# Avian community responses after logging in the Chiquitano Dry Forest, Bolivia.

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**01-10-2012**

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**Thesis code:** AV 2012_47

**Date:** 01-10-2012

## I. Abstract

Tropical dry forests are amongst the most threatened ecosystems, due to land conversion into soybean plantations and pastures. In order to prevent the on-going deforestation, forests should be maintained and managed in such a way that both biodiversity and economics goals can be met. The continuous demand for tropical timber and the need to maintain biodiversity, should be an incentive to manage these forests sustainably according certification requirements (e.g. FSC). The implementation of reduced impact logging (RIL) could be an possible way to ensure sustainable harvesting. To evaluate the impact of logging and silvicultural treatments (to increase timber volume) on the ecosystem functioning, birds can be used as biological indicators, as they can be susceptible to changes in forest structure.

The aim of this study is to use birds as indicators for the effect of different logging intensities and silvicultural treatments on the ecosystem condition. The objectives are to evaluate; (I) the influence of different logging intensities and silvicultural treatments on species richness, diversity, abundance, and composition of the avian community; (2) the recovery of bird composition with time after logging; and (3) the use of avian guilds as possible indicators for sustainable logging.

This study has been executed in the 30,000 ha private property of INPA Parket Ltda (INPA). This Chiquitano tropical dry forest is located in the Santa Cruz department, Bolivia. Fieldwork was carried out within the plots of the Long-Term Silvicultural Research Program (LTSRP) in order to evaluate the avian response to different logging intensities and silvicultural treatments. Three different logging treatments (1 “normal” harvested according Bolivian forestry law; 2 “light silviculture” harvested like normal with additional silvicultural treatments and 3 “Intensive silviculture” logged with double intensity and silvicultural treatments) were compared to an un-logged control plot. Harvesting ranges from 4 to 8 trees $ha^{-1}$. Plots are approximately 20 ha in size, containing 12 fixed sample points where avian community data has been collected twice. Additional avian community data was collected in compartments (ranging from 4 to 8 $km^2$) that were harvested annually by INPA. Compartments that were logged 2,4,6,8 and 10 years ago were compared to a unlogged (mature) forest compartment in order to evaluate the recovery of the bird community over time.

Data to evaluate the effect of the LTSRP on avian community structure was collected in two different blocks situated 25 km from each other. A total of 955 birds belonging to 50 species have been observed in the LTSRP plots. The main results of this study show that there is a clear difference in total richness and functional group richness’s between those two different studied blocks and that the treatment effect itself show little influence on the avian community. Only when separating the two areas, logging intensity and different silvicultural treatments do have an effect on total species richness, species diversity, understory richness, arboreal richness and insectivore richness, though showing opposite trends between blocks. Richness’s increased with disturbance intensity in block 2, however decreased in block 1.

A total of 889 individuals belonging to 51 species have been observed within the 7 studied compartments. The most striking result of the chronosequence study is that none of the 6 logged forest stands differ in any of the parameters from an unlogged mature forest stand. Some functional groups like understory species, insectivore species and bark-gleaning insectivore species show a significant decreasing trend over time since logging.

It appears that difference in logging intensity and additional silvicultural measures have little effect on the avian community 10 years post logging in the Chiquitano dry forest. Differences in richness, diversity, abundance and composition cannot solely be explained by logging. Possible other factors like floristic composition, presence or absence of fruiting trees, geographical differences, plot specific differences, presence of water bodies and other micro habitat differences explain the avian distribution over the area.

The executed selective logging in the Chiquitano dry forest following FSC requirements and the adherence to the Bolivian forestry law, using RIL techniques has no to very little impact on the avian community, suggesting that it is sustainable when birds are considered. The decreasing or increasing trends of some functional groups cannot solely be explained by logging. The heterogeneity of the forest, presence of water bodies and other geographical differences most likely explain avian distribution over the area. Also the maintained forest structure after logging as well as the harsh conditions of this ecosystem make this avian community less responsive to changed caused by logging.

In this study no functional group show a clear response to the intensified logging and silvicultural measures. Therefore it cannot be stated what functional group is an appropriate biological indicator for sustainable harvesting for the Chiquitano tropical dry forest.

