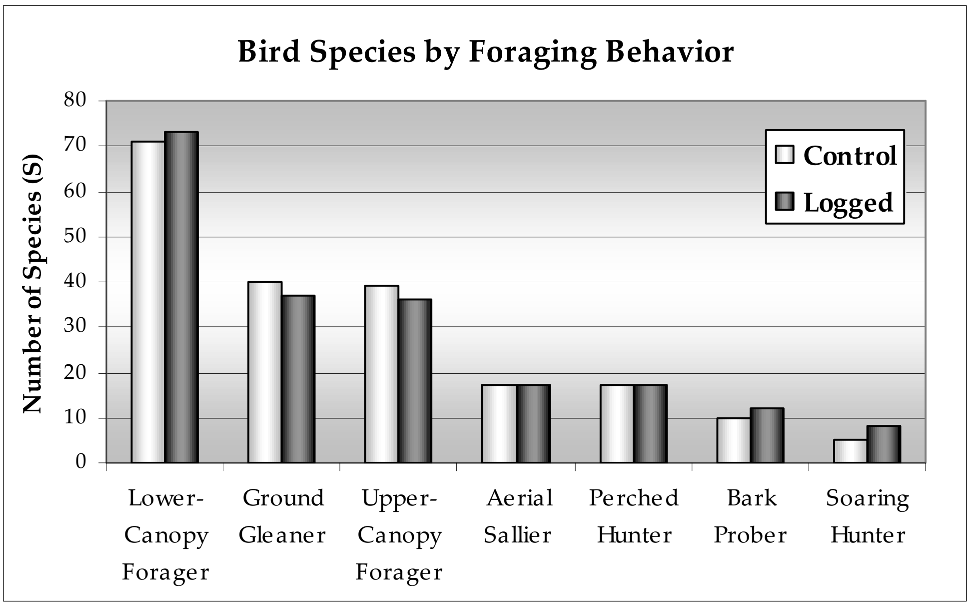

Figure 18. Number of bird species encountered in logged and unlogged plots per foraging behaviour guild

No significant differences were encountered between logged and unlogged areas in terms of nest placement guilds (Figures 19, 20). In unlogged areas, four more species of under- and mid-story nesters were encountered than in logged plots.

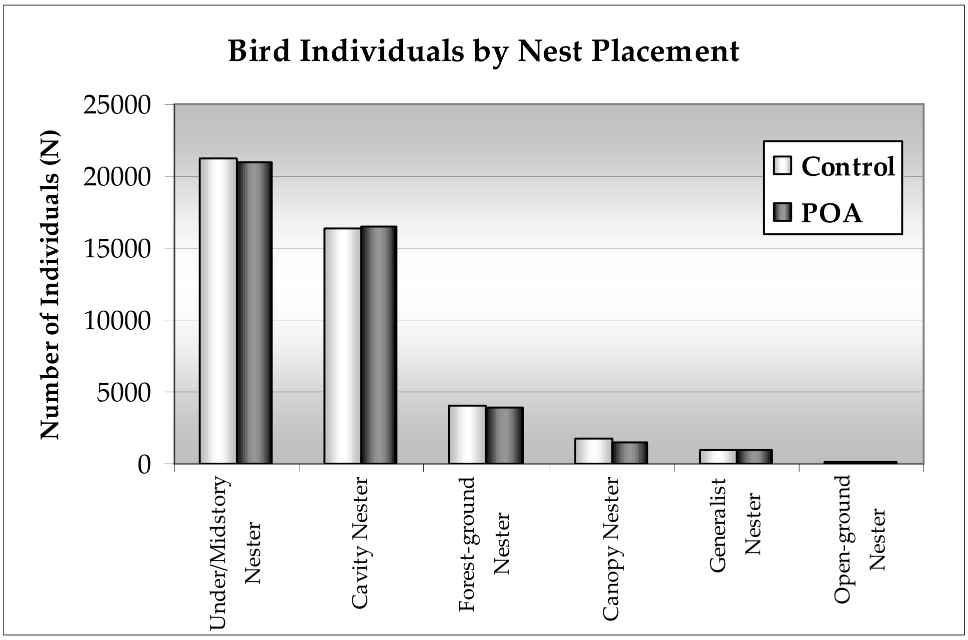

Figure 19. Total number of birds encountered in logged and unlogged plots per nest placement guild

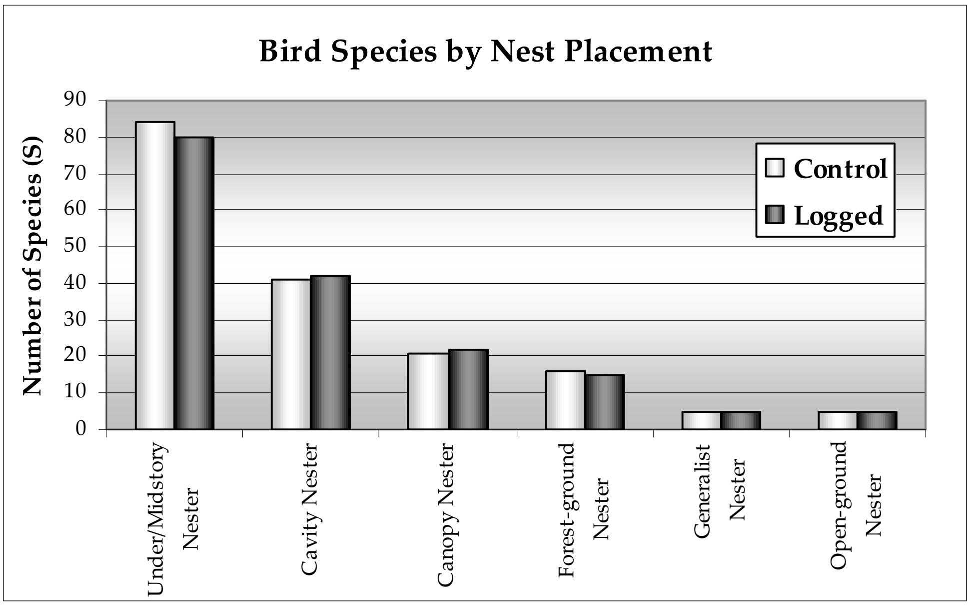

Figure 20. Number of bird species encountered in logged and unlogged plots per nest placement guild

Butterflies

In total, 10,144 individuals of 97 species were observed or captured during the study period. Of these 9550 individuals and 80 species were caught in baited traps, 582 individuals and 63 species were identified visually, and 12 individuals and 10 species were caught in nets. Species richness summaries by concession and by sampling round are included in appendix IV.

Species Richness

In most cases, butterfly species abundance and richness was either higher in logged areas than in unlogged areas, or nearly equal (Figure 21). Only in Carmelita was butterfly richness significantly lower in the logged plot than in the unlogged plot. This is due to an exceptionally high number of species encountered in the Carmelita control plot, and not an exceptionally low number of species in the logged plot.

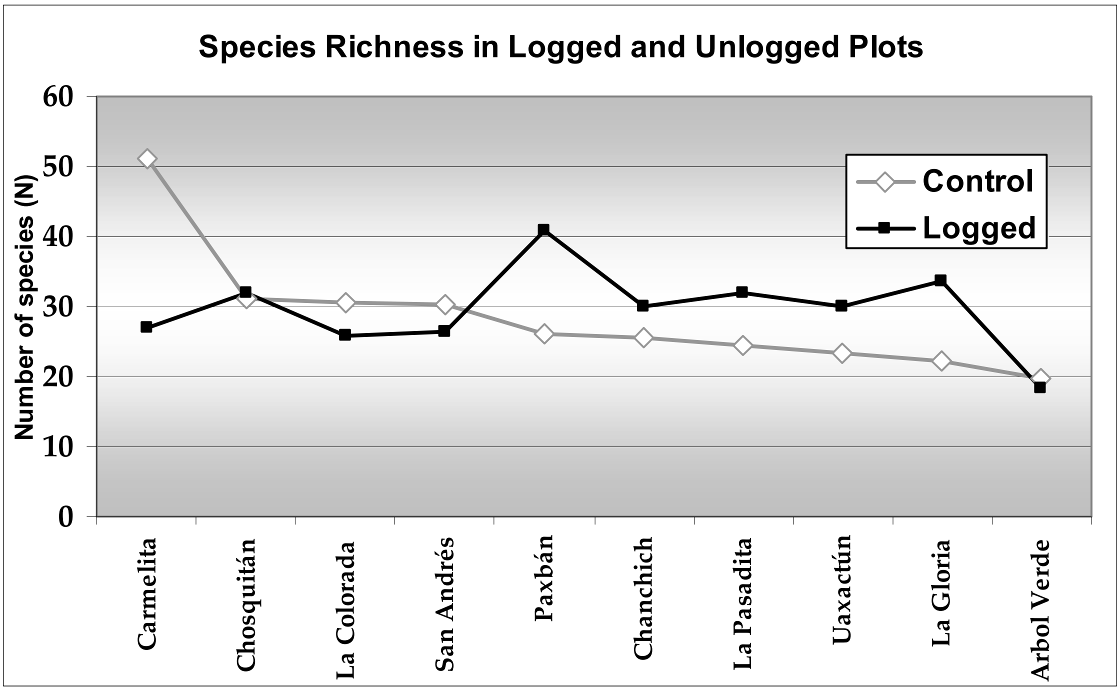

Figure 21. Mean butterfly species richness per sampling session in logged and unlogged paired plots

The relative species richness in logged versus unlogged plots, as estimated by altLambda, demonstrates that logged areas host more species (Figure 22, values > 1). In Arbol Verde, the logged plot hosted nearly 140% the number of species in the paired control plot. Again, only in Carmelita were less species encountered in the logged area than in the unlogged area.

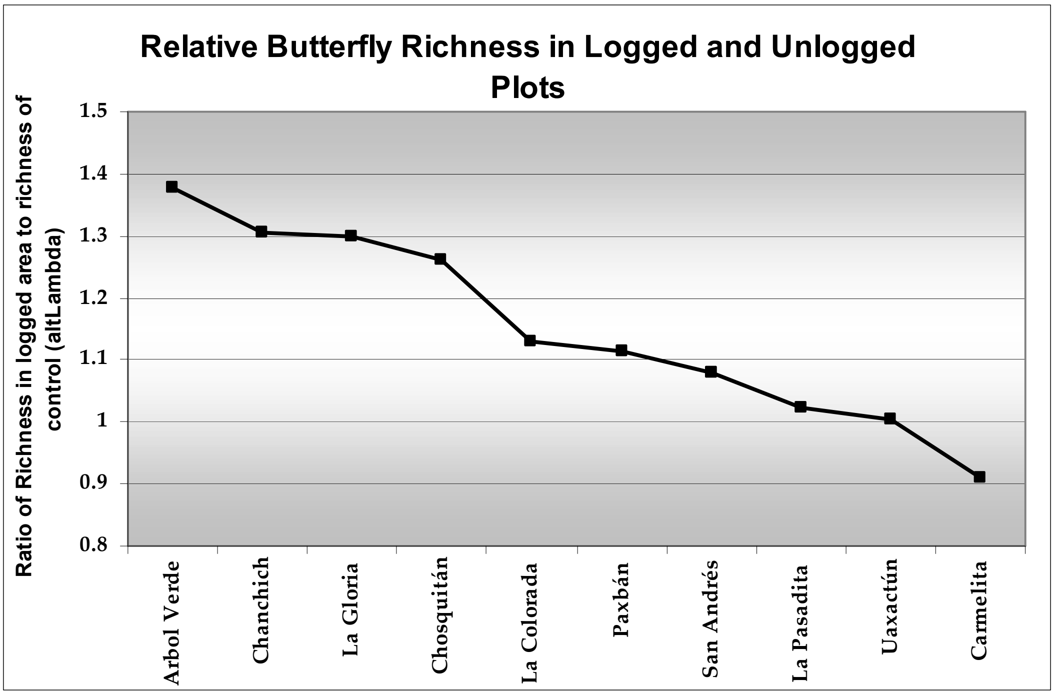

Figure 22. Relative species richness in logged versus unlogged plots, as estimated by altLambda

Similarity of Communities

Phi, the proportion of species in the unlogged plot that were also encountered in the logged plot, ranged from 0.90 in Paxban to 0.68 in Uaxactun (Figure 23). Gamma, the proportion of species in the logged plot that were also encountered in the unlogged plot, ranged from 0.90 in Chanchich to 0.58 in La Colorada. In seven out of ten concessions, phi is greater than gamma, suggesting that the more species rich logged areas may be adding new species to the community more than excluding species found in uncut plots. Phi and gamma summaries by concession and by sampling round are included in appendix IV.

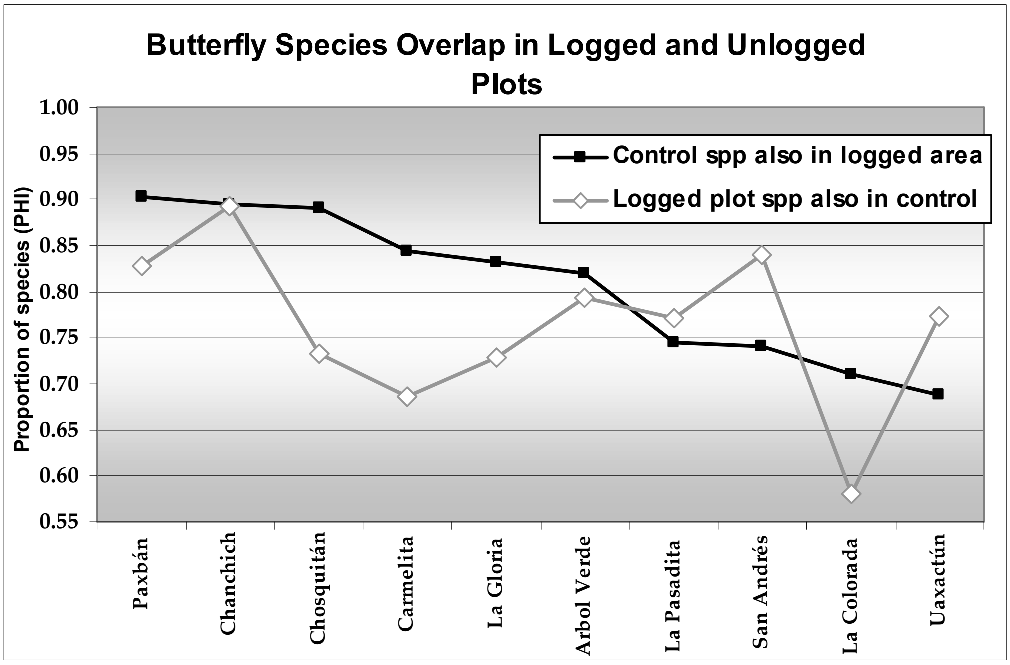

Figure 23. Proportion of species overlap between logged and unlogged plots in ten forest concessions.

Mean values for the Morisita-Horn similarity index ranged from 0.95 in Uaxactún to 0.60 in Chanchich. Due to anomalous weather conditions and subsequent low capture rates, some concessions experienced extremely low similarity estimates. It is therefore useful to examine the maximum similarity index of the four sampling rounds, which ranged from 1.0 in Uaxactún, Chosquitan, and Arbol Verde, to 0.78 in Chanchich.

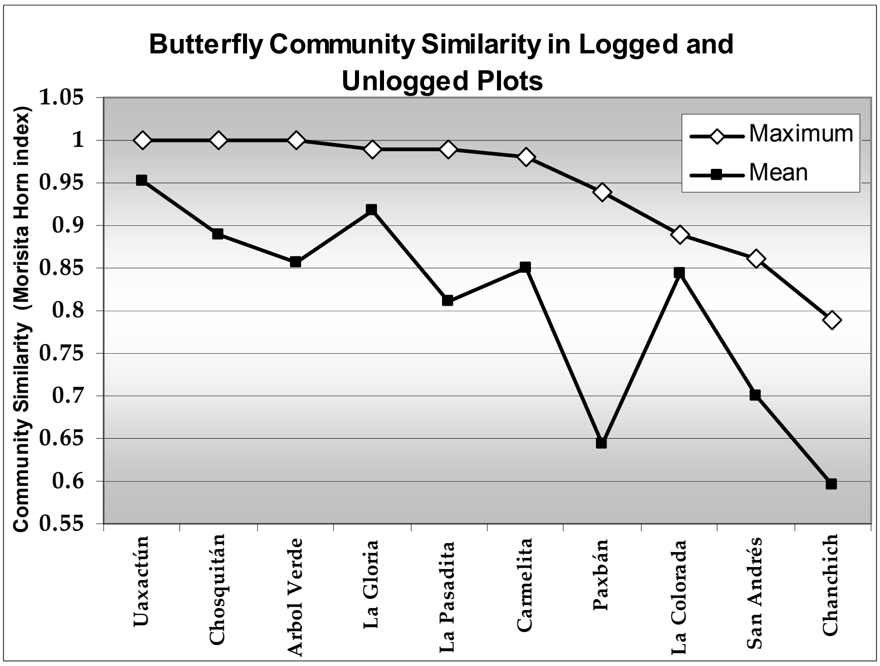

Figure 24. Maximum and mean butterfly similarity across four sampling rounds

Temporal Variation

Figure 25 shows altLambda, an estimator for the relative species richness in logged areas as compared with unlogged areas. Sampling sessions one and four occurred in the winter, when most butterflies are inactive, while sessions two and three occurred during the warm, rainy season, when butterfly richness and abundance are at their peaks. Species richness is especially higher in logged areas during sessions one and four, suggesting especially greater activity in logged areas than in unlogged areas during the winter.

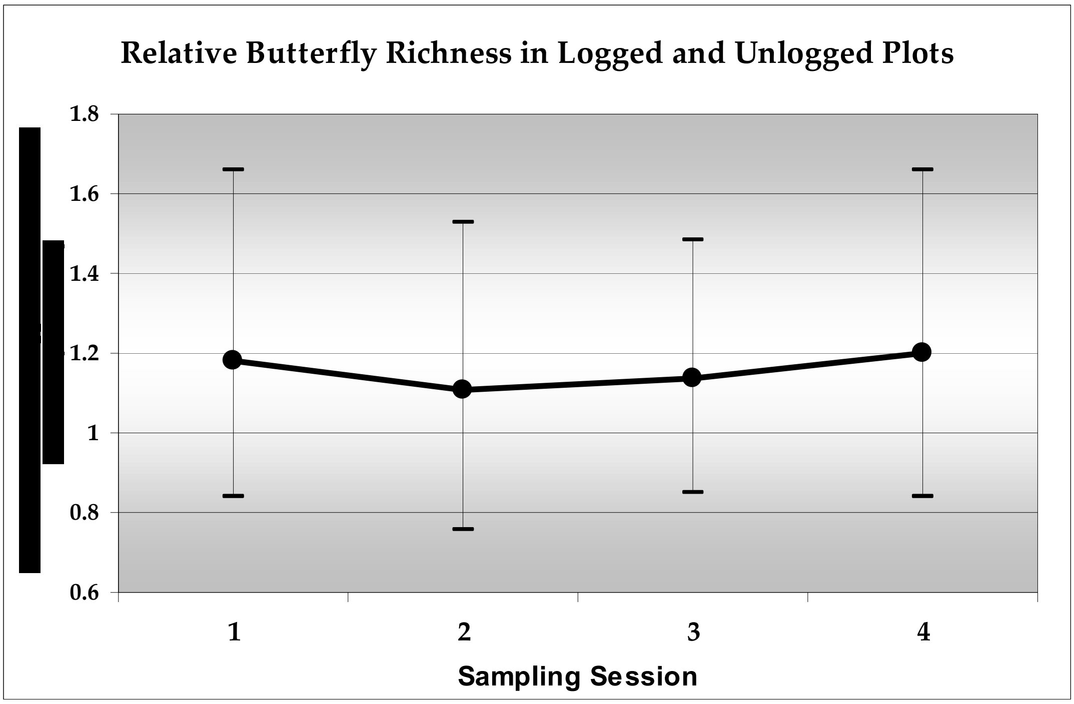

Figure 25. Relative species richness in logged versus unlogged plots, as estimated by altLambda

Ecological Explanations for Community Differences

Significant differences were found in the number of individuals and species per family between logged and unlogged treatments. In logged areas, more individuals of the families Nymphalidae, Pieridae, Papilionidae, and Lycaenidae and more species of Nymphalids and Pierids were encountered. Pierids, Papilionids, and some Nymphalid species are open area specialists, only found in clearings, roads, and tree fall gaps. Structural disturbance caused by logging is likely the cause of increases in these families.

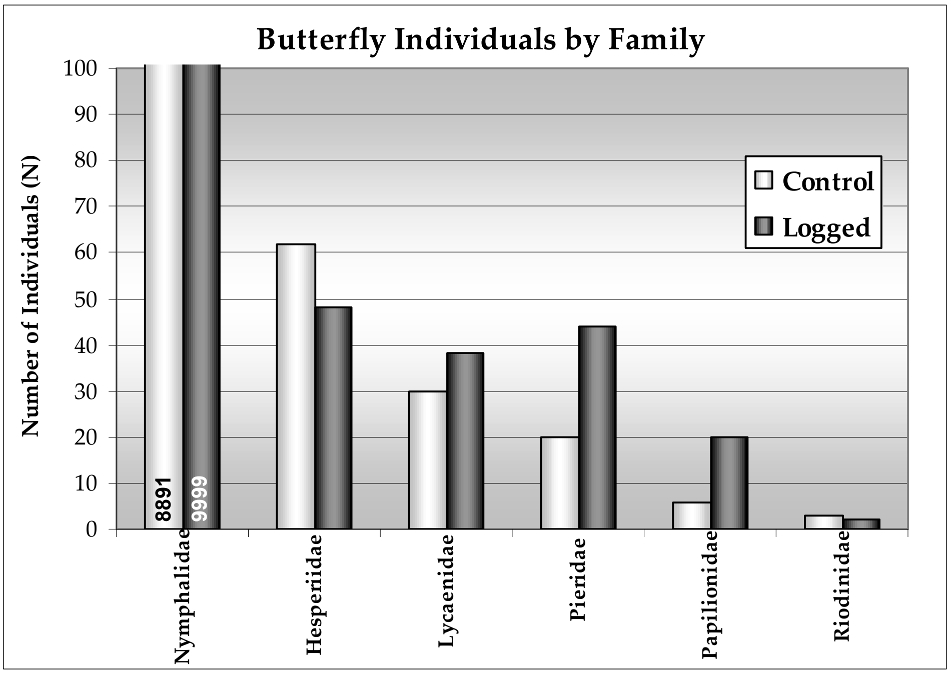

Figure 26. Number of butterflies per family observed in logged and unlogged areas

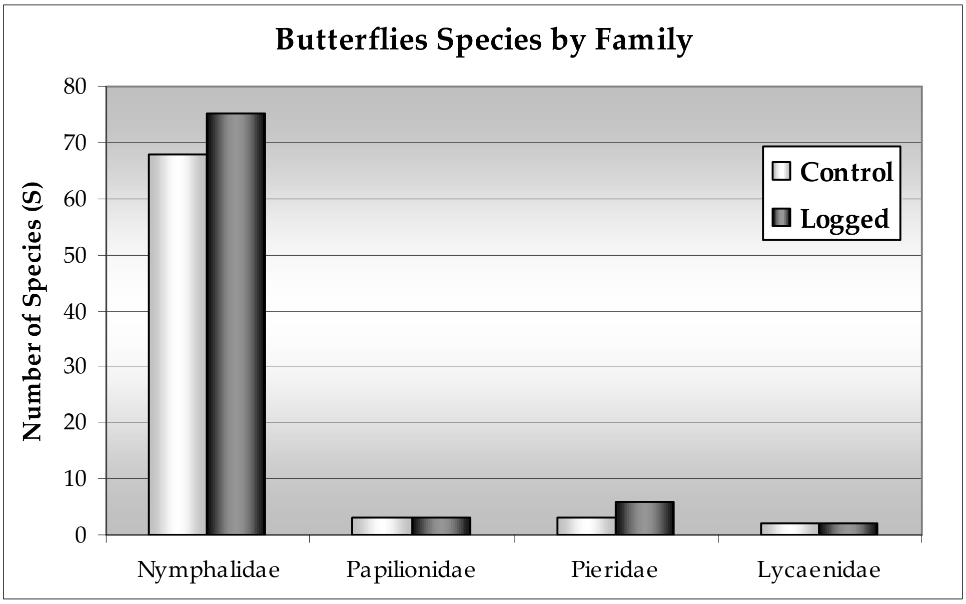

Figure 27. Number of butterfly species per family observed in logged and unlogged areas

In logged areas, more medium and small butterflies were encountered than in unlogged areas. The number of individuals and species of large butterflies remained constant. This may reflect the fact that most very large butterflies are forest interior fruit-feeders.

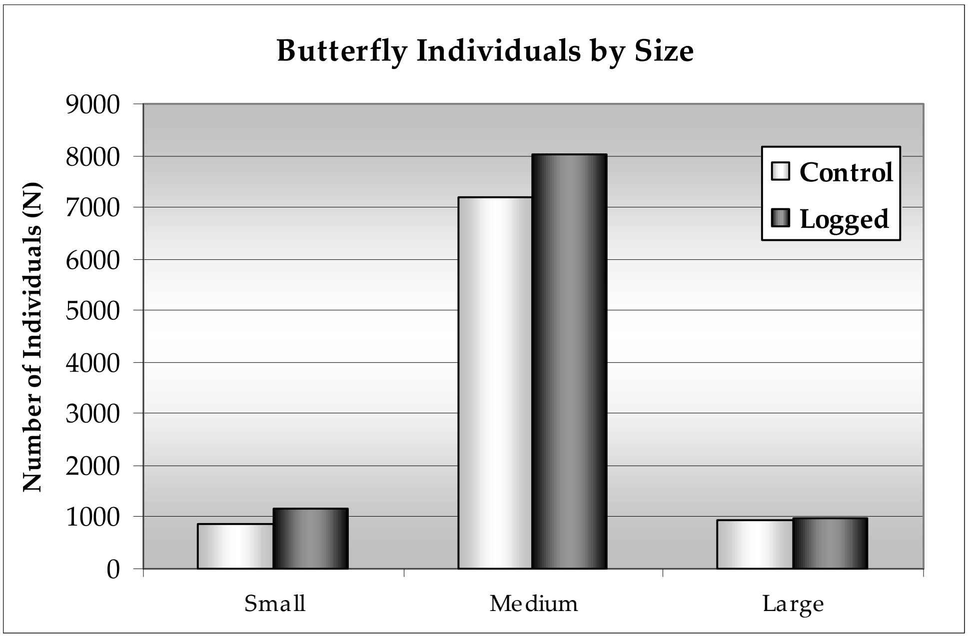

Figure 28. Number of butterflies per size class observed in logged and unlogged areas

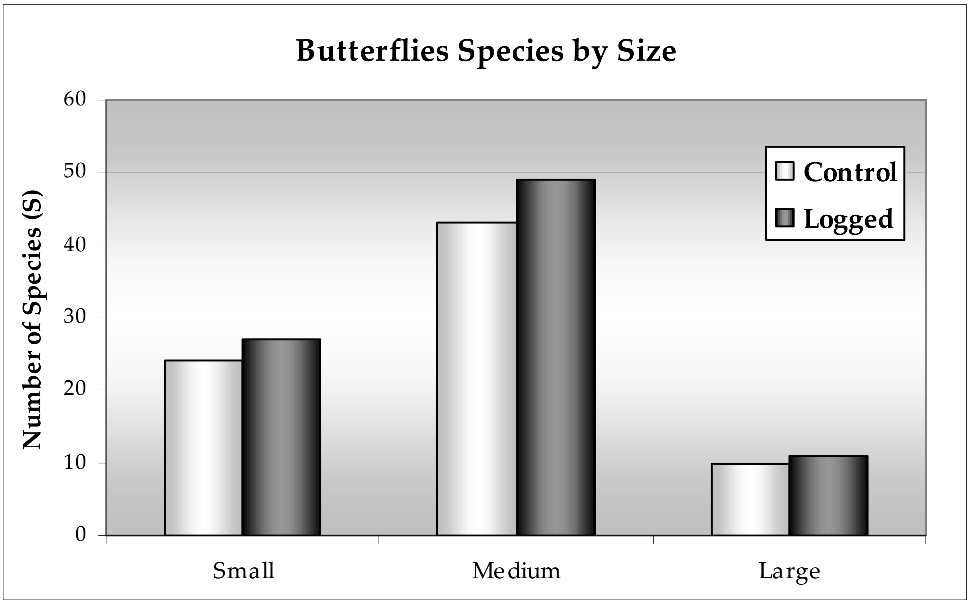

Figure 29. Number of butterfly species per size class observed in logged and unlogged areas

Butterflies showed slightly different responses in logged and unlogged areas depending on their color pattern (Figures 30, 31). Most notably, more obliquely-banded individuals and species were encountered in logged areas, largely due to higher encounter rates of *Opsiphanes cassina*. More sulphur-white species and fewer sand-patterned species were encountered in logged areas.

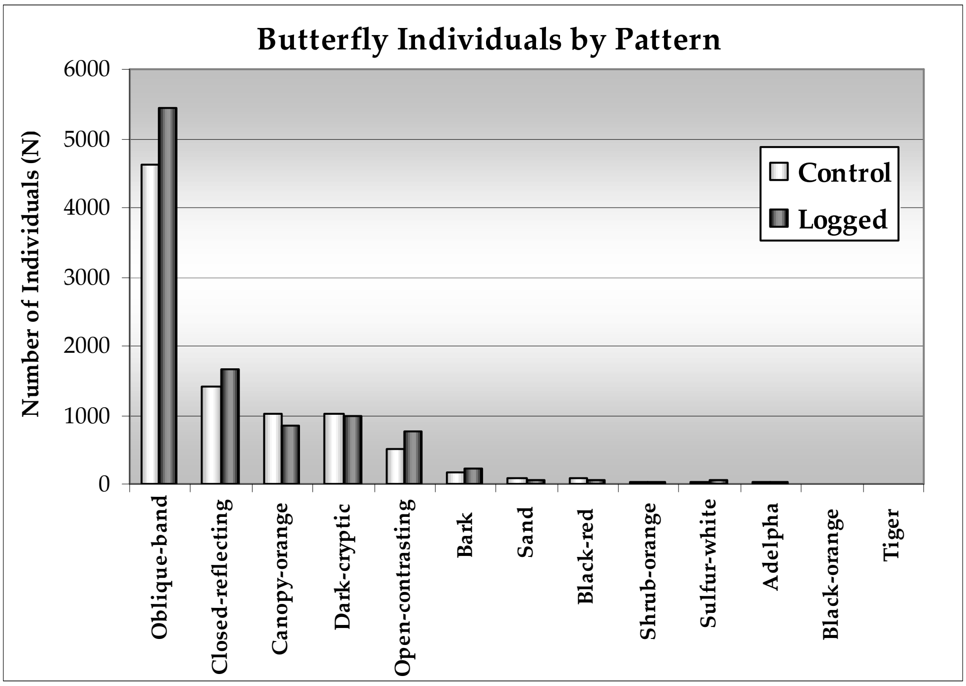

Figure 30. Number of butterflies with distinct patterns observed in logged and unlogged areas

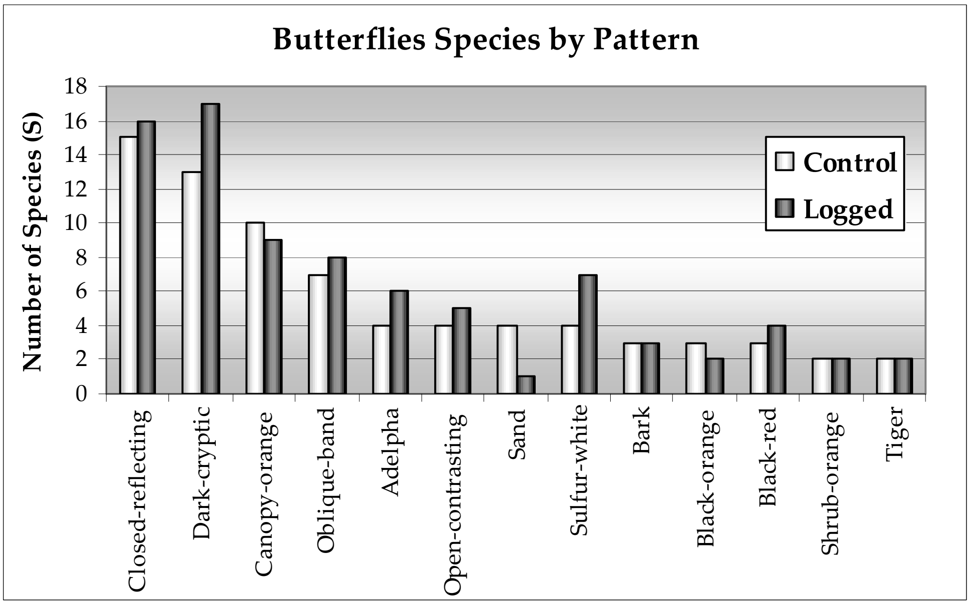

Figure 31. Number of butterfly species with distinct patterns observed in logged and unlogged areas

In logged areas, more butterfly individuals were encountered that use palms (*Arecaceae*) as host plants. Although the number of individuals encountered was similar, more species that use the host plant family *Poaceae* as their main food source were encountered in logged areas. This may be due to the proliferation of many species of grasses in roads and tree fall gaps.

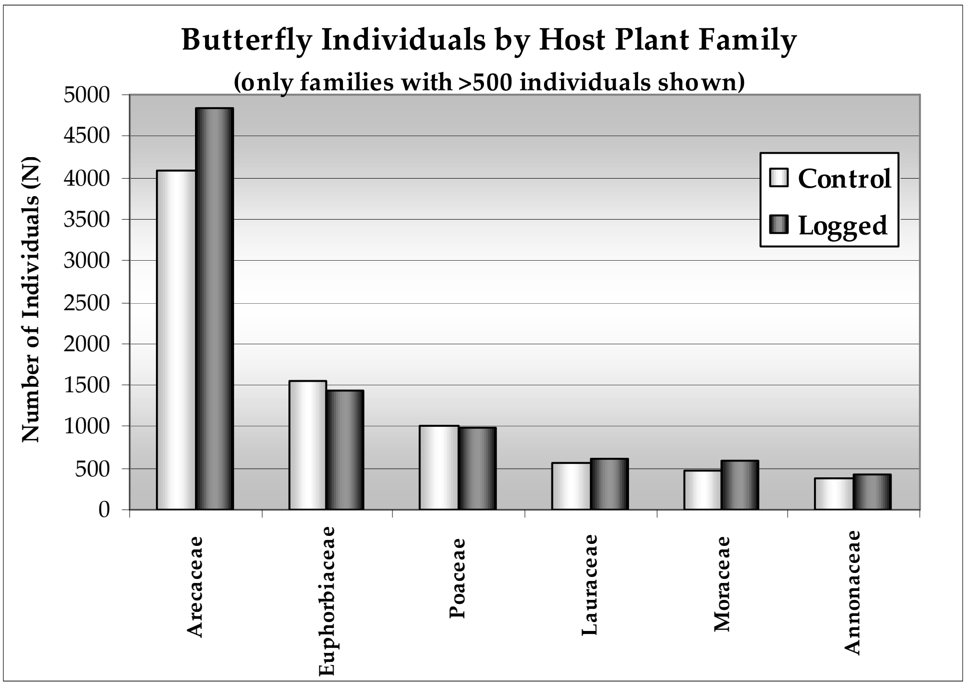

Figure 32. Number of butterflies by host plant family observed in logged and unlogged areas

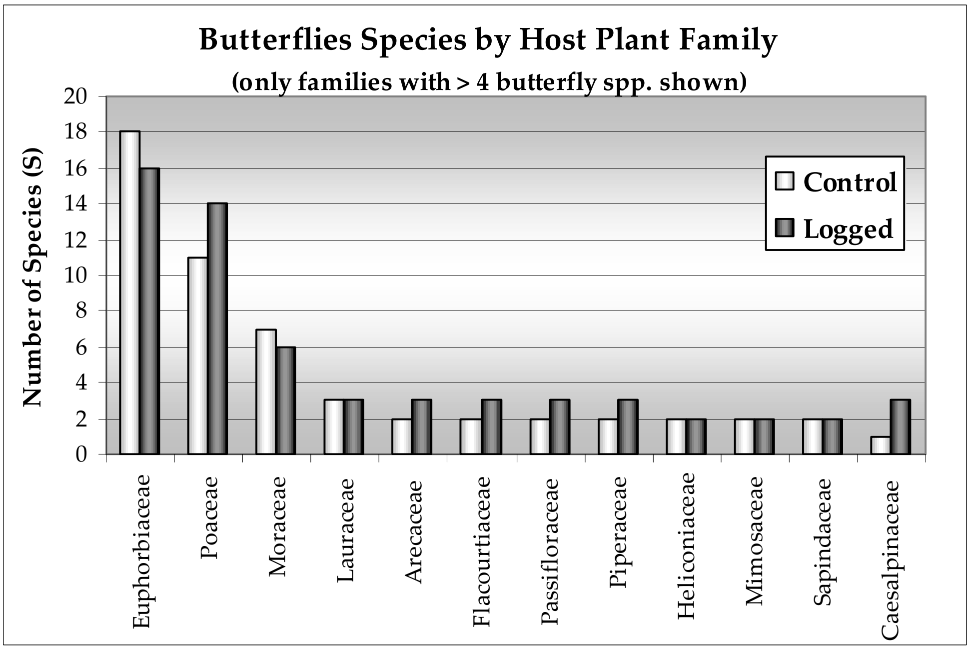

Figure 33. Number of butterfly species by host plant family observed in logged and unlogged areas

Dung Beetles

In total, 29,381 individuals of 40 species were captured during the study period. In unlogged areas, 15,504 individuals of 39 species were trapped. In unlogged areas, 13,807 individuals of 38 species were captured.