## II. Contents

# 1. Introduction

## 1.1 Justification

Of all tropical lowland forests, dry tropical forest is the most threatened ecosystem. Expanding agriculture and the high susceptibility to fire, makes this region vulnerable to degradation and fragmentation (Parker et al. 1993; Janzen 1998). Bolivia contains most of this endangered dry tropical forest in the Americas (Janzen 1998; Villegas et al. 2009). The largest and most pristine area of this forest is in the Santa Cruz department, currently threatened by increasing soy bean production and pasture establishment, the two main sources of deforestation (Parker et al. 1993; Killeen et al. 2007). Rates of deforestation have increased from 249 $km^2$ $y^{-1}$ before 1976 to 1608 $km^2$ $y^{-1}$ in the period of 2001-2004 in the Santa Cruz department alone (Killeen et al. 2007). This is the highest deforestation rate in the entire country. In order to reduce the on-going conversion of this threatened eco-region it is important to promote other economic viable alternatives. One option is to manage this forest area for sustainable timber production (Putz et al. 2001). With an increasing population and a continuous demand for tropical timber, tropical forests could be managed in such a way that both biodiversity and economics goals can be met. Therefore sustainable timber production is a possible viable strategy (Putz et al. 2001; Fredericksen & Putz 2003).

The implementation of reduced impact logging (RIL) is a form of selective harvesting aimed at reducing the impact of logging on the environment. Techniques as directional felling, liana cutting prior to harvesting, preliminary inventories for road construction, landing position and skidding trails as well as selection of future crop trees (FCTs) are applied (Putz et al. 2001; Felton et al. 2008; Peña-Claros et al. 2008). RIL shows a significant lower damage of canopy cover as well as ground cover compared to that of conventional logging (Pereira et al. 2001; Boltz et al. 2003; Putz et al. 2008). However strict supervision and skills are required to ensure minimum damage (Jackson et al. 2002). RIL alone seems not to be sufficient to ensure a sustainable harvest. In order to increase timber volume for sustainable harvesting, additional silvicultural treatments are needed (Sist & Ferreira 2007; Peña-Claros et al. 2008; Villegas et al. 2009). Additional silvicultural treatments that can be implemented are soil scarification to promote germination of commercial tree species, post-harvest girdling of non-commercial species and intensifying the above mentioned RIL measures (Peña-Claros et al. 2008).

## 1.2 Indicators for sustainable harvesting

In order to evaluate the impact of logging and silvicultural treatments on ecosystem functioning, proper biological indicators should be used (de Iongh & van Weerd 2006). Proper indicators are indicators that are able to detect changes caused by logging/silvicultural treatments, are easily measured and monitored and do not respond to changes occurring outside the system (Hilty & Merenlender 2000). Many different taxa have been examined as potential indicators to verify the impact of logging, ranging from very small invertebrates; dung-beetles, butterflies, termites (Davis et al. 2001; Hamer et al. 1997; Berry et al. 2010) to larger vertebrate taxa; birds, bats, small mammals, amphibians and reptiles (Ochoa & Soriano 2001; Mason & Thiollay 2001; Vitt & Caldwell 2001). The use of most of these taxa as indicators stay debatable as knowledge on species and their responses to logging is yet unknown (Meijaard et al. 2005). Numerous studies propose to use birds as potential indicators for forest disturbance, as they tend to be susceptible to changes in forest structure (Johns 1991; Grieser Johns 1996; Thiollay 1997; Barlow et al. 2006; Azevedo-Ramos et al. 2006; Felton et al.

2008). Additionally, birds are one of the best know and studied taxa globally and are easily identified visually as well as acoustically (de Iongh & van Weerd 2006).
The aim of this study is therefore to use birds to evaluate the effect of different logging/silvicultural treatments on ecosystem functioning, and to evaluate how the bird community recovers over time after logging.

### *1.3 Effect of logging on forest structure*

Logging has a direct effect on the structure of the forest. Changes in forest structure inflicted by logging depend on the intensity of the performed actions (Putz et al. 2008). Conventional logging as well as reduced impact logging, damage trees that are not harvested. Damage is caused directly by the felling of trees, creation of skid trails, skidding itself, road building or other logging activities. This results in an overall damage and mortality of trees in all classes, affecting the structure, microclimate and composition of the forest (Johns 1988; Mason & Thiollay 2001). All logging practices as well as dying off of damaged trees opens up the forest, resulting in a hotter, drier and lighter understory. The increased light availability results in a fast growth of light demanding tree species and invasive lianas, creating a dense secondary forest (Mason & Thiollay 2001; Putz et al. 2008).