Species Richness

In six of the concessions, dung beetle species richness was higher in unlogged areas than in unlogged areas, while in the other four concessions the pattern is reversed (Figure 34). Interestingly, where species richness was high in control plots, it tended to be lower in logged plots.

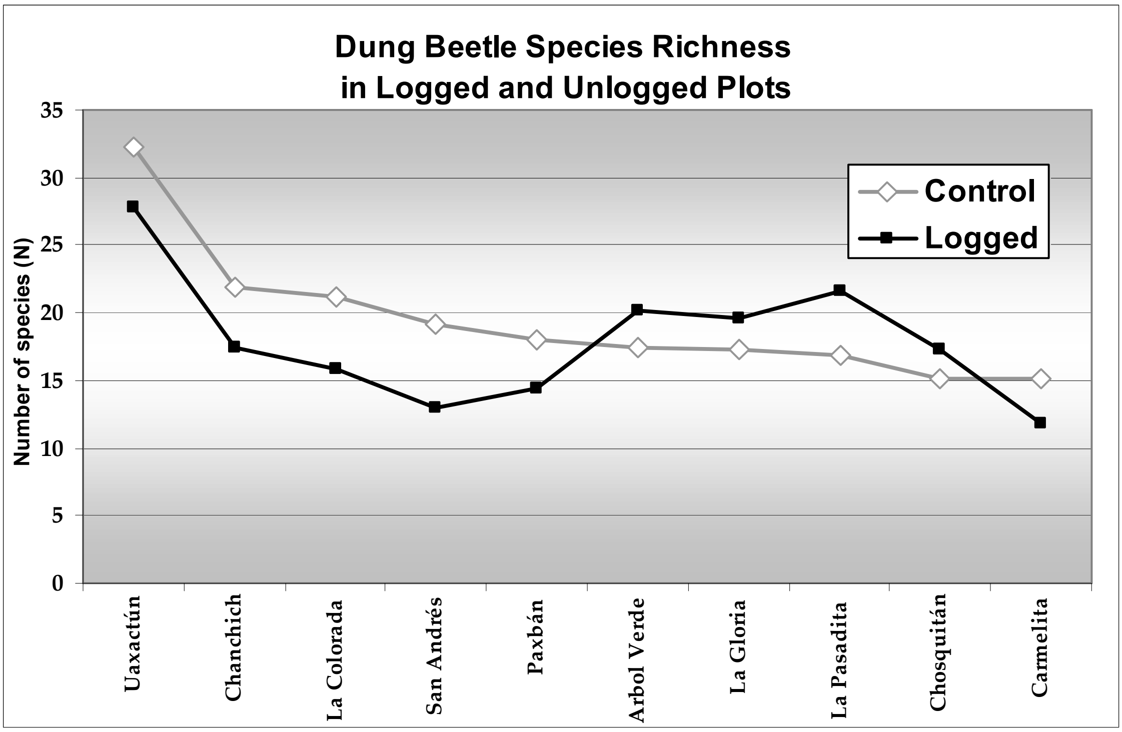

Figure 34. Observed number of species in logged and unlogged plots. Note that these are observed data, and not richness estimates as for birds and butterflies above.

Similarity of Communities

Mean values for the Morisita-Horn similarity index ranged from 0.93 in Uaxactún to 0.78 in Chanchich (Figure 35). During the dry season (sampling sessions 1 and 4), communities in logged and unlogged areas were more dissimilar than in the wet season (sampling sessions 2 and 3). This may be an effect of low sample sizes and low species richness estimates in the dry season, when many beetle species are inactive.

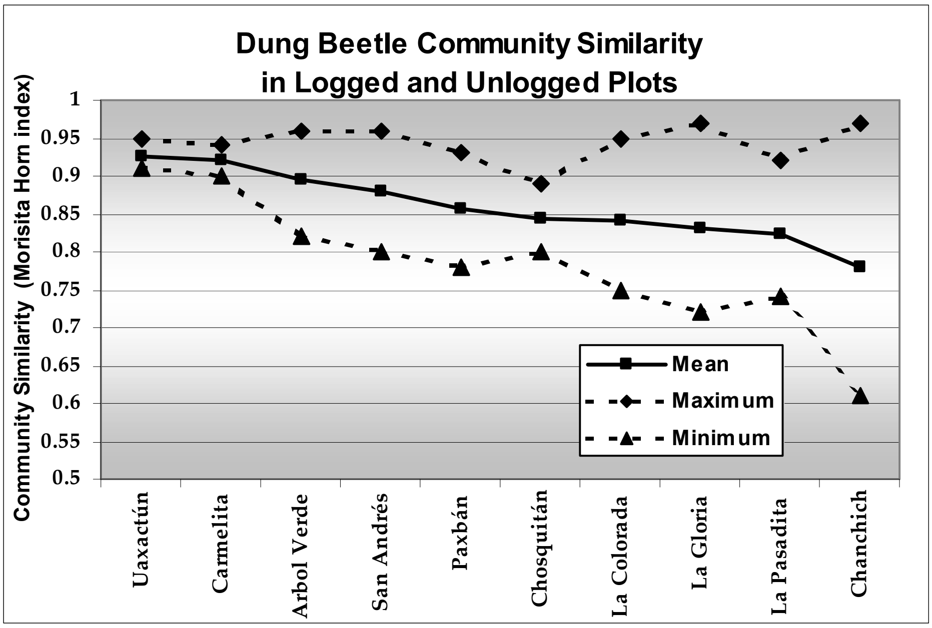

Figure 35. Morisita-Horn index for dung beetle community similarity. Only samples with greater than 5 species were included in figure.

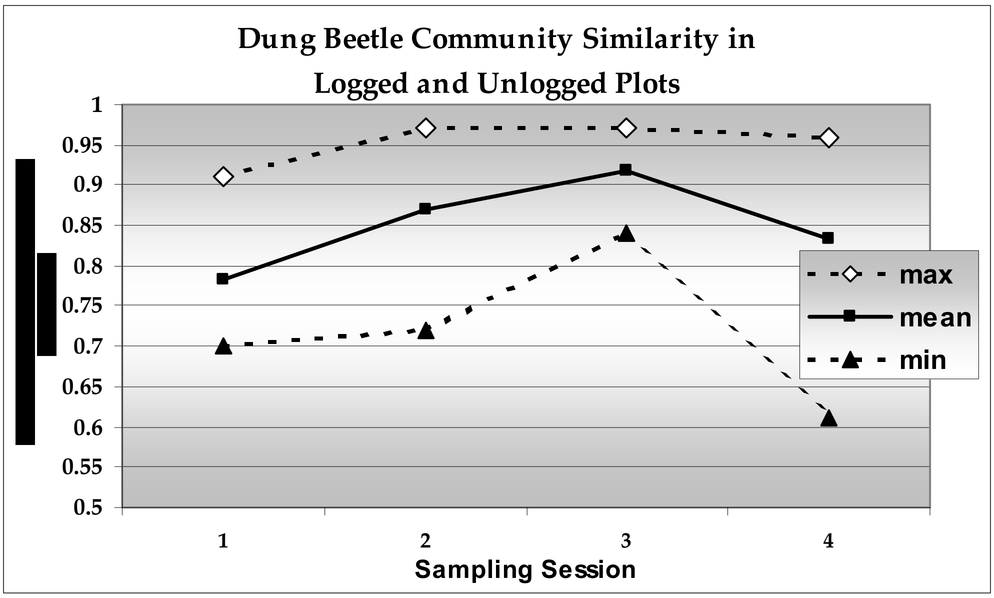

Figure 36. Morisita-Horn index for dung beetle community similarity over time.

Drivers of Ecological Change in Logged Areas

Above, we examined community differences between logged and unlogged areas for different animal groups. This section examines the attributes of logged areas that correlate with those community changes. Please note that correlation does not necessarily imply causality. In some cases, correlation may be due to covariance between variables.

For example, human access may correlate well with the presence of open-area specialist butterflies. However, it is not direct human influence that affects butterfly communities, but rather the forest cover change and forest fires that are often found in areas of high human access. Correlations should be interpreted carefully with all other evidence and should take into consideration the life histories of different groups.

Logging Intensity and Forest Structure

Logging intensity shows a significant relationship with several forest structure and microclimate parameters. For example, nearly 40% of the difference in percentage canopy openness between paired logged and unlogged plots is explained by the volume of timber extracted per hectare ($p = 0.05$) (Figure 37).

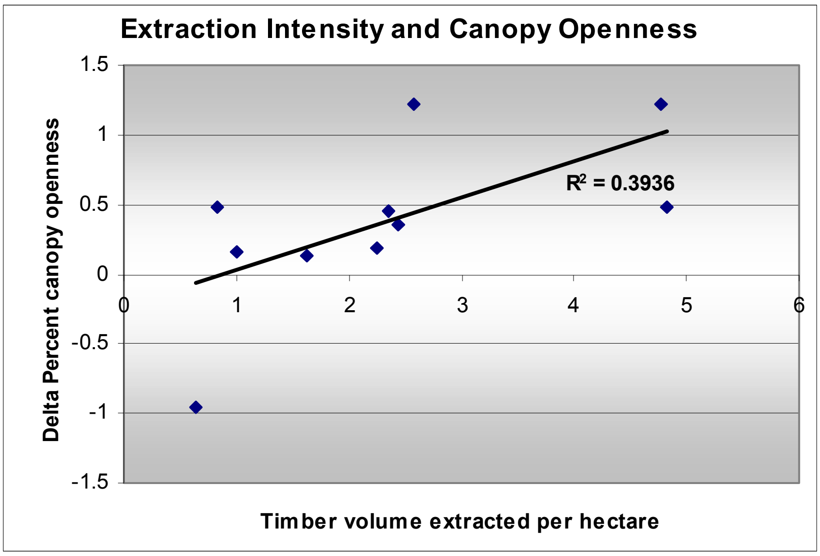

Figure 37. Difference in percentage canopy openness between paired logged and unlogged plots as a function of logging intensity.

Nearly 60% of the variation in canopy height differences between paired logged and unlogged plots is explained by timber harvest intensity (p = 0.01) (Figure 38).

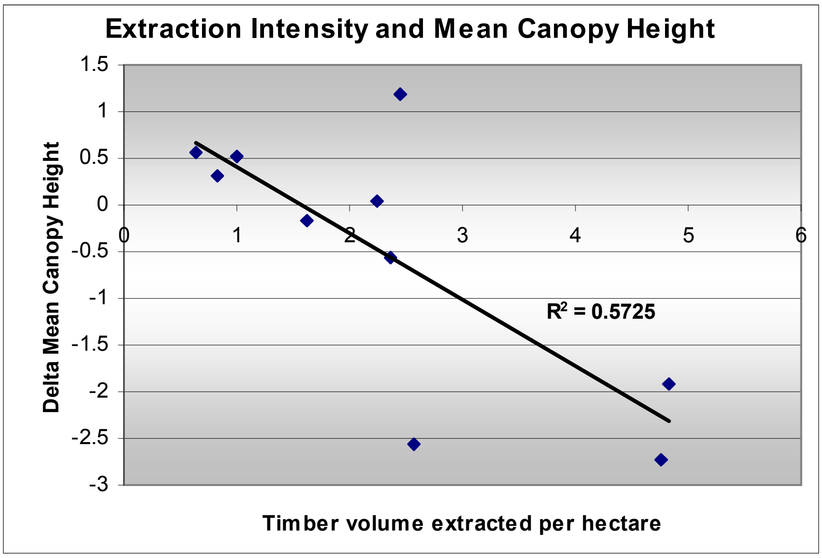

Figure 38. Difference in mean canopy height between paired logged and unlogged plots as a function of logging intensity.

Nearly 50% of the variation in soil temperature differences between paired logged and unlogged plots is explained by timber harvest intensity (p = 0.02) (Figure 39).

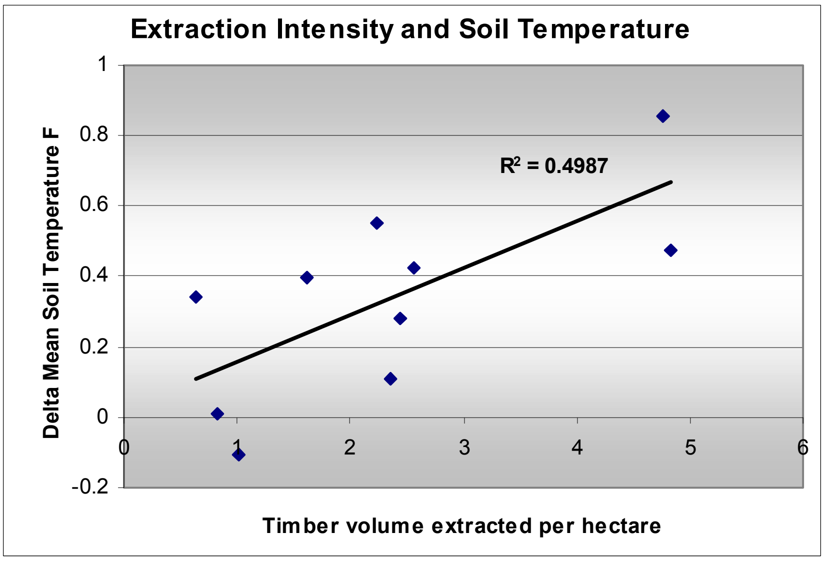

Figure 39. Difference in mean soil temperature between paired logged and unlogged plots as a function of logging intensity.

Logging Intensity and Animal Communities

Logging intensity also demonstrates significant relationships with animal community changes (Table 12). Game species, birds, and butterflies showed significant trends with respect to the number of trees extracted per hectare.

Table 12. P-values for linear regression models between timber extraction intensity and faunal similarity measurements between paired logged and unlogged plots.

	Trees extracted per hectare	Volume (m^3) extracted per hectare
Game species density (logged-unlogged)	**0.03**	**0.00**
Howler monkey density (logged-unlogged)	0.65	0.30
Birds phi (% unlogged area spp in logged area)	0.45	0.81
Bird similarity (Morisita-Horn)	**0.10**	0.37
Butterflies phi (% unlogged area spp in logged area)	0.24	0.31
Butterfly similarity (Morisita-Horn)	**0.09**	0.16
Beetle similarity (Morisita-Horn)	0.82	0.35

Almost 70% of the variation in game species differences between paired logged and unlogged plots is explained by timber harvest intensity ($p = 0.001$) (Figure 40).

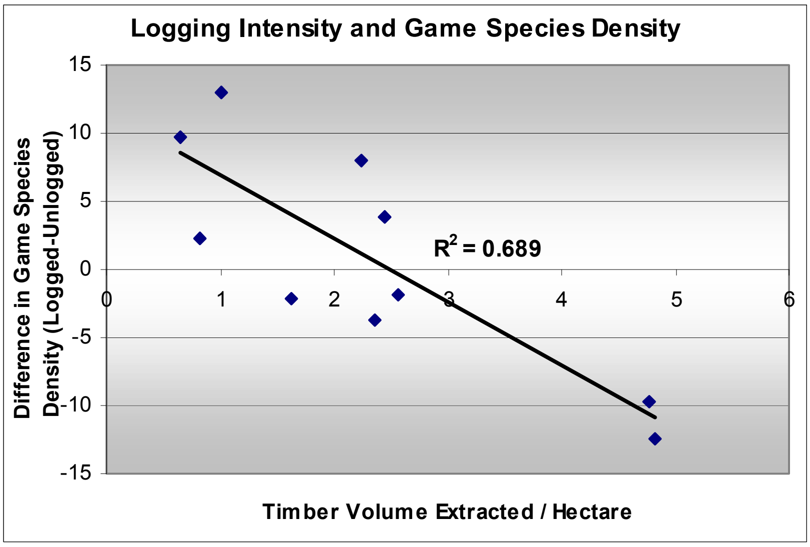

Figure 40. Difference in game species density between paired logged and unlogged plots as a function of logging intensity.

Thirty percent of the variation in bird community similarity between paired logged and unlogged plots is explained by timber harvest intensity (p = 0.10) (Figure 41).

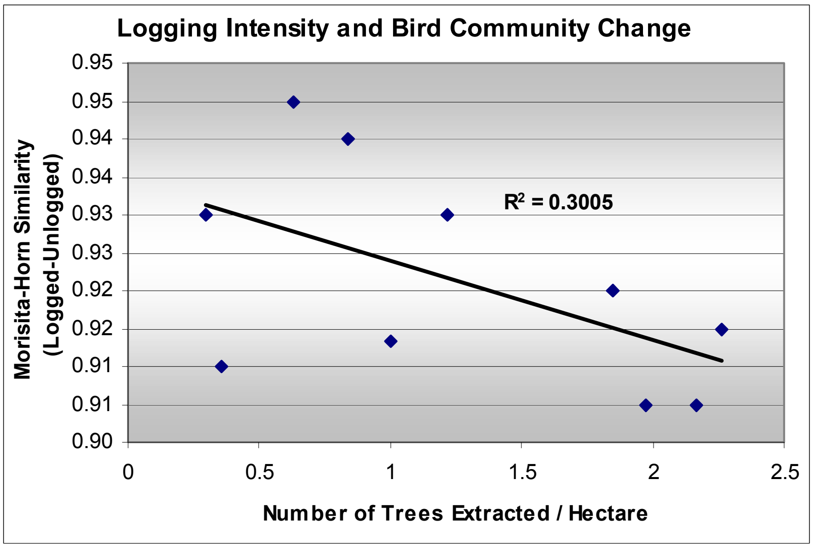

Figure 41 Difference in bird community similarity (Morisita-Horn index) between paired logged and unlogged plots as a function of logging intensity.

Slightly more than 30% of the variation in butterfly community similarity between paired logged and unlogged plots is explained by timber harvest intensity (p = 0.09) (Figure 42).