### *1.4 Effect of logging on the avian community*

The bird community can be divided into guilds, "groups of species that exploit the same environmental resource in the same way" (Root 1967). These guilds have therefore a direct relationship to structures within the ecosystem (de Iongh & van Weerd 2006). Bird species can be classified into guilds according to their diet and forage location. Bird guilds can specialize for insects (insectivores), fruit (frugivores), nectar (nectarivores), meat (carnivores) and seeds/grains (granivores). Bird guilds can also specialize for different foraging layers in the forest; terrestrial (< 5 m), understory (from 5 to 15 m) and arboreal (> 15 m). Guild composition in the Bolivian dry tropical forest is distributed as follows; insectivores 60%, frugivores, 24%, nectarivores 7%, carnivores 5% and omnivores 1% (Herzog & Kessler 2002).

Changes in forest structure caused by logging, affect the bird community in many different ways as they respond to changes in habitat structure and resource availability. Birds experience changes in foraging habitat, food availability and exposure. Some bird species are reluctant to cross gaps as this exposes them to possible predators. Such birds find themselves therefore in a more fragmented habitat. This fragmentation is a direct effect from logging activities creating forest edge structures, separating formerly continuous forests with barriers (Mason & Thiollay 2001). Hence species associated with edges and gaps are positively affected, while interior species (60% of bird community) are often more prone to disturbance (Thiollay 1992; Thiollay 1997; Flores & Martinez 2007). Edge and gap structures provide similar conditions to that of the upper canopy, having therefore a minimal effect on species associated to the this foraging layer (Mason & Thiollay 2001). Thiollay (1992) and Flores and Martinez (2007) found that total richness and abundance increases in disturbed areas as a result of an increase in species associated with disturbed forest. Other species experience a change in foraging habitat as microclimate condition in the forest understory have been changed (high temperature and low humidity) (Meijaard et al. 2005). Species that require dark humid undergrowth to forage are highly affected by these changes in forest structure (Thiollay 1992; Mason & Thiollay 2001). Dense secondary understory vegetation also makes foraging less optimal for understory birds, as food is more difficult to find and catch (Thiollay 1997). Species can experience an altered food availability. Increased irradiance on the forest floor results in rapid flowering and fruiting of pioneer tree species, positively affecting species that forage on fruits and nectar (Meijaard et al. 2005). On the other hand bird species foraging on insects might have to compete with more generalist insectivore species associated to edge habitat. Another explanation for the decline in food for insectivore species is the increase in frugivore species that also include insects in their diet (Meijaard et al. 2005).

### *1.5 Use of avian guilds as indicators for sustainable logging*

Avian guilds respond differently to changes in forest structure (Johns 1991; Thiollay 1992; Mason 1996; Thiollay 1997; Aleixo 1999; Woltman 2003; Gray et al. 2007; Felton et al. 2008), and are therefore proposed to be appropriate indicators for forest disturbance by logging (Ghazoul & Hellier 2000; de Iongh &van Weerd 2006). Nectarivore species are either positively (increase in abundance of 2 to 15%) or neutrally affected by logging as a result of increased irradiance on the forest floor, causing plants to flower (Thiollay 1992; Mason 1996; Fredericksen et al. 1999; Gray et al. 2007). Frugivore species turn out to be fairly resilient to logging, as they are able to forage over large areas (Thiollay 1992; Mason 1996). Increased fruit availability in secondary growth positively affect the understory frugivores (Mason & Thiollay 2001). Some studies have shown that after logging, frugivores abundance decline with 20 % (Gray et al. 2007; Felton et al. 2008). The guild mostly affected are the insectivore species (Johns 1991, Thiollay 1992; Gray et al. 2007; Felton et al. 2008). A decrease is visible in especially terrestrial (33 to 75% in diversity, 72 to 93% in abundance), mixed species feeders (48 to 57% in diversity, 69 to 88% in abundance) and solitary sallying insectivores (31 to 42% in diversity, 37 to 63% in abundance) since food availability drops and foraging habitat changes (Thiollay 1992). Another explanation is that understory insectivore are reluctant to cross gaps (Mason & Thiollay 2001). This latter guild could therefore be an appropriate candidate as indicator to verify the sustainability of timber harvesting.

### *1.6 Study aim*

This study focuses on the effect of different logging intensities and silvicultural treatments on richness, diversity, abundance, and composition of avian species and guilds in a Bolivian dry forest. The study builds on research done by Flores and Martinez (2007), in 2001 (prior to harvesting) and 2005 (three years post-harvesting). Additional data is gathered in different logging compartments, harvested in different years (1-10 years ago. This chronosequence is used to evaluate responses of the avian community over time.

### *1.7 Objectives and hypothesis*

The objectives of this study are to evaluate; (1) the influence of different logging intensities and silvicultural treatments (normal reduced impact logging, additional light silvicultural measures and additional intensive silvicultural measures) on species richness, diversity, abundance, and composition of the avian community; (2) the recovery of bird composition with time after logging; and (3) the use of avian guilds as possible indicators for sustainable logging.

It is hypothesised that: (1a) total species richness will increase or will stay stable due to an increase in different microhabitats and food availability (fruits and flowers), caused by different logging intensities. (1b) A shift in richness and abundance of different functional groups will be apparent as some species react positively (nectarivores and frugivores) and others negatively (insectivores) to logging. (1c) Understory insectivore species are highly susceptible to forest disturbance, therefore resulting in lower richness and abundance of this guild in the more disturbed plots. (2a) Avian richness, diversity, abundance and composition will recover towards its original state (mature forest) over time. (2b) Different avian functional groups will respond differently over time as some groups react positively (nectarivores and frugivores) and others negatively (insectivores) to logging. (3) Especially understory insectivore species will be an appropriate indicator for sustainable logging because they are sensitive to changes in forest structure.

## 2. Methods

### *2.1 Study area*

This study has been carried out in the 30,000 ha private property of INPA Parket Ltda (INPA), a deciduous dry tropical forest, situated 30 km northeast of the village Concepción (16°06'S, 61°43'W) in the Santa Cruz department, Bolivia (Fig.1). The area has a mean annual temperature of 24,3 °C, a mean annual precipitation of 1160 mm and is characterised by rolling hills with an elevation between 400-500 m (Mostacedo et al. 2009). This forest area is known as the Chiquitano dry forest (Villegas 2009). The dry season is from May to October in which most trees are deciduous. The average tree density (≥ 10 cm at DBH) is 437 trees ha$^{-1}$ with a basal area of 21 m$^{2}$ ha$^{-1}$ and an average number of 34 species ha$^{-1}$ (Villegas et al. 2009). Most abundant tree species are *Acosmium cardenasii, Neea hermaphrodita, Aspidosperma tomentosa* and *Galipea trifoliata*. This forest type has an approximate height of 20 m (Killeen et al. 1998). The Chiquitano dry forest eco-region comprises the second highest floristic alpha diversity of all dry tropical forests in the world (Gentry et al. 1995; Killeen et al. 1998). Compared to other dry tropical forests, this area is less studied in terms of avian diversity. Avian species richness in the Chiquitano dry forest is estimated to be around 120 species (Flores et al. 2001; Brooks et al. 2005). Most abundant species in the area are Golden-crowned Warbler (*Basileuterus culicivorus*), White-backed Fire-eye (*Pyriglena leuconota*), Fuscous Flycatcher (*Cnemotriccus fuscatus*) and Moustached Wren (*Thryothorus genibarbis*) (Flores & Martinez 2007).

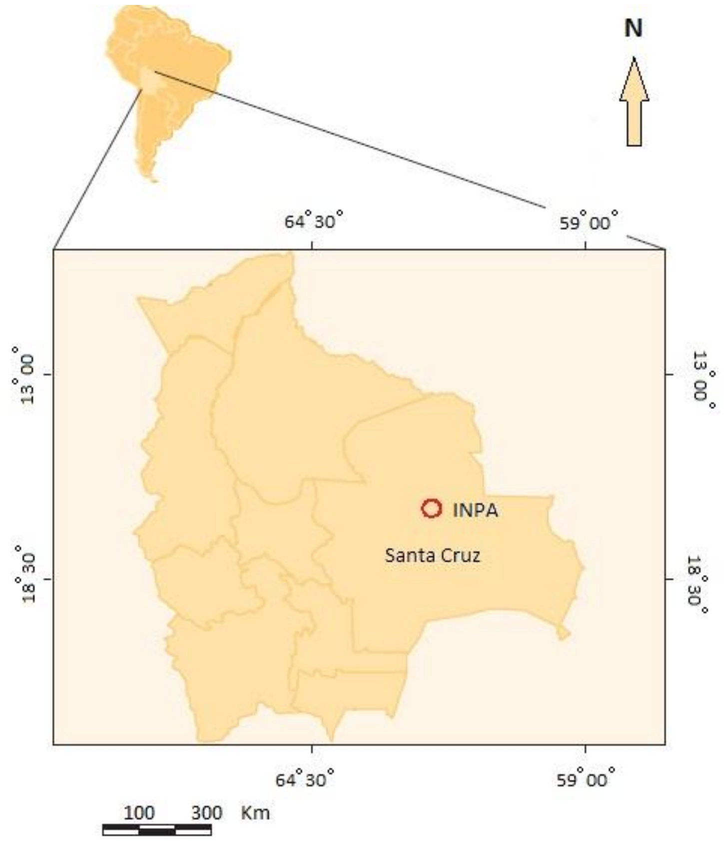


Figure 1: Study area INPA in the Santa Cruz department, Bolivia (Flores & Martinez 2007)