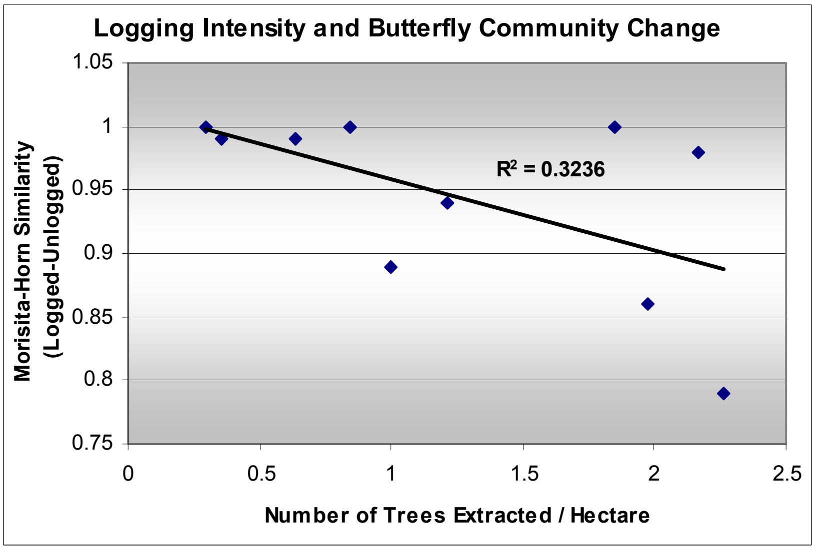

Figure 42. Difference in butterfly community similarity (Morisita-Horn index) between paired logged and unlogged plots as a function of logging intensity.

Forest Structure and Animal Communities

Much of the relationship between logging intensity and faunal responses is probably due to the structural and microclimatic impacts of logging. Logging may also cause threshold changes that do not correlate with logging intensity, but exist in any logged area regardless of the intensity of extraction. This section explores the relationships between structural and microclimatic changes and subsequent faunal responses.

Two forest structure parameters correlate especially well with logging impacts on fauna: percent canopy openness and canopy height. Significant relationships exist between these two parameters and game species, butterfly, and dung beetle community changes (Table 13). Only birds showed no trend with respect to these changes. Birds showed a significant relationship at the conservative 10% level with change in the number of seedlings (p = 0.09). Where logged areas contained more seedlings than unlogged areas, bird communities were more dissimilar.

Table 13. P-values for linear regression models between forest structure and microclimate parameters and faunal similarity measurements between paired logged and unlogged plots.

	Game spp density change	Bird similarity	Butterfly similarity	Beetle similarity
Canopy openness (%)	**0.06**	0.18	**0.04**	**0.09**
Mean canopy height (m)	**0.01**	0.50	**0.03**	**0.06**
Max canopy height (m)	**0.02**	0.57	**0.02**	**0.06**
Max emergent height (m)	**0.10**	0.98	**0.04**	0.15
Seedlings (<5cm DBH)	0.14	**0.09**	**0.01**	0.73
Saplings (5-10cm DBH)	0.68	0.79	**0.05**	0.17
Dead standing trees	0.81	0.99	0.68	0.29
Dead fallen trees	0.27	0.14	0.51	0.87
Leaf litter depth (cm)	0.65	0.85	0.63	0.46
Air temperature (degrees F)	0.72	0.58	0.96	0.26
Air humidity (%)	0.46	0.73	0.53	0.34
Air speed (km/hr)	0.29	0.23	0.75	0.90
Soil temperature (degrees F)	0.11	0.89	0.19	0.74
Soil humidity (%)	0.46	0.63	0.87	**0.08**

Context of Logged Area and Animal Communities

In order to determine the composition of an ecological community, it is often important to look beyond immediate habitat characteristics and consider a greater context. This may be especially important in the Maya Biosphere Reserve, where five-year logging plans often slate harvests contiguous to previously logged areas, thereby increasing the effective harvested areas several fold. Table 14 shows the p-values for linear regression models between logging context and fauna.

Table 14. P-values for linear regression models between percent logged area surrounding logged study plot and faunal similarity measurements between paired logged and unlogged plots.

	Percent logged area in 1 km buffer	Percent logged area in 2 km buffer	Percent logged area in 5 km buffer
Game species density (logged-unlogged)	0.56	0.87	0.65
Howler monkey density (logged-unlogged)	0.66	0.46	0.85
Birds phi (% unlogged area spp in logged area)	**0.03**	**0.05**	0.11
Bird similarity (Morisita-Horn)	0.47	0.66	0.68
Butterflies phi (% unlogged area spp in logged area)	0.43	0.32	0.11
Butterfly similarity (Morisita-Horn)	0.76	0.31	0.89
Beetle similarity (Morisita-Horn)	0.80	0.73	0.80

For birds, logging context predicts phi fairly well ($R^2 = 0.48$, $p = 0.03$) (Figure 43). This suggests that the context around a logged area may play a more important role in determining the proportion of species excluded from logged areas than the parameters of the logged areas themselves. The number of hectares burned around a logged area also correlates well with bird community similarity ($R^2 = 0.60$, $p = 0.01$) (Figure 44).

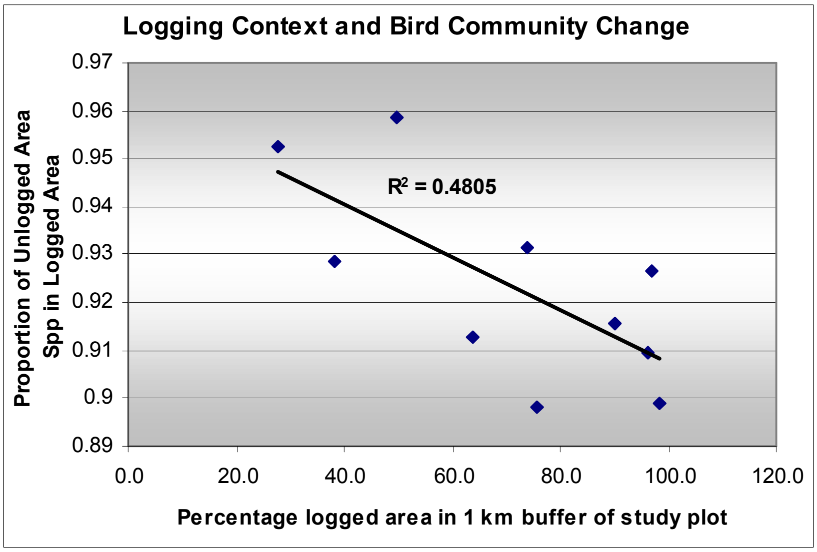

Figure 43. The proportion of species in unlogged areas also found in logged areas as a function of the amount of logged area surrounding the logged plot.

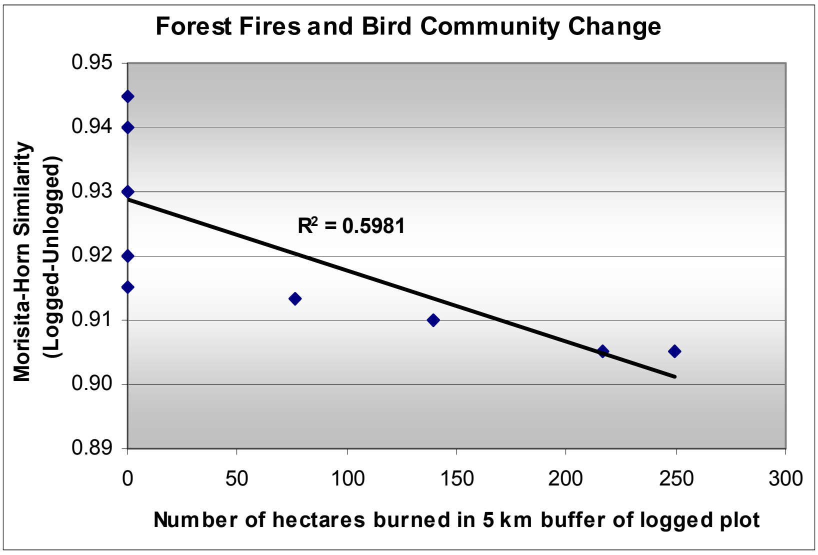

Figure 44. Bird community similarity as a function of area burnt by forest fires surrounding logged areas

Correlation of Faunal Responses

It has often been argued that faunal responses to threats vary so differently that indicator groups may not indicate much about ecological integrity as a whole. In this section, faunal responses are compared with one another through correlation and graphical analysis to examine their utility in making general predictions.

Table 15 gives correlation coefficients between all combinations of indicators.In general, game species density change best correlates with all other similarity indices (Figure 46). Morisita-Horn similarity indices also tend to correlate well with each other. Only game species density change correlates well with howler monkey density change (Figure 45).

Table 15. Correlation coefficients for different faunal indicators

	Beetle Similarity	Butterfly Similarity	Butterfly phi	Bird Similarity	Bird phi	Howler Monkey change	Game spp change
Beetle Similarity	*						
Butterfly Similarity	0.51	*					
Butterfly phi	-0.36	-0.09	*				
Bird Similarity	0.10	0.44	0.06	*			
Bird phi	0.22	0.21	-0.37	0.47	*		
Howler Monkey change	0.14	0.01	-0.26	0.11	0.31	*	
Game spp change	0.47	0.56	-0.36	0.55	0.24	0.65	*

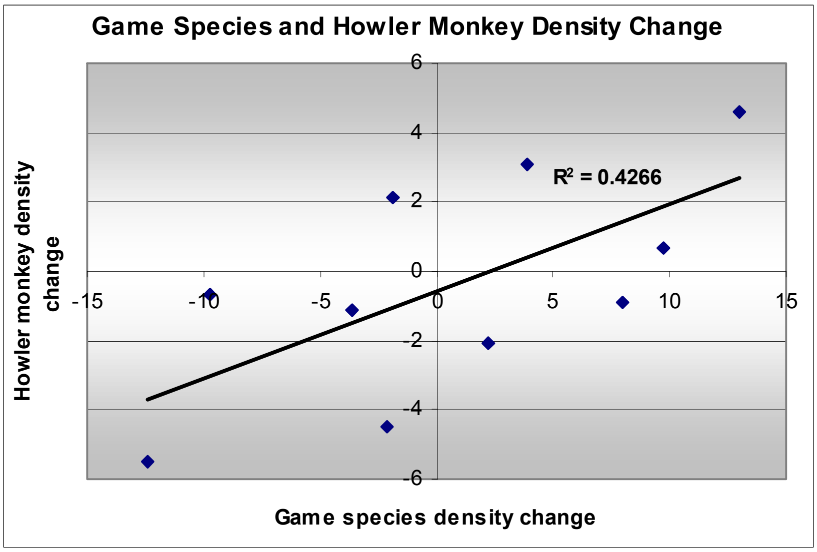

Figure 45. Density change of howler monkeys (*Alouatta pigra*) as a function of game species density change

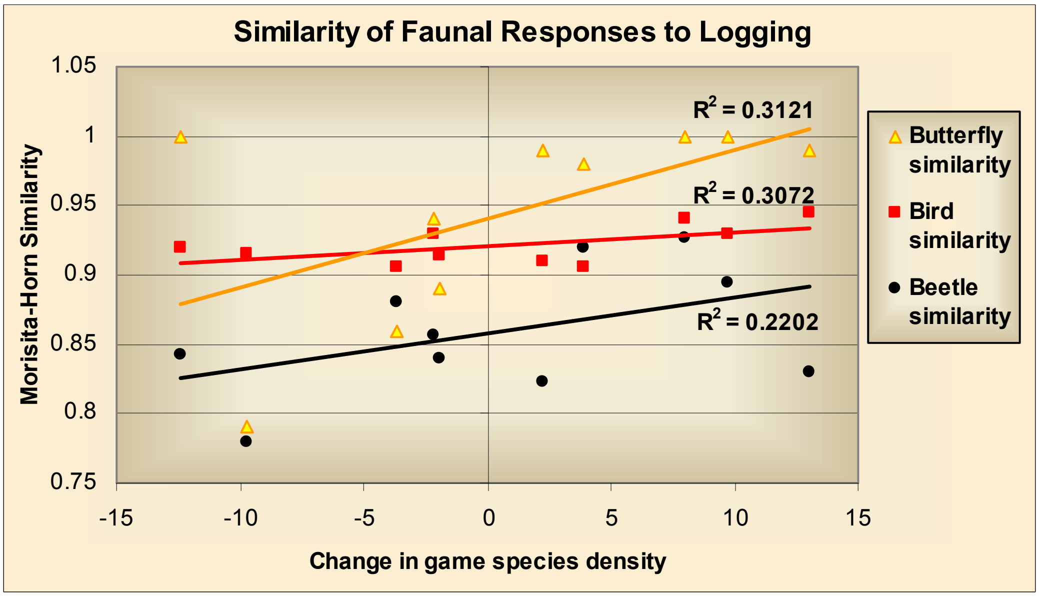

Figure 46. Butterfly, bird, and dung beetle similarity indices as a function of game species density change between logged and unlogged areas.

Conclusions

Logging in the Maya Biosphere Reserve is conducted at some of the lowest intensities worldwide and with improved management techniques such as directional felling, road planning, liberation of lianas, and use of lightweight machinery. If logging can ever be sustainable and ecologically undisruptive, these are the conditions under which it should be possible. Three years after timber extraction, we found that ecological impacts of such low-impact harvests are minor and relatively harmless. Furthermore, logging has provided incentives for responsible community-based management - a conservation strategy that may be the best option for maintaining wilderness and wildlife in high-pressure tropical environments.

Several physical impacts of logging were found to be significant. In general, logged areas showed greater canopy openness, lower canopy height, a higher density of seedlings, and a higher density of dead fallen trees than unlogged areas. These structural changes probably drive microclimatic changes, causing logged areas to be warmer and drier than their unlogged counterparts.

Several significant faunal responses to logging were found. Of the large vertebrates, only the mantled howler monkey (*Alouatta pigra*) was found at significantly lower rates in logged areas. However, density changes did not correlate with any structural or contextual parameters of logged areas. Whether density differences are due to the effects of logging or other confounding factors should be further examined, especially in light of the species' recent upgrade from the IUCN status "Least Concern" to "Endangered".

The secondary effects of logging caused by increased access are often cited as a major threat to wildlife. Interestingly, no difference was found between logged and unlogged plots in terms of human presence during this study. This may reflect the forest culture of Petén, where hunters and non-timber forest product harvesters travel throughout the forest far from roads. Almost 70% of the logging impact on game species is explained by timber harvest intensity, suggesting that immediate structural changes are more important determinants of logging impacts on game species than increased access.

In general, bird, butterfly, and dung beetle similarity correlated well with logging intensity and/or structural and microclimatic changes caused by logging. Butterfly and beetle communities appear to respond strongly to immediately local changes while bird communities may be more heavily influenced by habitat quality at a wider scale.

Community dissimilarity appears to be driven mostly by the addition of new species in logged areas, rather than the exclusion of existing species. For birds and butterflies, logged areas tend to host more species than their unlogged counterparts. The difference is especially marked where logging intensity is high, canopy openness high, and canopy height low. The proportion of intact-forest species in logged plots tends to be equal or higher than the proportion of logged plot species in intact-forest plots. This evidence suggests that increased habitat heterogeneity caused by logging roads and gaps may attract new species, thereby increasing species richness.

It is not surprising that immediate logging impacts do not exclude forest-interior specialists since harvests typically affect less than 10% of logged areas. The exclusion of species from logged areas tends to correlate better with the context of the logged area. For example, in logged areas surrounded by other logged areas or burnt forest, fewer intact-forest bird species were encountered.

At current intensities, logging appears not to pose a major threat to the ecological integrity of the Maya Biosphere Reserve. On the contrary, logging operations create jobs for community members, thereby decreasing the likelihood of other, less conservation-friendly land-use practices. The protection of timber and non-timber forest resources also provides an incentive for community members to protect their concessions against forest fires, illegal logging, and illegal colonization.

However, forest managers should always operate under the precautionary principle due to incomplete knowledge of tropical ecology, uncertainty in ecological processes, and potential threshold effects. Many questions remain to be answered. For example, what are the cumulative effects over time of annual timber harvests? What ecological impacts would arise if logging intensity were to increase? It is dangerous to extrapolate beyond the scope of existing data. In order for timber extraction to be sustainable, managers and certifying organizations must make informed and wise decisions that reflect current scientific knowledge.