### *2.2 Experimental design*

Fieldwork has been carried out within the plots of the Long-Term Silvicultural Research Program (LTSRP) designed by the Instituto Boliviano de Investigación Forestal (IBIF) within the INPA property. Plots have an average size of approximately 21,25 ha (450 x 500 m) and are managed following four different silvicultural intensities (Table 1). (I) Control (un-harvested); (II) Normal (harvested according the Bolivian forestry law, using RIL techniques); (III) Light silviculture (harvested like normal with additional light silvicultural measures; (IV) Intensive silviculture (harvested with twice the intensity of normal treatment with additional intensive silvicultural measures). In the normal and light silvicultural plots approximately 4 trees ha$^{-1}$ were harvested following species-specific minimum cutting diameters of 40-50 cm DBH. In the intensive silviculture plots, approximately 8 trees $ha^{-1}$ were harvested (Villegas et al. 2009). A total of 8 plots divided over two blocks following a complete randomized block design were established. Each block was located in a different logging compartment and harvested in subsequent years (2002-2003). Pre-harvest inventory was conducted to find blocks/plots with similar tree densities of merchantable commercial trees, vegetation type and topography. Each plot was randomly assigned to one of the four treatments. The un-harvested plot was positioned is such a way to maximised undisturbed area around this control plot. A buffer of at least 50 m separates the control plot from harvested areas (Peña-Claros et al. 2008). During this study avian species richness, abundance and composition has been measured in these experimental plots to compare between different logging/silvicultural intensities.

The 30,000 ha of INPA is divided into approximately 25 logging compartments, in which each compartment (ranging from 4 to 8 $km^2$) is logged in subsequent years, following the 25 year cutting cycle (Villegas et al. 2009). Data on avian species richness, abundance and composition has been collected outside the experimental plots in the normal harvested compartments. Compartments of 1, 2, 4, 6, 8 and 10 years post-logging are surveyed and compared to an un-logged compartment with mature forest. This chronosequence is used to evaluate recovery of the bird community over time after harvesting and whether the community recovers towards its initial “mature forest” state.

Table 1: Harvest/silvicultural measures implemented in the four plots with an average size of approximately 21,25 ha. Treatments: C (control); N (normal); LS (light silviculture); IS (intensive silviculture). X measures applied; XX measures applied with double intensity (Peña-Claros et al. 2008).

| Harvest/silvicultural measures | Treatments | | | |
|---|---|---|---|---|
| | C | N | LS | IS |
| Pre-harvest inventory of commercial tree species | x | x | x | x |
| Liana cutting | | x | x | x |
| Skid trail planning | | x | x | x |
| Retention of 20% commercial trees as seed trees | | x | x | x |
| Directional felling | | x | x | x |
| Commercial trees harvested following minimum diameters (50-70 cm DBH | | x | x | xx |
| Pre-harvest marking of FCTs ≥ 10 cm DBH | | | x | xx |
| Liana cutting on FCTs | | | x | xx |
| Post-harvest liberation of FCTs | | | x | xx |
| Soil scarification in felling gaps during logging (1.1 gaps $ha^{-1}$) | | | | x |
| Post-harvest girdling of non-commercial trees >40 cm DBH (0.13 trees $ha^{-1}$) | | | | x |

### 2.3 Bird survey

Bird surveys were conducted in the wet season from January to March, following the point count method (Bibby et al. 1992). Within the experimental set-up, each plot has 12 selected fixed points, all situated at least 100 meters apart (Fig.2). This ensures independent sound samples as most understory birds have small territories. A total of eight plots divided over two blocks (two replications) results in a total of 96 fixed points in which all birds were recorded visually as well as acoustically (sound-recordings) within a 25 meter radius (Flores & Martinez 2007). Surveys were conducted from approximately 06:00 (first light) until 09:00 and each sample point was surveyed for 10 minutes. This coincides with the daily peak in bird vocal activity (Felton et al. 2008). Birds that fly off on arrival have been included and no surveys were done during heavy rain. Per survey one entire plot was measured (Fig.2). This resulted in a survey of 12 fixed sample points per day. Each plot was measured twice in subsequent days. The second survey was conducted in the opposite direction in order to overcome a possible time bias within the plot, for birds which become less active right after first light. Sixteen days were required to survey all 96 sample points twice.

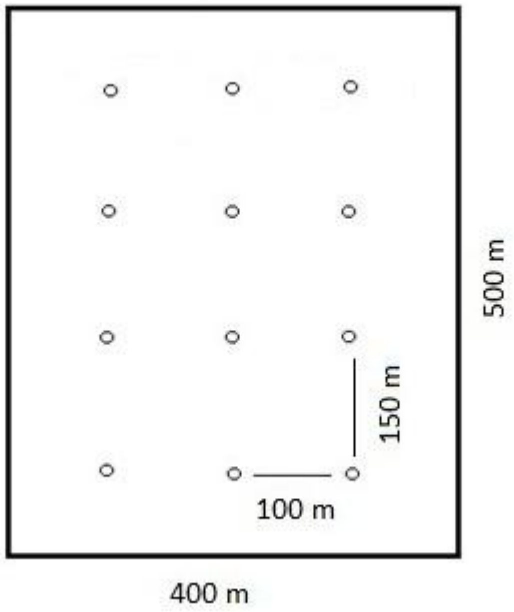


Figure 2: 21 ha plot assigned to one of the 4 treatments with every dot representing a sample point. 12 sample points, at least 100 m apart from one another, are measured twice in subsequent days following the point count method.

A total of 7 compartments were surveyed which are logged in subsequent years from 1, 2, 4, 6, 8 and 10 years post-logging. These logged compartments were compared to a control compartment (mature forest) that has not been logged. For the chronosequence study two transects per compartment have been established and surveyed following the point-transect method (Bibby et al. 1992). Each transect has a length of 750 m having 6 sample points situated at least 150 m apart, resulting in a total of 12 sample points per compartment (Fig.3). Each transect was measured twice in subsequent days, with the second survey in the opposite direction to overcome a time bias within the compartment. Surveys were conducted at first light, counting all birds for 10 min within a 25 m radius. Compartments were randomly chosen per survey day. Both transects were measured during a survey day. Fourteen days were required to survey all 84 sample points twice.

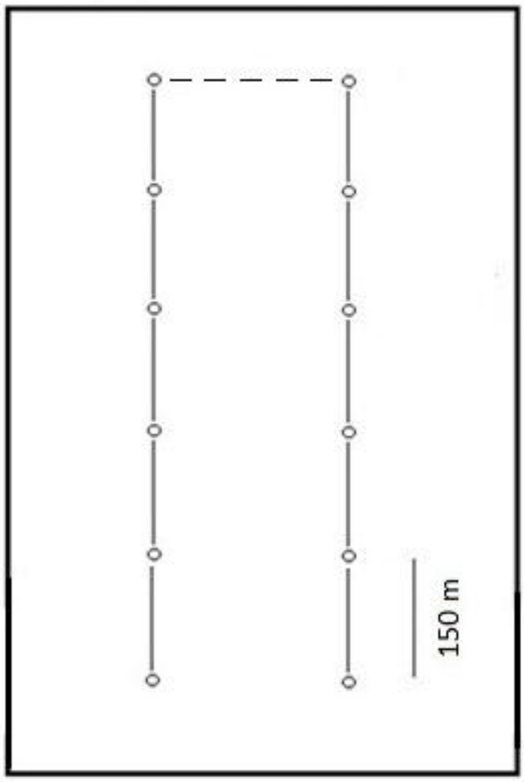


Figure 3: Transects situated in one of the 7 compartments with every dot representing a sample point. 12 sample points, at least 150 m apart, are measured twice in subsequent days following the point-transect method.

Species excluded from the analysis are:

(I): Raptors; as they are not bound to a restricted areas and observing depend on visibility.
(II): Nocturnal species; as these species are not active during daily hours and therefore a different systematic survey is needed.
(III): Water birds; the presence of these species is merely dependent on the presence of water bodies.
(IV): Wintering migrants; in order to prevent seasonal bias.
(V): Aerial feeders; as their observations depend on visibility.

*2.4 Statistical analysis*

Avian species richness, diversity, abundance and composition were compared between the four treatments. Each plot contained 12 independent sample points. Sample points were nested within plots and the plots were nested within blocks. All sample points have been sampled twice at different moments during the morning to overcome a possible bias of time. Both samples per sample point were combined in order to ensure independence of measurements within the plot. Species richness was counted and species frequency averaged in order to have a clear representation of the avian community per sample point. Single species frequency per plot was used as a proxy for abundance. A two-way ANOVA was used with fixed effects of block, treatment en the interaction between block and treatment. Species richness, Shannon-Wiener (H'), Shannon evenness (J') and the richness of different foraging strata (understory, arboreal and terrestrial) and one diet (insectivores) were compared with this model. Residuals of these parameters followed a normal distribution. All other parameters (other diet types and specific guilds) did not show a normal distribution. For these parameters differences between treatments were compared for each block separately using a non-parametrical Kruskal-Wallis test. A Principal Component Analysis was executed to visualize whether the 96 sample points were clustered around their designated plots and whether this clustering was associated to the different avian parameters (diet-type, foraging layer and guild composition). These avian parameters were used as environmental variables.