Management Recommendations

Given the above results, we suggest the following management recommendations:

- Always minimize canopy opening and road building as much as possible
- Close roads after harvests
- Use extra precaution in areas inhabited by species of special concern

Recommendations for Research and Monitoring

In order to make informed management decisions without sacrificing the profitability of logging, we suggest the following recommendations for research and monitoring:

- Further examine the effects of logging on mantled howler monkey populations
- If management techniques remain the same, do not spend resources on repeated annual evaluations. Medium- to long- term monitoring should be implemented to examine potential cumulative or threshold effects.
- Monitor impacts if logging intensity increases significantly (to > $5m^3$ / ha)

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Appendices

Appendix I. Forest structure summaries by concession

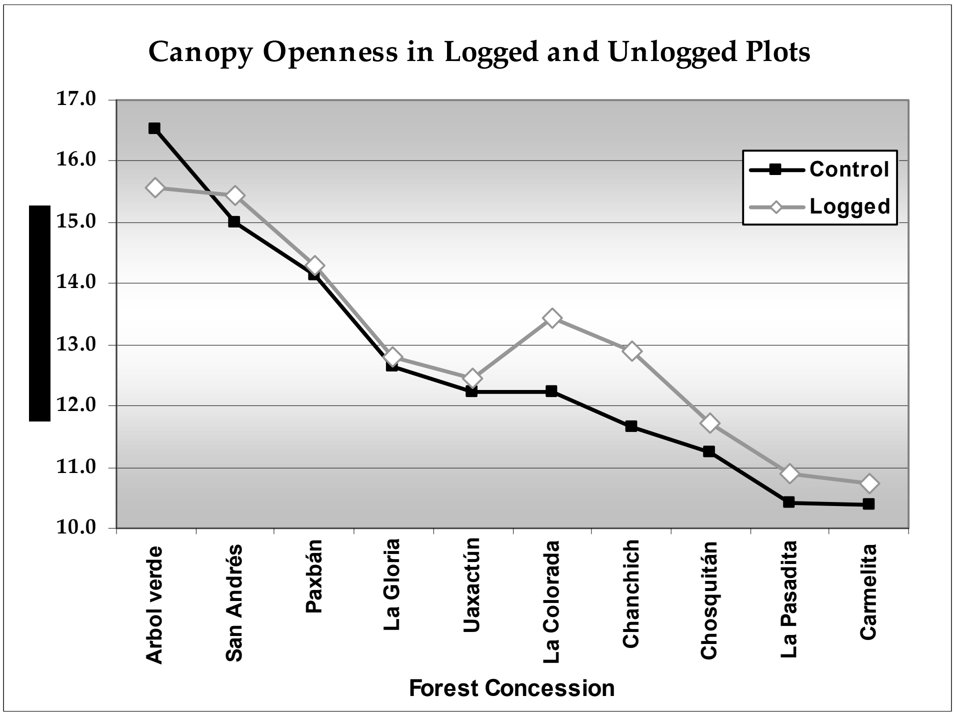
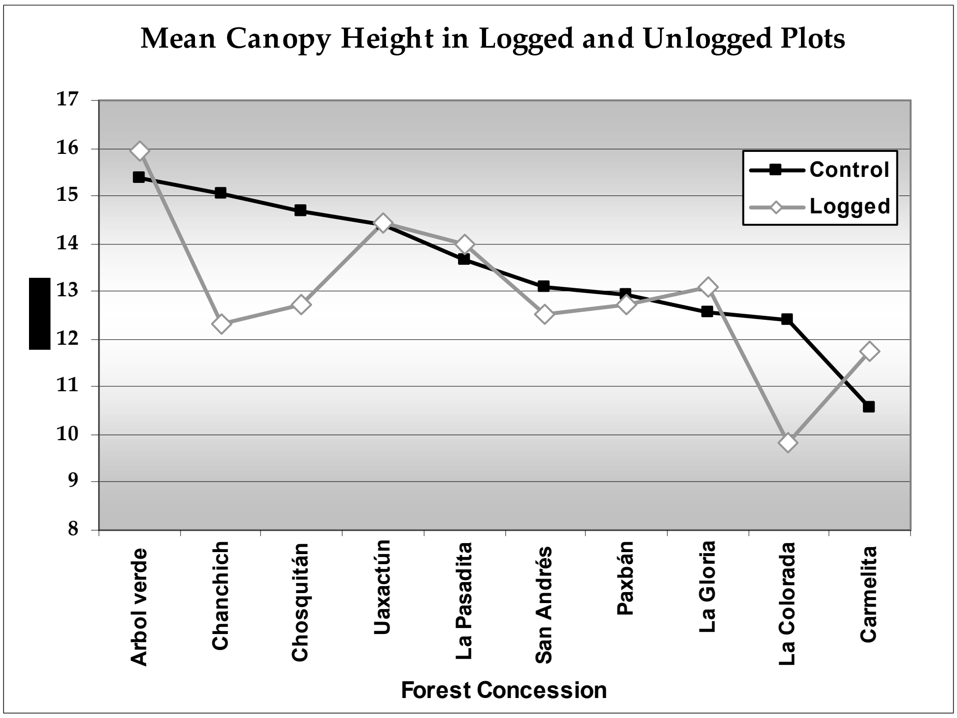


Figure 47



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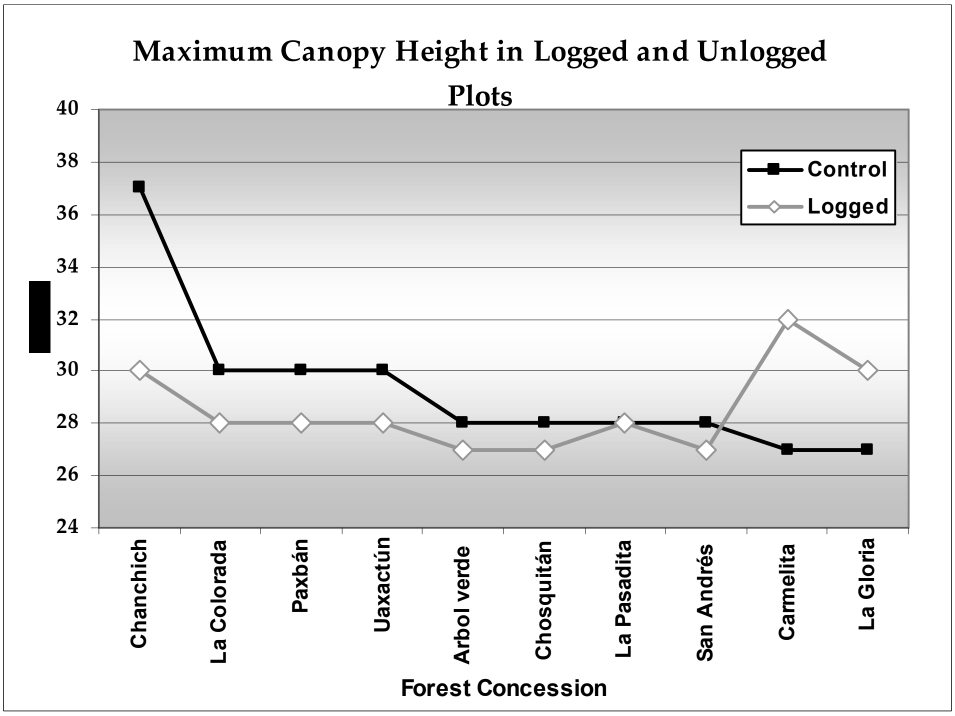

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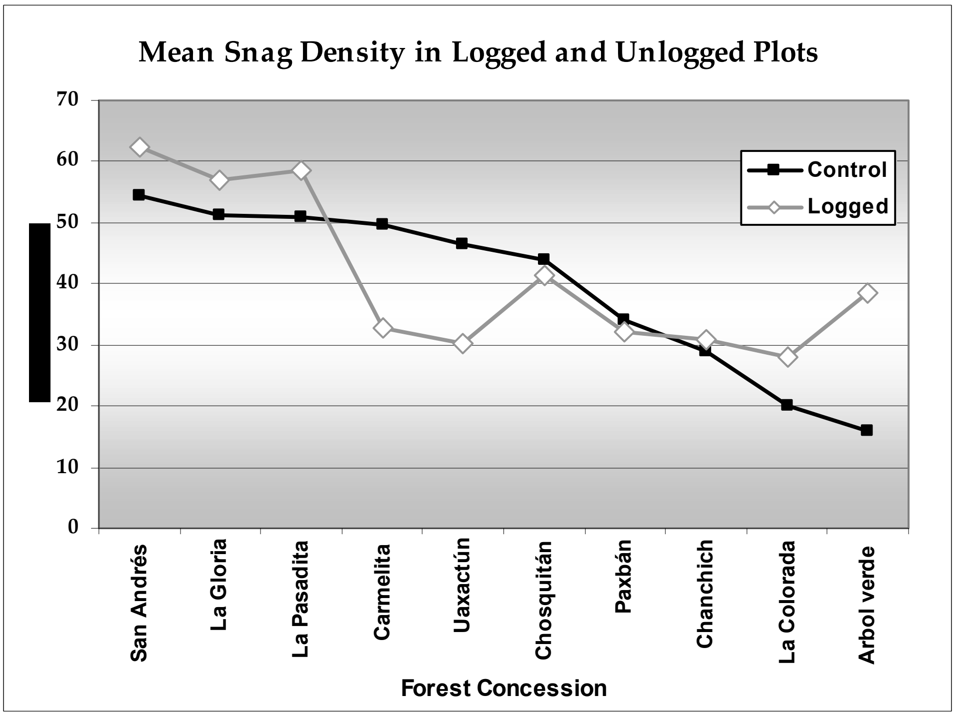

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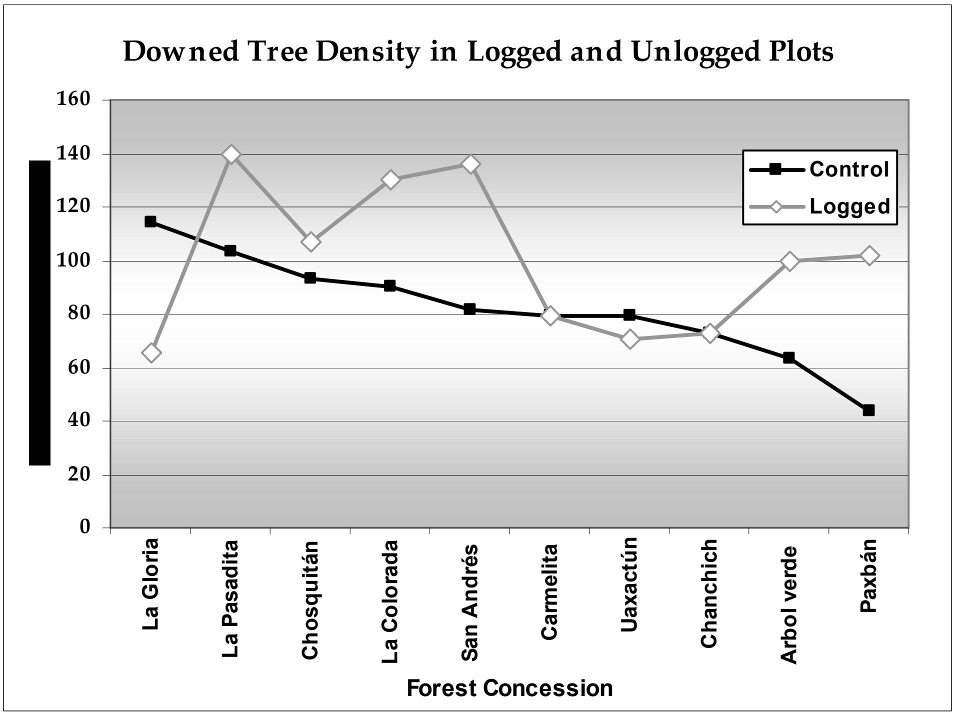

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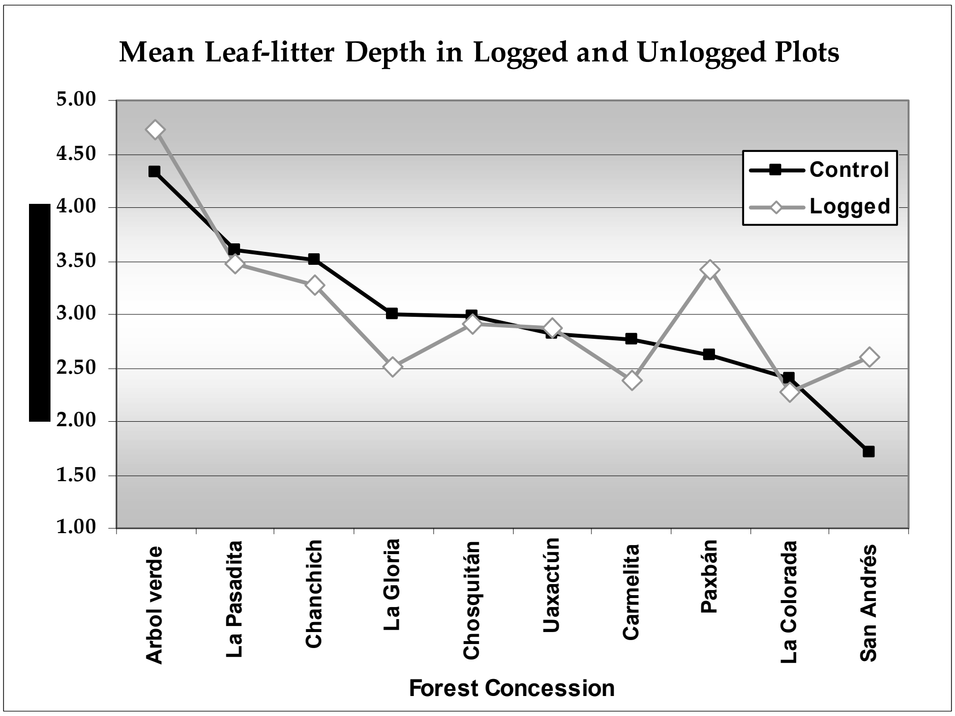

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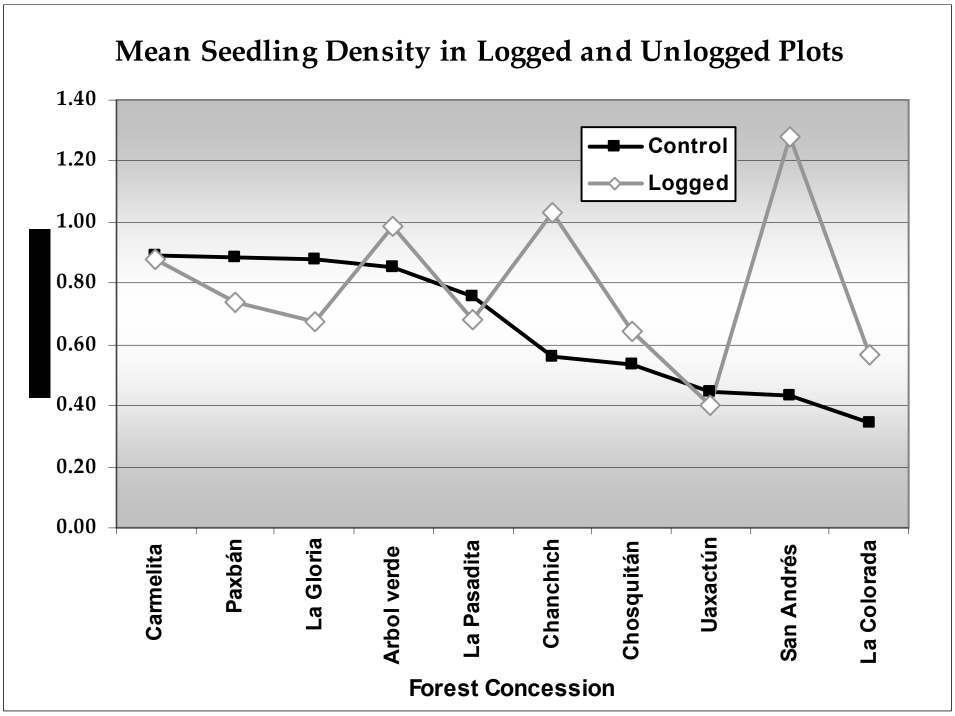

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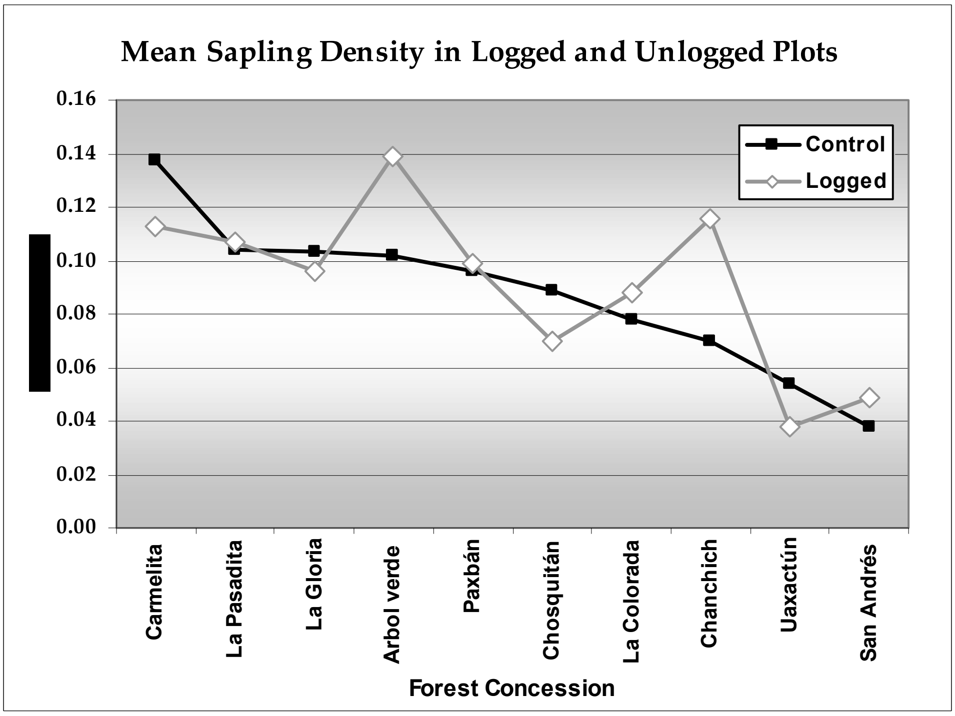
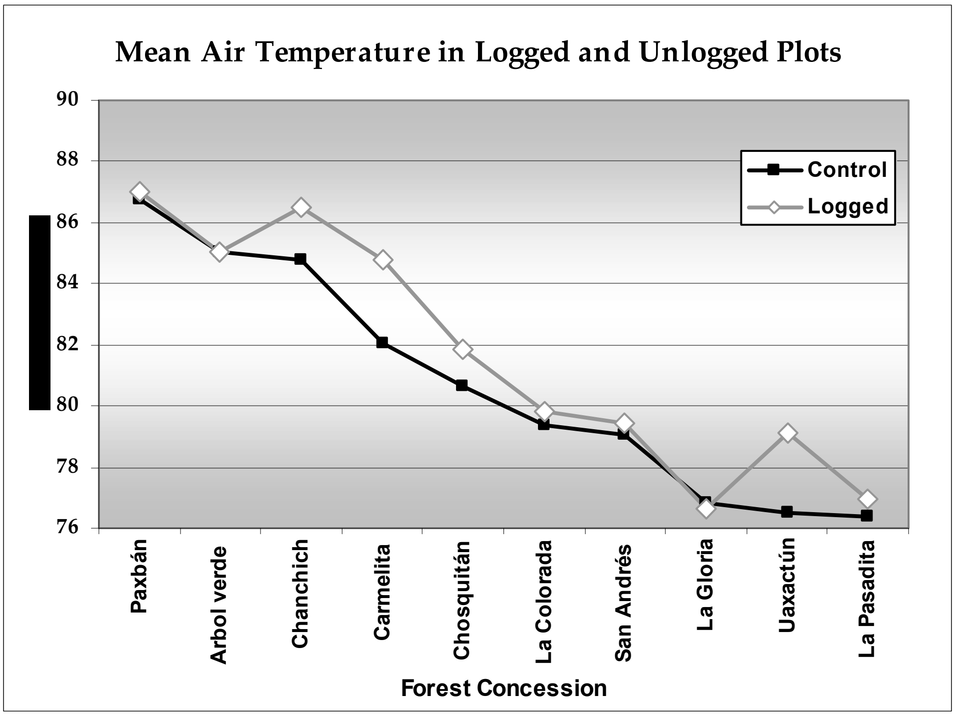