Avian species richness, diversity, abundance and composition were also compared between the different compartments following the chronosequence. Each compartment, containing 12 independent sample points, were measured twice at different moments during the morning. From these two measurements, total species richness and average frequency per sample point was calculated. One-way ANOVA's were executed for the parameters that followed a normal distribution. For those parameters that did not follow a normal distribution, a Kruskal-Wallis test was performed. Regressions were executed to indicate possible responses over time of the different avian parameters and single species (presence/absence of species). Different trend lines were compared to indicate which trend line best explains the avian response over time. A Principal Component Analysis was executed to visualize whether the 84 sample points within the same compartments are clustered and whether different avian parameters were associated with this sample point clustering.

## 3. Results: Treatment effects on the avian community structure

### *3.1 Description of avian community structure*

A total of 955 individual birds belonging to 50 species have been observed during point-count measurements in the experimental plots of the Long-Term Silvicultural Research Program divided over two different blocks. A significantly higher species richness is observed in block 1 compared to block 2 (t-test, t=7.57, p=<0.001, Table 2). The avian community mainly consists of species foraging on insects (56% of all species). Approximately half of the bird community forages in the upper part of the forest (48%) and 42% in the understory (5-15m) (Table 2). The two most abundant species are Fawn-breasted Wren (*Cantorchilus guarayanus*) and Bolivian Slaty Antshrike (*Thamnophilus sticturus*), occurring in approximately every sample point. Other abundant species are Tropical Parula (*Setophaga pitiayumi*), Red-eyed Vireo (*Vireo olivaceus*), Guira Tanager (*Hemithraupis guira*), Golden Crowned Warbler (*Basileuterus culicivorus*), Buff-throated Woodcreeper (*Xiphorhynchus guttatus*) and Olivaceous Woodcreeper (*Sittasomus griseicapillus*).

Table 2: Percentage and total number (between brackets) of avian species and composition measured during point-count sampling of 96 sample points within the experimental plots of the Long-Term Silvicultural Research Program divided over two different blocks. Total richness indicates all the different species observed in both blocks and total observations are the sum of all individual species observed in both blocks. (F) Frugivores; (I) Insectivores; (I/F) Insect/Frugivores; (N) Nectarivores; (O) Omnivores; (Und) Understory species; (Arb) Arboreal species; (Ter) Terrestrial species.

| | Richness | Observations | F | I | I/F | N | O | Und | Arb | Ter |
|---|---|---|---|---|---|---|---|---|---|---|
| Block 1 | 45 | 589 | 8,9 (4) | 57,8 (26) | 22,2 (10) | 8,9 (4) | 2,2 (1) | 44,4 (20) | 44,4 (20) | 11,1 (5) |
| Block 2 | 36 | 366 | 8,3 (3) | 58,3 (21) | 22,2 (8) | 8,3 (3) | 2,8 (1) | 41,7 (15) | 52,8 (19) | 5,6 (2) |
| Total | 50 | 955 | 12 (6) | 56 (28) | 22 (11) | 8 (4) | 2 (1) | 42 (21) | 48 (24) | 10 (5) |

More than 50% of the avian guild composition within the experimental design was comprised of Sallying (20%), Bark-gleaning (16%) and Understory (18%) insectivore species (Table 3). Most of the Sallying and all the Understory insectivore species can be found in the understory of forest. There are no significant differences in guild composition between the two blocks.