Figure 54

Appendix II. Microclimate summaries by concession



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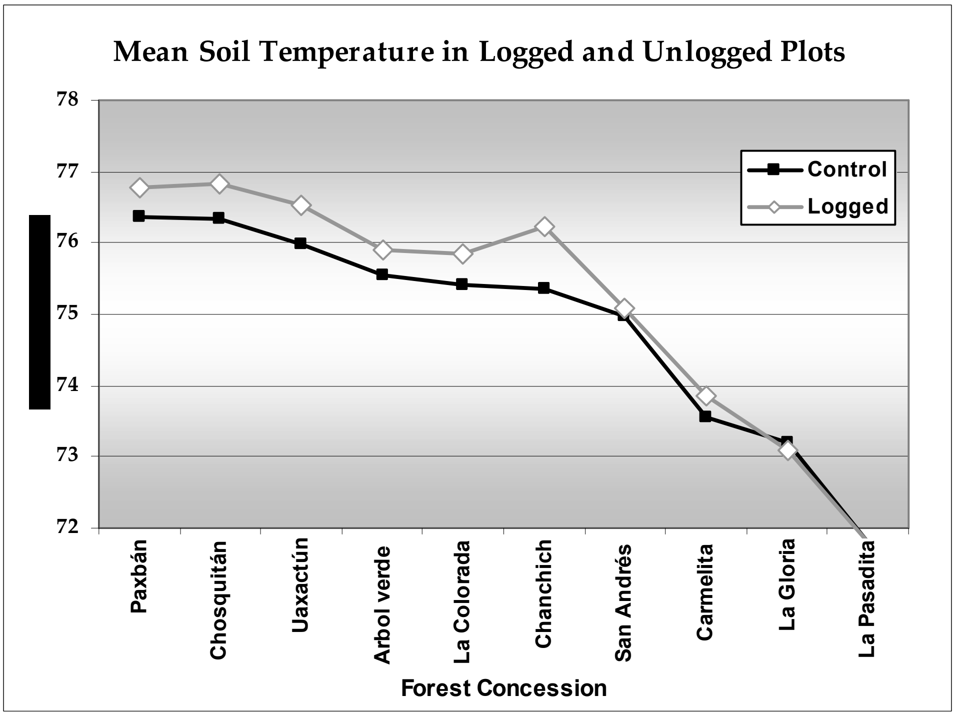
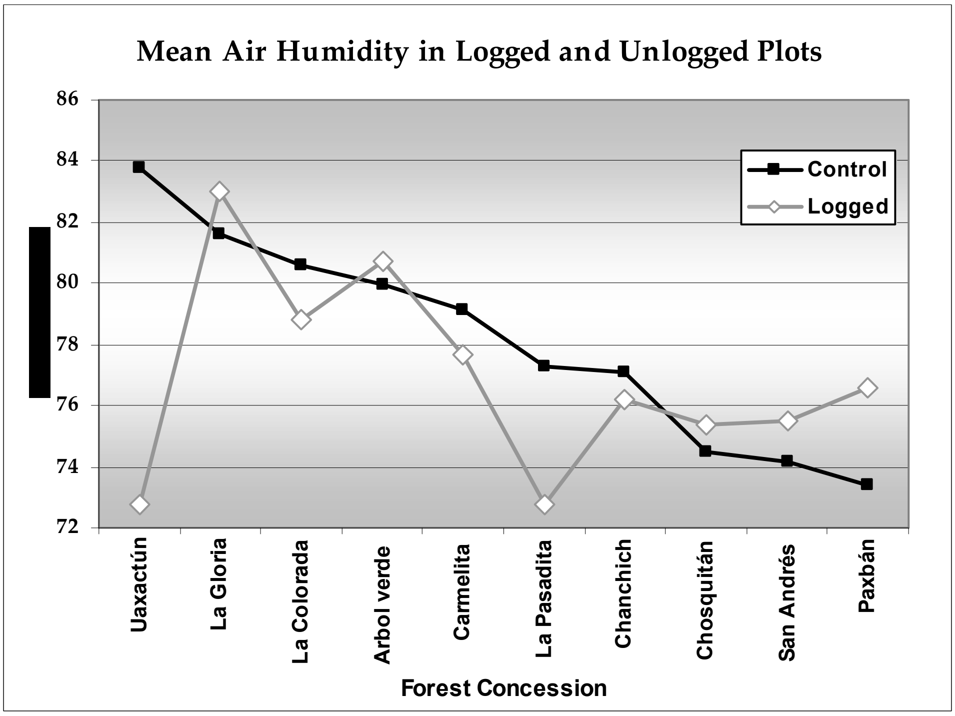


Figure 56.



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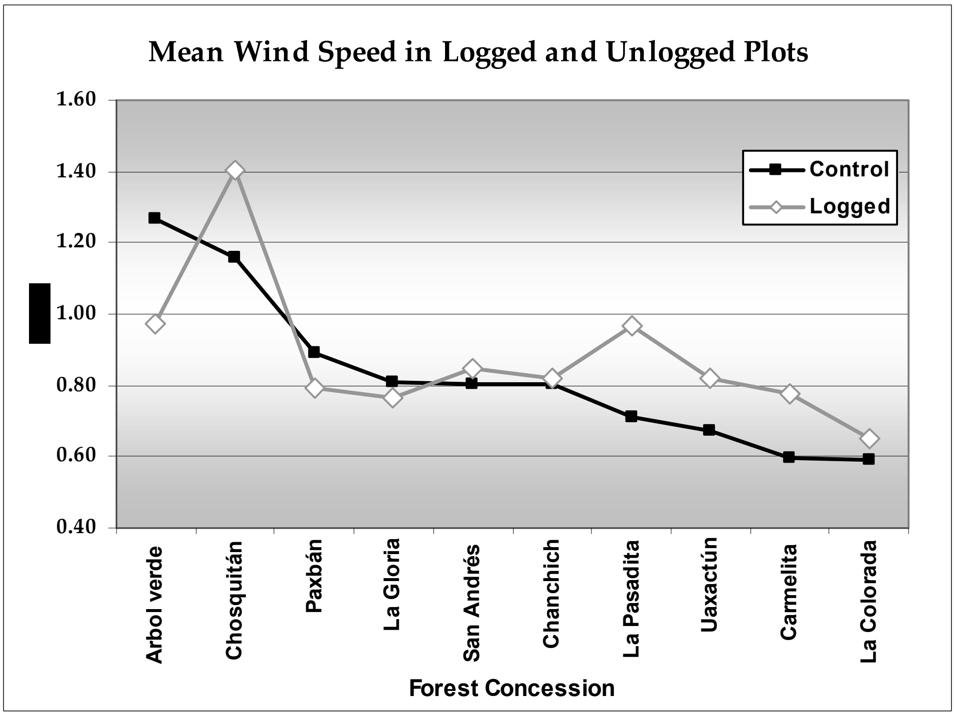

Figure 58

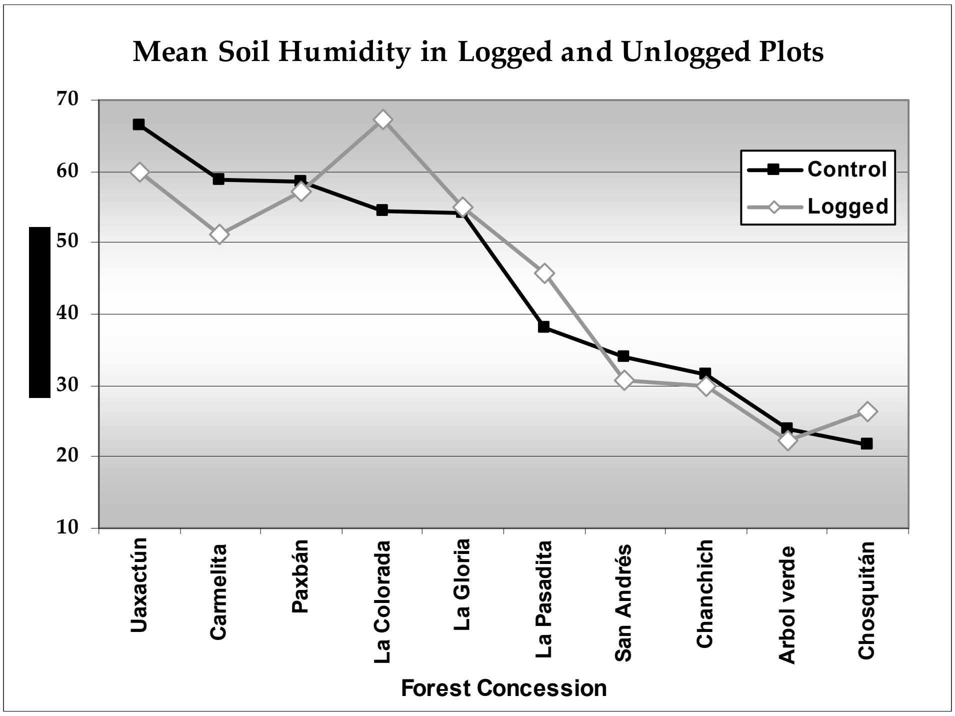
Mean Soil Humidity in Logged and Unlogged Plots
[redacted]
70
60
50
40
30
20
10
Control
Logged
Uaxactún
Carmelita
Paxbán
La Colorada
La Gloria
La Pasadita
San Andrés
Chanchich
Arbol verde
Chosquitán
Forest Concession

Figure 59

Appendix III. **Bird summaries by concession**

Table 16. Species Richness

		Round 1				Round 2				Round 3				Round 4			
Concession	Treat-ment	Data est	Boot-strap est	95% CI lower	95% CI upper	Data est	Boot-strap est	95% CI lower	95% CI upper	Data est	Boot-strap est	95% CI lower	95% CI upper	Data est	Boot-strap est	95% CI lower	95% CI upper
Arbol Verde	Control	91.9	102.0	79.0	178.3	76.2	81.9	67.0	126.8	129.1	141.5	108.2	226.4	74.1	87.5	63.0	158.3
	Logged	95.9	105.8	85.3	164.8	121.7	123.5	71.2	208.2	132.8	142.7	100.0	219.2	84.6	112.4	73.7	210.6
Carmelita	Control	100.0	108.2	90.3	191.9	131.6	139.9	108.5	195.7	129.0	142.2	95.3	223.5	96.3	97.5	88.3	110.9
	Logged	119.9	133.9	96.4	217.7	121.0	129.3	96.6	189.0	106.9	114.0	93.3	180.7	108.3	112.1	89.0	147.7
Chanchich	Control	111.5	112.9	99.2	129.3	94.4	98.1	87.4	149.7	92.3	93.2	83.0	106.3	126.5	129.7	116.3	157.6
	Logged	112.4	126.1	98.4	209.0	126.0	133.2	91.0	210.8	90.2	94.5	79.3	122.0	139.3	145.4	121.0	201.4
Chosquitán	Control	105.3	106.9	96.3	120.6	96.8	100.2	86.3	126.4	189.1	187.3	107.3	275.2	143.9	135.2	87.0	236.6
	Logged	148.0	157.8	108.2	236.9	162.5	163.2	84.6	234.3	114.6	115.4	104.2	131.0	104.0	107.3	90.3	137.8
La Colorada	Control	196.2	199.4	115.9	282.8	95.1	102.9	85.3	169.5	141.8	152.3	109.9	222.0	140.1	146.1	127.5	195.7
	Logged	210.8	213.2	135.9	292.1	105.9	116.0	93.3	181.1	144.7	154.8	121.0	225.5	137.7	141.8	121.8	174.4
La Gloria	Control	100.9	108.8	81.8	177.6	126.6	133.5	114.6	181.2	109.4	122.0	89.0	210.7	119.9	126.1	110.2	183.6
	Logged	77.1	77.9	70.0	85.6	132.0	138.6	114.2	185.1	92.6	94.9	81.9	114.3	121.3	122.3	112.7	133.2
La Pasadita	Control	111.4	119.7	96.1	173.6	132.4	138.2	109.3	191.6	99.3	101.0	92.3	111.2	92.7	97.6	82.3	138.4
	Logged	175.7	174.4	100.8	265.6	108.7	110.3	95.3	131.2	123.3	131.3	106.9	187.7	99.8	104.1	85.1	128.9
Paxbán	Control	155.4	162.1	103.1	245.8	95.6	99.2	87.0	133.7	94.8	95.7	88.0	102.7	136.8	141.2	126.1	172.5
	Logged	121.4	126.2	97.4	178.7	100.6	105.9	92.4	169.5	98.2	110.0	84.5	184.8	149.7	165.7	127.2	265.4
San Andrés	Control	93.3	95.2	84.9	111.9	124.1	125.4	116.1	136.2	101.1	106.3	88.6	175.0	127.1	139.5	116.4	241.5
	Logged	112.8	122.8	94.3	190.8	149.5	162.7	124.4	235.4	78.4	80.1	69.4	94.3	128.1	129.8	117.7	142.3
Uaxactún	Control	103.1	109.8	92.8	183.0	117.1	118.1	107.4	128.9	79.7	87.0	72.0	166.6	123.3	136.3	108.6	199.7
	Logged	103.2	104.5	93.7	117.0	113.3	128.2	98.9	191.5	103.8	120.9	79.9	188.6	120.5	133.5	112.0	247.3

AltLambda – #spp Poa/control spatial differences poa vs control

Table 17

	Round 1				Round 2				Round 3				Round 4			
Concession	Data est	Boot-strap est	95% CI lower	95% CI upper	Data est	Boot-strap est	95% CI lower	95% CI upper	Data est	Boot-strap est	95% CI lower	95% CI upper	Data est	Boot-strap est	95% CI lower	95% CI upper
Arbol Verde	1.05	1.06	0.94	1.19	1.04	1.05	0.88	1.24	0.97	0.97	0.85	1.12	1.20	1.20	1.03	1.38
Carmelita	1.02	1.02	0.88	1.17	0.92	0.92	0.80	1.04	0.99	0.99	0.85	1.11	0.95	0.95	0.84	1.09
Chanchich	0.97	0.97	0.87	1.09	1.05	1.04	0.91	1.16	0.95	0.95	0.85	1.09	1.02	1.01	0.91	1.13
Chosquitán	1.04	1.04	0.89	1.21	0.94	0.94	0.77	1.14	0.98	0.98	0.83	1.13	1.00	1.00	0.83	1.16
La Colorada	1.01	1.01	0.82	1.18	1.07	1.08	0.97	1.22	1.12	1.11	0.96	1.29	0.97	0.96	0.87	1.06
La Gloria	0.93	0.94	0.83	1.06	1.04	1.03	0.93	1.15	0.94	0.94	0.81	1.10	1.05	1.05	0.96	1.13
La Pasadita	1.06	1.06	0.91	1.22	0.95	0.95	0.81	1.07	1.12	1.12	1.00	1.24	1.05	1.06	0.91	1.20
Paxbán	1.01	1.01	0.84	1.19	1.06	1.06	0.99	1.15	0.93	0.93	0.83	1.05	1.03	1.02	0.92	1.13
San Andrés	1.04	1.04	0.89	1.15	1.03	1.02	0.92	1.12	0.82	0.82	0.72	0.92	1.01	1.01	0.92	1.11
Uaxactún	1.05	1.05	0.93	1.16	0.94	0.94	0.85	1.05	1.07	1.07	0.92	1.20	1.05	1.05	0.97	1.15

Phi – proportion of Control spp still in POA

Table 18

		Round 1				Round 2				Round 3				Round 4			
Concession	**Treat-ment**	Data est	Boot-strap est	95% CI lower	95% CI upper	Data est	Boot-strap est	95% CI lower	95% CI upper	Data est	Boot-strap est	95% CI lower	95% CI upper	Data est	Boot-strap est	95% CI lower	95% CI upper
Arbol Verde	**Control**	0.94	0.93	0.77	1.00	0.86	0.89	0.73	1.00	0.91	0.93	0.80	1.00	0.83	0.87	0.68	1.00
	Logged	0.93	0.93	0.81	1.00	0.95	0.95	0.82	1.00	0.89	0.91	0.78	1.00	0.88	0.92	0.78	1.00
Carmelita	**Control**	0.89	0.90	0.77	1.00	1.00	0.97	0.86	1.00	0.93	0.93	0.82	1.00	0.89	0.90	0.77	1.00
	Logged	0.95	0.94	0.81	1.00	0.90	0.90	0.75	1.00	0.89	0.90	0.77	1.00	0.93	0.93	0.79	1.00
Chanchich	**Control**	0.90	0.90	0.77	1.00	0.92	0.93	0.80	1.00	0.83	0.84	0.71	0.98	0.98	0.97	0.87	1.00
	Logged	0.86	0.87	0.74	1.00	0.95	0.96	0.87	1.00	0.86	0.86	0.69	1.00	1.00	0.96	0.83	1.00
Chosquitán	**Control**	0.92	0.93	0.78	1.00	0.89	0.90	0.74	1.00	0.96	0.96	0.86	1.00	0.83	0.87	0.73	1.00
	Logged	1.00	0.97	0.88	1.00	0.90	0.93	0.75	1.00	0.94	0.94	0.80	1.00	0.88	0.88	0.73	1.00
La Colorada	**Control**	1.00	0.97	0.82	1.00	0.90	0.90	0.76	1.00	1.00	0.96	0.83	1.00	0.94	0.94	0.83	1.00
	Logged	0.97	0.96	0.81	1.00	0.96	0.95	0.83	1.00	0.99	0.97	0.88	1.00	0.96	0.95	0.83	1.00
La Gloria	**Control**	0.98	0.96	0.83	1.00	1.00	0.98	0.88	1.00	1.00	0.97	0.82	1.00	0.92	0.93	0.83	1.00
	Logged	0.88	0.88	0.73	1.00	0.98	0.97	0.87	1.00	0.92	0.92	0.78	1.00	0.96	0.96	0.88	1.00
La Pasadita	**Control**	0.88	0.88	0.71	1.00	0.99	0.97	0.86	1.00	0.85	0.86	0.75	1.00	0.86	0.87	0.70	1.00
	Logged	1.00	0.80	0.57	1.00	0.92	0.91	0.78	1.00	0.97	0.96	0.87	1.00	0.92	0.92	0.77	1.00
Paxbán	**Control**	0.94	0.94	0.78	1.00	0.89	0.90	0.79	1.00	0.87	0.86	0.71	1.00	0.94	0.94	0.84	1.00
	Logged	0.91	0.90	0.74	1.00	0.92	0.94	0.83	1.00	0.82	0.82	0.70	0.94	1.00	0.98	0.89	1.00
San Andrés	**Control**	0.87	0.88	0.76	1.00	0.90	0.91	0.79	1.00	0.86	0.88	0.71	1.00	1.00	0.98	0.89	1.00
	Logged	0.95	0.94	0.83	1.00	1.00	0.96	0.83	1.00	0.71	0.71	0.59	0.86	1.00	0.98	0.91	1.00
Uaxactún	**Control**	0.96	0.95	0.84	1.00	0.96	0.95	0.85	1.00	0.89	0.90	0.77	1.00	1.00	0.98	0.89	1.00
	Logged	0.96	0.96	0.82	1.00	0.90	0.90	0.78	1.00	1.00	0.97	0.88	1.00	1.00	0.98	0.89	1.00

Table 19. Total number of observations per species in treatment plots. POAs are logged areas.

	Arbol VerdeControl	Arbol VerdePOA	CarmelitaControl	CarmelitaPOA	ChanchichControl	ChanchichPOA	ChosquitánControl	ChosquitánPOA	La ColoradaControl	La ColoradaPOA	La GloriaControl	La GloriaPOA	La PasaditaControl	La PasaditaPOA	PaxbánControl	PaxbánPOA	San AndrésControl	San AndrésPOA	UaxactúnControl	UaxactúnPOA
Accipiter bicolor	0	0	0	1	0	3	0	0	0	0	0	0	1	0	2	0	0	0	1	1
Amazilia candida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
Amazilia rutila	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Amazilia tzacatl	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0
Amazona albifrons	69	24	60	30	2	14	27	120	4	21	13	19	55	69	71	59	32	36	6	10
Amazona autumnalis	48	11	90	94	34	44	67	78	77	92	21	34	35	90	103	60	143	78	86	68
Amazona farinosa	105	83	114	160	195	107	160	255	214	265	85	133	302	206	104	103	162	173	154	136
Amblycercus holosericeus	5	0	0	1	2	9	0	1	2	12	12	11	6	3	4	2	11	19	0	10
Ara macao	0	0	2	7	0	0	0	0	0	2	0	0	0	0	0	0	10	0	0	0
Aramides cajanea	0	0	0	0	0	2	0	0	0	0	0	0	0	0	6	3	0	0	0	0
Aramus guarauna	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aratinga nana astec	58	124	104	138	83	179	104	203	87	107	131	64	57	145	82	126	145	183	60	94
Arremonops chloronotus	22	44	106	90	31	90	37	67	78	125	70	91	29	34	61	94	119	148	48	74
Arremonops rufivirgatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0
Attila spadiceus	84	97	103	93	96	95	104	91	102	109	111	107	65	94	93	105	63	61	114	95
Aulacorhynchus prasinus	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Automolus ochrolaemus	1	0	0	0	6	0	0	0	1	1	0	0	1	0	0	1	0	0	2	1
Automolus rubiginosus	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Basileuterus culicivorus	110	105	11	22	77	66	53	14	51	40	36	50	56	55	42	15	13	15	63	58
Bucco (Notharcus) macrorhynchus	0	0	0	0	1	1	2	1	1	2	0	0	0	3	0	1	0	0	0	3
Buteo magnirostris	19	21	19	7	10	11	9	16	26	22	12	21	5	13	27	34	36	31	34	32
Buteo nitidus	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0
Buteogallus urubitinga	1	1	0	0	1	0	0	1	0	2	0	0	0	0	1	0	0	1	0	0
Campephilus guatemalensis	19	24	29	32	33	20	35	28	45	51	40	33	48	45	22	24	36	47	53	45
Campylopterus curvipennis	0	0	2	0	0	0	5	2	3	2	0	1	0	2	3	7	2	2	0	0
Campylopterus hemileucurus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Caryothraustes poliogaster	29	18	47	36	87	96	84	59	49	84	27	33	70	62	48	86	38	53	40	33
Cathartes aura	0	1	2	0	0	0	0	2	1	3	0	1	1	0	0	8	8	5	3	0
Catharus dryas	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2	0	0	0
Catharus ustulatus	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Celeus castaneus	21	20	26	23	55	35	38	27	50	61	79	63	36	37	49	63	44	28	63	67
Cercomacra tyrannina	1	1	10	8	13	3	5	9	7	6	2	8	2	3	4	7	15	10	5	9
Chloroceryle aenea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Chlorophanes spiza	0	0	0	0	1	0	1	0	1	3	0	0	0	0	0	0	0	0	1	0
Chlorophonia occipitalis	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Claravis pretiosa	0	2	3	2	30	31	2	0	27	51	6	3	9	12	7	11	16	9	5	0
Coereba flaveola	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	3	0	0	0
Columba cayannensis	0	0	2	0	0	0	4	1	0	2	0	3	1	2	1	8	0	8	0	3
columba nigrirostris	10	7	12	31	133	81	67	60	166	129	14	31	20	14	86	83	43	18	44	36
Columba speciosa	12	14	26	12	40	31	25	35	40	31	45	42	13	7	25	46	20	12	25	9

	Arbol VerdeControl	Arbol VerdePOA	CarmelitaControl	CarmelitaPOA	ChanchichControl	ChanchichPOA	ChosquitánControl	ChosquitánPOA	La ColoradaControl	La ColoradaPOA	La GloriaControl	La GloriaPOA	La PasaditaControl	La PasaditaPOA	PaxbánControl	PaxbánPOA	San AndrésControl	San AndrésPOA	UaxactúnControl	UaxactúnPOA
Columbina talpacoti	8	6	27	11	26	23	7	8	28	48	18	16	10	12	20	17	28	16	12	11
Contopus cinereus	0	0	0	0	2	9	0	0	0	0	0	0	0	0	4	4	0	1	0	0
Coragyps atratus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0
Cotinga amabilis	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0
Crax rubra	38	23	29	41	51	19	35	33	16	29	27	39	21	19	49	46	8	9	19	16
Crypturellus boucardi	6	0	0	4	18	13	2	0	10	3	4	8	1	5	4	8	6	4	2	3
Crypturellus cinnamomeus	5	10	34	28	22	27	6	5	9	11	32	27	14	10	45	36	12	9	5	6
Crypturellus soui	5	10	0	6	7	5	5	0	5	13	10	9	13	10	5	3	4	2	6	4
Cyanerpes cyaneus	78	66	116	92	60	76	85	96	138	120	114	120	57	73	49	89	109	151	90	85
Cyanerpes lucidus	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
Cyanocompsa cyanoides	2	5	10	7	21	25	10	12	17	42	18	16	5	13	10	10	35	31	26	20
Cyanocompsa parellina	2	7	8	15	8	11	6	15	12	8	1	19	8	1	2	1	11	22	16	13
cyanocorax morio	20	54	144	66	25	39	43	93	52	65	163	139	100	149	115	138	163	128	101	105
Cyanocorax yncas	0	0	2	0	9	5	8	2	0	15	6	4	2	1	8	25	0	7	0	0
Cyanocorax yucatanicus	0	0	1	6	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
Dendrocincla anabatina	53	48	56	67	44	47	65	47	69	62	48	51	29	48	65	54	42	39	68	64
Dendrocincla homochroa	17	16	14	19	19	19	25	17	30	32	28	19	14	20	23	22	13	8	26	27
Dendrocolaptes certhia	4	10	14	11	26	12	15	18	20	13	18	17	9	12	22	16	13	9	14	20
Dendroica fusca	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Dendroica magnolia	46	45	100	96	64	53	54	55	82	83	70	108	62	80	63	78	106	117	90	82
Dendroica occidentalis	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dendroica pensylvanica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
Dendroica petechia	0	1	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	2	1	0
Dendroica virens	0	0	1	0	0	0	2	1	0	0	0	0	3	0	1	1	0	0	0	0
Dives dives	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Dromococcyx phasianellus	0	0	0	0	3	2	0	0	0	0	0	0	0	0	4	0	0	0	0	0
Dryocopus lineatus	0	4	1	4	3	2	7	6	2	10	4	5	4	8	1	4	3	3	5	5
Dumetella carolinensis	21	33	141	112	74	132	31	60	53	71	66	42	48	104	23	63	223	265	42	33
Dysithamnus mentalis	6	3	3	1	7	2	1	0	2	5	16	13	2	4	5	2	6	4	11	9
Elanoides forficatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0
Elanus leucurus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
eucometis penicillata	45	27	36	24	28	31	42	29	77	50	44	39	36	43	61	43	73	27	57	46
Euphonia affinis	0	0	0	0	6	9	1	2	8	2	1	4	1	4	2	4	0	0	1	1
Euphonia elegantissima	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphonia gouldi	20	25	20	15	44	26	40	29	40	24	16	39	20	35	38	32	29	43	22	24
Euphonia hirundinacea	37	64	73	50	90	62	59	54	80	88	89	76	41	69	75	88	82	88	49	71
Falco rufigularis	0	0	6	6	0	0	0	1	8	4	1	1	0	0	1	0	2	4	1	0
Formicarius analis	36	19	54	47	100	62	99	67	181	186	73	84	50	71	113	109	34	25	96	129
Galbula ruficauda	8	17	32	19	15	11	15	12	33	54	30	39	19	20	3	14	16	5	22	24
Geotrygon montana	21	14	43	32	49	25	31	22	23	39	29	16	22	23	15	20	17	11	23	19
Geranospiza caerulescens	3	0	0	1	2	0	5	1	1	4	0	0	1	5	1	0	1	2	5	4
Glaucidium brasilianum	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Arbol VerdeControl	Arbol VerdePOA	CarmelitaControl	CarmelitaPOA	ChanchichControl	ChanchichPOA	ChosquitánControl	ChosquitánPOA	La ColoradaControl	La ColoradaPOA	La GloriaControl	La GloriaPOA	La PasaditaControl	La PasaditaPOA	PaxbánControl	PaxbánPOA	San AndrésControl	San AndrésPOA	UaxactúnControl	UaxactúnPOA
Glaucidium griseiceps	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyphorynchus spirurus	2	1	0	0	6	2	4	3	5	0	6	7	1	5	0	0	2	1	5	3
Granatellus sallaei	5	7	2	12	2	11	8	6	11	12	5	8	0	4	7	4	14	4	9	9
Habia fuscicauda	154	166	234	262	219	283	289	190	284	226	291	277	226	194	200	236	220	187	163	182
habia rubica	0	4	12	16	2	19	6	11	13	24	6	18	12	10	13	7	6	8	6	12
Harpagus bidentatus	0	2	0	1	2	1	0	3	1	0	0	0	0	0	0	0	0	1	2	1
Heliothryx barroti	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Helmitheros swainsonii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Helmitheros vermivorus	8	7	4	3	10	10	7	1	7	7	19	18	7	3	5	6	14	15	20	24
Henicorhina leucosticta	156	161	114	153	225	174	252	213	220	201	141	224	141	129	133	132	136	127	208	215
Herpetotheres cachinnans	1	4	5	8	3	2	2	7	6	10	3	2	2	3	4	4	4	5	4	7
Hylocichla mustulina	11	18	93	96	47	42	44	39	82	58	100	73	32	66	58	23	96	77	17	35
Hylomanes momotula	10	23	9	3	15	14	26	25	39	39	16	20	7	21	7	2	3	4	16	16
Hylophilus decurtatus	111	133	37	41	105	66	76	69	47	48	48	61	52	60	51	51	37	37	47	39
Hylophilus ochraceiceps	68	90	28	47	77	72	52	42	51	41	84	63	46	46	64	26	38	44	63	68
Icteria virens	0	0	1	0	0	1	0	0	6	6	0	3	0	0	1	1	17	27	0	0
Icterus chrysater	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	2	4	0	0
Icterus dominicensis	1	0	2	0	4	2	2	0	0	2	0	0	0	0	6	11	6	2	2	0
Icterus galbula	0	2	4	2	2	0	0	0	11	6	8	12	2	0	2	6	10	15	18	18
Icterus mesumela	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Icterus spurius	0	0	0	0	0	2	0	0	0	0	1	2	0	0	1	0	0	2	0	3
Icterus wagleri	0	2	0	1	0	0	1	1	0	0	0	2	0	0	0	0	0	0	0	0
Ictinia plumbea	2	0	0	0	0	0	0	0	0	2	0	1	0	0	0	2	0	0	0	0
Lanio aurantius	57	51	30	28	58	49	85	39	102	44	99	91	66	47	57	64	67	39	120	135
Lepidocolaptes souleyetii	0	0	4	7	8	11	3	5	4	0	3	0	2	5	7	9	4	2	2	5
Leptodon cayanensis	3	2	10	3	0	0	0	5	5	2	4	7	1	4	8	5	2	1	3	6
Leptopogon amaurocephalus	1	2	0	0	0	1	1	0	0	0	1	2	0	0	1	0	1	0	1	1
Leptotila cassinii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0
Leptotila verreauxi	15	13	67	54	74	39	26	23	65	46	52	36	15	42	54	61	38	29	32	25
Leucopternis albicollis	2	0	0	0	7	2	0	1	1	1	0	0	1	0	0	0	0	0	0	0
Lipaugus unirufus	17	27	0	0	19	14	0	0	31	3	1	0	0	0	0	0	0	0	2	1
Malacoptila panamensis	0	0	0	2	2	1	0	2	0	0	2	0	0	2	3	0	0	2	2	2
Manacus candei	1	1	0	1	2	0	0	0	11	2	0	0	0	0	1	1	0	0	0	0
Megarynchus pitangua	0	2	0	0	2	0	0	0	4	1	2	3	0	1	1	1	1	2	0	0
Melanerpes (Centurus) aurifrons	0	1	20	18	23	5	21	40	37	43	26	22	9	18	22	36	29	44	6	10
Melanerpes pygmaeus	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
meleagris ocellata	6	15	5	23	12	13	38	22	4	7	28	24	1	4	27	12	12	9	28	6
micrastur ruficollis	8	9	15	16	14	13	17	14	31	17	14	19	25	18	21	22	8	14	16	17
Micrastur semitorquatus	2	0	8	7	2	3	2	8	2	2	7	3	1	9	5	15	1	3	8	6
Microrhopias quixensis	10	29	7	4	67	37	47	20	24	30	5	10	2	1	8	17	14	10	26	39
Mionectes oleaginus	31	25	17	23	26	20	14	6	33	12	16	13	22	17	32	23	25	9	37	14
Mniotilta varia	6	8	14	8	10	8	11	5	37	7	26	20	14	7	15	10	17	19	17	18

	Arbol VerdeControl	Arbol VerdePOA	CarmelitaControl	CarmelitaPOA	ChanchichControl	ChanchichPOA	ChosquitánControl	ChosquitánPOA	La ColoradaControl	La ColoradaPOA	La GloriaControl	La GloriaPOA	La PasaditaControl	La PasaditaPOA	PaxbánControl	PaxbánPOA	San AndrésControl	San AndrésPOA	UaxactúnControl	UaxactúnPOA
Molothrus aeneus	0	0	0	0	0	0	0	0	0	0	0	3	0	2	0	0	0	0	0	0
Momotus momota	44	12	25	9	62	38	47	37	45	55	46	53	29	25	41	68	16	6	26	38
Morphnus guianensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Mycteria americana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
Myiarchus tuberculifer	21	18	71	61	21	44	32	40	40	48	46	38	34	22	53	53	50	46	61	80
Myiarchus tyrannulus	9	10	28	17	14	12	11	21	16	16	21	34	17	15	23	16	27	39	29	41
Myiobius sulphureipygius	30	46	19	22	43	27	24	16	35	26	27	29	33	33	35	30	28	22	24	36
Myiodynastes luteiventris	1	0	1	0	0	0	3	6	1	1	0	3	0	0	4	0	14	11	0	0
Myiopagis viridicata	0	7	2	0	1	6	0	2	0	4	0	4	1	0	0	0	4	2	0	0
Myiozetetes similis	0	0	0	0	2	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
Myrmotherula schisticolor	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nyctibius jamaicensis (griseus)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0
Odontophorus guttatus	0	5	4	0	18	17	23	10	25	13	30	43	18	32	6	8	4	0	11	22
Oncostoma cinereigulare	103	92	147	118	115	98	112	94	115	120	124	124	110	105	177	166	139	99	132	113
Onychorhynchus coronatus	2	0	5	2	0	1	8	4	5	4	0	4	3	4	3	4	2	0	2	5
Oporornis formosus	51	75	54	70	92	77	105	92	146	127	129	121	104	88	73	64	121	104	150	151
Ornithion semiflavum	7	4	22	19	2	1	14	9	2	4	10	2	11	10	4	4	0	1	2	4
Ortalis vetula	16	29	56	21	36	52	19	29	93	108	49	56	39	31	47	48	79	65	28	25
Otus guatemalae	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1
Pachyramphus aglaiae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pachyramphus cinnamomeus	2	3	0	2	0	0	3	0	0	0	0	2	0	0	3	0	0	1	1	1
Passerina caerulea	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Passerina cyanea	0	0	0	0	0	0	0	4	5	3	0	0	1	0	0	0	3	7	0	0
Penelope purpurascens	50	74	29	21	86	66	66	57	78	73	47	54	30	39	36	38	68	50	38	36
Phaethornis superciliosis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0
Piaya cayana	35	24	40	33	72	38	55	37	36	48	51	42	29	35	57	61	29	20	50	43
Piculus rubiginosus	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Pionopsitta haematotis	103	115	32	119	88	67	165	106	109	67	97	101	83	85	168	107	72	34	159	94
Pionus senilis	87	58	94	152	134	99	163	175	77	133	81	99	164	151	118	80	151	134	103	97
Pipra mentalis	64	88	61	63	116	97	53	33	96	72	59	87	53	64	106	96	57	71	78	88
Piranga roseogularis	0	3	1	0	5	14	0	1	0	0	6	0	2	0	2	7	0	0	0	0
Piranga rubra	2	3	3	5	8	3	5	1	0	1	1	2	5	7	4	2	9	6	11	3
Pitangus sulphuratus	1	9	22	2	0	6	6	12	6	17	2	20	0	8	6	13	68	30	5	16
Platyrinchus cancrominus (mystaceus)	92	103	103	118	125	94	98	81	92	88	84	97	118	120	81	86	85	72	130	143
Polioptila plumbea	11	13	7	5	9	11	3	8	6	10	6	6	5	7	9	5	0	9	5	8
Psarocolius montezuma	64	5	18	5	18	27	87	54	47	56	12	21	12	6	10	31	77	21	41	54
Pteroglossus torquatus	22	46	15	27	88	60	65	69	68	83	70	60	77	42	34	56	39	46	53	68
Pygmornis longuemareus	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Ramphastos sulfuratus	201	245	143	176	190	178	178	171	165	200	255	255	212	222	134	160	147	128	111	125
Ramphocaenus melanurus	72	63	83	53	106	120	64	56	67	97	58	58	34	29	65	101	61	74	97	114
Rhynchocyclus brevirostris	17	11	9	9	18	9	7	9	4	7	11	15	9	9	9	8	8	8	6	5
Rhytipterna holerythra	13	17	0	0	20	15	5	0	5	3	1	2	1	0	1	2	1	0	2	9

	Arbol VerdeControl	Arbol VerdePOA	CarmelitaControl	CarmelitaPOA	ChanchichControl	ChanchichPOA	ChosquitánControl	ChosquitánPOA	La ColoradaControl	La ColoradaPOA	La GloriaControl	La GloriaPOA	La PasaditaControl	La PasaditaPOA	PaxbánControl	PaxbánPOA	San AndrésControl	San AndrésPOA	UaxactúnControl	UaxactúnPOA
saltator atriceps	0	0	4	0	18	0	0	0	17	50	0	0	0	0	0	0	114	79	4	0
Sarcoramphus papa	0	0	0	0	0	1	0	0	0	0	1	0	0	2	0	1	0	1	0	0
Schiffornis turdinus	109	126	93	122	110	128	102	71	107	85	144	107	96	108	106	97	40	49	132	96
Sclerurus guatemalensis	4	8	4	12	21	13	32	15	40	24	9	22	19	33	24	13	12	2	13	34
Sclerurus mexicanus	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seiurus aurocapillus	0	0	11	5	0	0	0	4	2	8	17	4	1	2	8	5	13	13	0	2
Seiurus noveboracensis	0	0	5	5	0	0	0	1	0	0	0	0	0	0	6	0	2	0	0	0
Setophaga ruticilla	32	28	48	58	36	31	27	25	32	26	59	76	39	41	47	60	81	55	32	41
Sittasomus griseicapillus	84	89	87	99	128	87	124	94	98	90	114	129	120	143	100	87	98	135	158	148
Sphyrapicus varius	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Spizaetus ornatus	3	1	4	5	2	3	1	0	3	5	7	6	1	0	4	6	3	8	4	4
Spizaetus tyrannus	0	0	2	0	0	0	0	3	0	0	0	0	0	0	1	0	0	1	0	0
Sporophila aurita	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Sporophila torqueola	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	10	10	0	0
Strix (Ciccaba) virgata	0	2	5	0	0	1	0	0	0	0	2	0	0	2	1	0	0	0	2	4
Tangara lavarta	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	3	1	1	3
Tapera naevia	0	0	7	4	1	0	0	0	0	1	0	0	2	7	2	2	0	0	0	0
Taraba major	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Terenotriccus erythrurus	1	0	0	4	2	4	0	0	2	4	4	3	3	3	1	0	4	3	5	9
Thamnophilus doliatus	10	19	108	19	26	46	18	17	70	97	54	44	12	18	66	68	50	90	32	12
Thraupis abbas	3	0	4	4	3	12	3	2	7	6	2	9	2	0	2	5	5	11	3	8
Thryothorus ludovicianus	2	0	0	0	0	2	0	0	0	0	2	0	0	1	5	0	0	0	0	0
Thryothorus maculipectus	82	54	151	128	86	96	100	90	185	189	63	102	75	65	106	119	98	116	150	110
Thryothorus rufalbus	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0
Tinamus major	18	25	21	32	33	45	12	10	53	32	35	28	14	12	53	30	22	14	10	13
Tityra inquisitor	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Tityra semifasciata	15	13	11	16	40	8	19	27	13	18	16	18	13	18	10	20	33	21	12	23
Todirostrum sylvia	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
Tolmomyias sulphurescens	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Troglodytes aedon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Trogon collaris	32	21	26	30	35	13	31	5	54	29	34	35	27	51	51	28	14	13	21	29
Trogon elegans	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Trogon massena	35	39	21	24	89	61	70	78	82	70	52	20	24	50	61	67	30	49	27	33
Trogon melanocephalus	52	70	114	75	74	104	58	47	47	75	75	40	69	76	76	95	37	30	59	49
Trogon violaceus	83	92	36	29	101	71	60	35	56	48	58	45	63	54	32	36	14	19	23	16
Turdus assimilis	9	1	1	4	7	5	1	0	7	8	11	10	4	2	0	4	14	29	8	8
Turdus grayi	3	9	36	42	18	13	16	14	59	63	21	15	18	26	31	18	104	83	11	14
Tyrannus melancholicus	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tyrannus vociferans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0
Uropsila leucogaster	84	79	102	77	95	98	86	97	80	102	126	110	91	73	91	108	80	109	82	84
Veniliornis fumigatus	19	13	12	23	29	14	22	14	9	31	25	23	19	20	17	22	19	13	23	9
Vermivora pinus	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0

	Arbol VerdeControl	Arbol VerdePOA	CarmelitaControl	CarmelitaPOA	ChanchichControl	ChanchichPOA	ChosquitánControl	ChosquitánPOA	La ColoradaControl	La ColoradaPOA	La GloriaControl	La GloriaPOA	La PasaditaControl	La PasaditaPOA	PaxbánControl	PaxbánPOA	San AndrésControl	San AndrésPOA	UaxactúnControl	UaxactúnPOA
Vireo flavifrons	0	0	3	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Vireo flavoviridis	0	2	6	1	0	0	1	1	2	4	2	0	4	2	2	0	1	0	0	0
Vireo griseus	7	12	37	10	6	22	13	17	19	24	65	47	10	15	22	26	19	26	18	28
Vireo hypochryseus	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Vireo leucophrys	0	0	0	0	0	3	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Vireo olivaceous	49	44	51	41	50	53	45	36	44	32	79	62	47	47	48	49	25	44	33	35
Vireo pallens	12	9	32	7	0	41	2	13	9	3	11	3	12	7	10	11	2	5	0	0
Vireo philadelphicus	2	9	3	0	6	15	7	4	12	8	60	48	7	2	18	13	4	19	12	8
Vireo solitarius	0	0	0	0	1	0	0	0	0	0	2	2	0	0	2	3	0	2	2	0
Vireolanius pulchellus	12	36	22	15	103	80	51	35	110	69	51	89	73	88	92	81	13	26	8	23
Wilsonia citrina	8	21	33	35	23	25	21	37	51	36	55	77	40	47	30	37	66	55	60	82
Wilsonia pusilla	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	2	0	0
Xenops minutus	30	20	10	14	17	24	29	11	20	23	24	22	9	13	18	19	15	9	23	21
Xiphocolaptes promeropirhynchus	0	0	0	0	2	2	2	0	3	0	1	0	1	0	1	0	0	0	0	0
Xiphorhynchus flavigaster	70	83	67	72	86	76	59	59	93	76	76	82	61	69	104	100	77	53	78	94
Zenaida asiatica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0

Appendix IV. Butterfly summaries by concession

Table 20 richness

		Round 1				Round 2				Round 3				Round 4			
Concession	Treat-ment	Data est	Boot-strap avg	95% CI lower	95% CI upper	Data est	Boot-strap avg	95% CI lower	95% CI upper	Data est	Boot-strap avg	95% CI lower	95% CI upper	Data est	Boot-strap avg	95% CI lower	95% CI upper
Arbol Verde	Control	14.9	15.4	12.0	27.6	4.0	5.4	3.0	12.7	14.9	14.2	12.0	16.9	41.4	43.4	14.7	73.5
	Logged	12.6	18.4	11.0	51.1	8.9	15.0	7.0	36.4	23.6	26.1	17.0	50.7	10.7	13.8	8.0	39.0
Carmelita	Control					54.2	60.5	26.0	101.2	79.5	76.3	26.0	138.6	16.9	16.6	14.0	22.2
	Logged					21.7	23.9	21.1	27.0	24.9	23.1	21.0	26.9	33.0	33.8	15.0	56.9
Chanchich	Control	22.8	24.5	20.0	39.2	11.9	12.6	9.0	24.3	28.5	31.4	22.0	62.8	18.2	33.3	14.0	81.2
	Logged	52.6	54.3	28.0	91.5	12.1	15.5	11.0	30.4	26.9	26.4	24.0	29.9	22.8	23.7	21.0	27.0
Chosquitán	Control	56.0	54.4	16.0	97.5	15.5	21.3	12.0	60.3	23.6	29.1	17.0	61.9	16.2	19.1	13.0	40.5
	Logged	19.4	22.0	16.0	44.2	33.5	36.1	19.0	67.4	32.0	41.5	20.0	89.1	25.0	27.6	16.1	48.1
La Colorada	Control	40.2	46.4	23.3	97.9	31.9	35.0	12.0	71.3	20.7	24.4	20.5	50.8	12.9	15.8	12.9	32.1
	Logged	28.7	35.0	24.0	76.2	13.6	17.2	11.0	43.6	34.1	36.5	29.0	64.2	12.9	14.8	12.9	24.6
La Gloria	Control	22.6	32.8	13.0	72.2	15.9	20.4	15.8	46.0	20.7	23.3	20.7	34.3	12.0	12.0	12.0	12.0
	Logged	19.1	20.0	15.0	33.3	54.6	51.3	18.0	100.5	25.2	30.7	22.0	72.7	27.0	31.9	21.0	61.2
La Pasadita	Control	13.6	17.8	10.0	46.4	22.8	30.0	18.0	70.3	26.2	29.8	22.0	68.1	17.4	20.2	13.0	39.8
	Logged	20.7	22.9	14.0	36.2	13.2	14.7	11.0	22.3	33.7	38.3	17.0	69.9	41.8	51.4	17.0	94.3
Paxbán	Control	26.7	28.3	25.0	32.5	19.3	25.4	13.0	52.6	25.2	28.2	22.0	52.7	17.0	22.7	15.0	66.6
	Logged	35.8	38.7	27.0	87.5	25.1	24.8	10.0	51.9	41.4	44.9	32.0	80.6	67.2	54.7	18.0	111.1
San Andrés	Control	9.1	11.3	8.0	24.6	29.6	34.1	24.0	80.2	36.2	48.8	28.0	101.8	23.9	26.4	21.0	45.8
	Logged	17.0	18.5	14.0	29.3	24.3	27.8	20.0	61.5	23.3	25.9	20.0	51.6	25.0	33.1	21.0	70.1
Uaxactún	Control	20.0	21.9	16.0	35.1	32.4	34.3	25.0	55.3	17.4	21.2	14.0	42.9	14.9	15.6	12.0	33.7
	Logged	12.1	17.1	11.0	55.3	24.7	26.5	19.0	45.0	24.3	25.8	19.0	45.6	52.4	51.2	15.0	79.4

AltLambda – #spp Poa/control spatial differences poa vs control

Table 21

	Round 1				Round 2				Round 3				Round 4			
Concession	Data est	Boot-strap est	95% CI lower	95% CI upper	Data est	Boot-strap est	95% CI lower	95% CI upper	Data est	Boot-strap est	95% CI lower	95% CI upper	Data est	Boot-strap est	95% CI lower	95% CI upper
Arbol Verde	0.92	0.93	0.69	1.22	2.33	2.35	1.67	2.67	1.42	1.44	1.00	2.00	0.73	0.78	0.38	1.33
Carmelita	NA	NA	NA	NA	0.81	0.83	0.64	1.11	0.81	0.85	0.57	1.21	1.07	1.06	0.67	1.55
Chanchich	1.40	1.39	1.00	1.82	1.22	1.23	0.90	1.71	1.09	1.09	0.88	1.41	1.50	1.51	1.18	2.00
Chosquitán	1.00	1.06	0.65	1.70	1.58	1.58	1.07	2.22	1.18	1.17	0.81	1.67	1.23	1.24	0.87	1.82
La Colorada	1.09	1.10	0.79	1.53	0.92	0.97	0.54	1.86	1.45	1.45	1.20	1.65	1.00	1.00	1.00	1.00
La Gloria	1.15	1.18	0.80	1.75	1.20	1.17	0.80	1.60	1.10	1.10	0.95	1.25	1.75	1.76	1.42	2.08
La Pasadita	1.40	1.44	0.92	2.29	0.61	0.60	0.42	0.80	0.77	0.76	0.48	1.10	1.31	1.29	0.71	2.00
Paxbán	1.08	1.07	0.88	1.25	0.77	0.77	0.33	1.25	1.45	1.44	1.09	1.76	1.20	1.17	0.71	1.69
San Andrés	1.75	1.78	1.33	2.50	0.83	0.83	0.64	1.04	0.71	0.71	0.55	0.88	1.00	1.00	0.78	1.21
Uaxactún	0.69	0.69	0.50	0.86	0.76	0.75	0.56	1.00	1.36	1.36	0.94	1.90	1.25	1.22	0.69	1.89

Phi and gamma

Table 22

		Round 1				Round 2				Round 3				Round 4			
Concession	Treat-ment	Data est	Boot-strap avg	95% CI lower	95% CI upper	Data est	Boot-strap avg	95% CI lower	95% CI upper	Data est	Boot-strap avg	95% CI lower	95% CI upper	Data est	Boot-strap avg	95% CI lower	95% CI upper
Arbol Verde	Control	0.72	0.70	0.33	1.00	0.29	0.27	0.00	0.67	0.76	0.71	0.35	1.00	0.62	0.64	0.13	1.00
	Logged	0.66	0.65	0.29	1.00	0.67	0.69	0.00	1.00	0.97	0.97	0.69	1.00	0.54	0.54	0.07	1.00
Carmelita	Control					1.00	0.80	0.38	1.00	0.85	0.84	0.62	1.00	0.67	0.68	0.33	1.00
	Logged					0.65	0.66	0.44	1.00	0.62	0.63	0.38	0.94	0.78	0.77	0.50	1.00
Chanchich	Control	0.60	0.67	0.42	0.96	0.72	0.66	0.33	1.00	0.80	0.84	0.52	1.00	0.62	0.74	0.47	1.00
	Logged	0.87	0.92	0.66	1.00	0.77	0.75	0.38	1.00	0.77	0.75	0.50	1.00	0.99	0.92	0.66	1.00
Chosquitán	Control	1.00	0.67	0.12	1.00	0.58	0.67	0.35	1.00	0.73	0.81	0.52	1.00	0.69	0.78	0.43	1.00
	Logged	0.87	0.91	0.62	1.00	0.99	0.90	0.62	1.00	0.77	0.85	0.53	1.00	0.94	0.91	0.55	1.00
La Colorada	Control	0.81	0.84	0.53	1.00	0.81	0.86	0.44	1.00	0.62	0.61	0.37	0.86	0.91	0.87	0.58	1.00
	Logged	0.79	0.86	0.56	1.00	0.74	0.75	0.33	1.00	0.85	0.85	0.65	1.00	0.83	0.82	0.50	1.00
La Gloria	Control	0.68	0.78	0.42	1.00	0.50	0.53	0.26	0.92	0.90	0.87	0.64	1.00	0.57	0.57	0.32	0.80
	Logged	0.91	0.82	0.46	1.00	0.60	0.60	0.40	0.80	0.91	0.95	0.80	1.00	1.00	1.00	1.00	1.00
La Pasadita	Control	0.81	0.80	0.42	1.00	0.99	0.93	0.64	1.00	0.99	0.97	0.79	1.00	0.86	0.87	0.46	1.00
	Logged	1.00	0.97	0.76	1.00	0.74	0.81	0.33	1.00	1.00	0.85	0.43	1.00	0.93	0.95	0.70	1.00
Paxbán	Control	0.88	0.86	0.66	1.00	0.71	0.87	0.46	1.00	0.65	0.72	0.51	1.00	0.88	0.85	0.55	1.00
	Logged	1.00	0.93	0.67	1.00	0.91	0.79	0.28	1.00	1.00	0.92	0.74	1.00	1.00	0.96	0.73	1.00
San Andrés	Control	0.44	0.59	0.23	1.00	0.94	0.89	0.65	1.00	1.00	0.95	0.79	1.00	0.89	0.93	0.71	1.00
	Logged	1.00	0.51	0.00	1.00	0.79	0.74	0.52	1.00	0.71	0.78	0.50	1.00	0.99	0.93	0.74	1.00
Uaxactún	Control	0.90	0.83	0.51	1.00	0.89	0.85	0.64	1.00	0.63	0.72	0.44	1.00	0.66	0.69	0.32	1.00
	Logged	0.56	0.54	0.27	0.93	0.64	0.69	0.36	1.00	0.92	0.86	0.53	1.00	0.91	0.88	0.55	1.00

Appendix V. Dung beetle summaries by concession

Table 23

		Round 1					Round 2					Round 3					Round 4				
Concession	Treat-ment	S Obs	S est	Shared obs	Shared est	Morisita-Horn	S Obs	S est	Shared obs	Shared est	Morisita-Horn	S Obs	S est	Shared obs	Shared est	Morisita-Horn	S Obs	S est	Shared obs	Shared est	Morisita-Horn
Arbol Verde	Control	7	9.0	7	7.7	0.82	12	14.4	10	10.0	0.93	20	23.3	19	21.5	0.96	22	22.8	21	22.0	0.87
	Logged	11	16.3				13	15.4				23	24.7				23	24.2			
Carmelita	Control	3	6.0	1	NA	0.49	6	17.1	1	1.0	0.23	24	26.0	15	15.6	0.90	9	11.6	8	16.7	0.94
	Logged	8	9.6				3	6.0				16	18.2				11	13.3			
Chanchich	Control	11	13.3	9	10.2	0.70	14	33.5	10	10.4	0.97	16	17.6	14	15.3	0.84	18	23.1	15	17.8	0.61
	Logged	10	10.4				13	16.1				17	19.7				20	23.8			
Chosquitán	Control	8	8.6	6	7.3	0.80	15	15.9	12	13.8	0.89	17	18.4	15	18.4	0.88	16	17.9	12	16.1	0.80
	Logged	8	10.4				13	15.6				19	21.5				16	21.6			
La Colorada	Control	9	15.1	4	6.3	0.93	18	21.1	13	14.6	0.82	25	28.7	22	24.5	0.95	17	20.1	12	12.7	0.75
	Logged	4	5.1				14	15.3				25	26.8				15	16.3			
La Gloria	Control	10	11.9	5	5.3	0.73	9	10.4	7	7.0	0.72	27	30.1	25	34.4	0.97	16	16.7	12	12.9	0.90
	Logged	7	9.3				9	10.3				27	33.4				19	25.5			
La Pasadita	Control	11	14.7	7	11.0	0.74	8	9.1	3	NA	0.52	19	23.5	17	37.5	0.92	18	19.8	16	17.7	0.81
	Logged	8	16.4				4	NA				24	26.5				21	21.8			
Paxbán	Control	5	5.0	4	4.0	0.78	1	NA	1	NA	1.00	14	16.3	9	12.2	0.93	27	32.7	13	16.0	0.86
	Logged	7	8.7				1	NA				13	17.5				14	16.9			
San Andrés	Control	6	8.1	4	4.5	0.98	11	15.4	5	5.0	0.80	NA	NA	NA	NA	NA	26	34.1	20	26.3	0.96
	Logged	4	4.6				6	6.8				NA	NA				23	27.7			
Uaxactún	Control	31	34.8	29	31.2	0.91	20	34.7	18	25.6	0.95	22	27.2	20	26.2	0.92	1	NA	1	NA	1.00
	Logged	30	31.5				21	24.3				24	27.4				1	NA			