Table 3: Percentage and total number (between brackets) of the specific guild composition (combination of foraging layer and diet) measured during point-count method within the experimental plots of the Long-Term Silvicultural Research Program divided over two different blocks. Total are all the different species belonging to that guild observed in both blocks. (Arb/Und) Arboreal/Understory; (AF) Arboreal Frugivores; (AI) Arboreal Insectivores; (AIF) Arboreal Insect/Frugivores; (AO) Arboreal Omnivores; (BgI) Bark-gleaning Insectivores; (Sal) Sallying Insectivores; (IN) Insect/Nectarivores; (UF) Understory Frugivores; (UI) Understory Insectivores; (UIF) Understory Insect/Frugivores, (TF) Terrestrial Frugivores; (TFI) Terrestrial Frugi/Insectivores; (TI) Terrestrial Insectivores.

| | **Arboreal** | | | | **Arb/Und** | | **Understory** | | | | **Terrestrial** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AF | AI | AIF | AO | BgI | SaL | IN | UF | UI | UIF | TF | TFI | TI |
| Block 1 | 6,7 (3) | 8,9 (4) | 8,9 (4) | 2,2 (1) | 15,6 (7) | 20 (9) | 6,7 (3) | 2,2 (1) | 15,6 (7) | 2,2 (1) | 4,4 (2) | 4,4 (2) | 2,2 (1) |
| Block 2 | 8,3 (3) | 11,1 (4) | 11,1 (4) | 2,8 (1) | 13,9 (5) | 22,2 (8) | 5,6 (2) | 0 (0) | 19,4 (7) | 0 (0) | 0 (0) | 5,6 (2) | 0 (0) |
| Total | 6 (3) | 8 (4) | 10 (5) | 2 (1) | 16 (8) | 20 (10) | 6 (3) | 2 (1) | 18 (9) | 2 (1) | 4 (2) | 4 (2) | 2 (1) |

## *3.2 Treatment effects on the avian community structure*

Three fixed factors (block, treatment and interaction between block and treatments) are used to compare avian community differences. From these three factors, block is the most important factor explaining differences in most avian parameters, based on the high F-values (Table 4). From nine parameter that follow a normal distribution of the residuals, eight differ significantly among the two different blocks. The second most important factor explaining avian community differences is the interaction of block and treatment, in which seven out of nine parameters differ significantly. This indicates that treatment has a different effect in each block. Treatment effect itself has less effect on the avian community as only four out of nine parameters show a significant difference, though with very low F-values. For some parameters (species richness, H', understory species richness and insectivore richness), 48-60% of the differences in avian community structure are explained by this model, mainly due to the block effect.

There is a significant interaction between block and treatment for most avian parameters, with treatment showing opposite trends in each block. In block 1, species richness and are highest in the control plot and lowest in the plot with highest logging intensity and silvicultural measures. The opposite trend is visible in block 2 (Fig. 4A,B). This opposite trend within treatments between the two blocks, is also visible for other avian parameters when looking at species richness of the three different foraging layers and at the insectivore species (Fig. 4C,D,E). The first component of the Principal Component Analysis, also clearly shows the difference in species composition between the two different blocks (Fig. 4F; annex 2A). Beside the difference of the light silvicultural plot of block 1, no clear clustering of the different treatments are visible.

Table 4: Output of two-way ANOVA results of avian parameters that follow a normal distribution of the unstandardized residuals. Three fixed factors are used to compare different avian parameters (block, treatment and interaction between block and treatment). For those parameters that do show a significant treatment effect, a post-hoc test has been conducted. Treatment means followed by a different letter are significantly different at p < 0.05. Treatments differ in intensity from unlogged mature forest (control) to logged (normal) with additional silvicultural measures (light and intensive silviculture) and higher logging rates (intensive silviculture). R squared represents how much is explained by this model. Block d.f. 1; Treatment and Interaction d.f. 3.

| | **Block** | | **Treatment** | | **Interaction** | | | **Treatment means** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | F | p | F | p | F | p | $r^2$ | Control | Normal | Light Sil | Intensive Sil |
| **Species** | | | | | | | | | | | |
| Species Richness (S) | 84.4 | <0.005 | 3.3 | 0.023 | 12.5 | <0.005 | 0.60 | 10.13 a/b | 8.58 b | 10.63 a | 10.46 a/b |
| Shannon-Wiener (H') | 47.3 | <0.005 | 2.9 | 0.040 | 8.4 | <0.005 | 0.48 | 1.65 a/b | 1.52 b | 1.77 a | 1.78 a |
| Shannon Evenness (J") | 4.3 | 0.040 | 0.349 | n.s. | 1.0 | n.s. | 0.09 | n.s. | n.s. | n.s. | n.s. |
| **Foraging Layer** | | | | | | | | | | | |
| Understory Richness | 98.2 | <0.005 | 4.2 | 0.008 | 7.3 | <0.005 | 0.60 | 5.42 a | 4.29 b | 5.50 a | 4.96 a/b |
| Arboreal Richness | 19.9 | <0.005 | 1.6 | n.s. | 5.9 | <0.001 | 0.32 | n.s. | n.s. | n.s. | n.s. |
| Terrestrial Richness | 6.0 | 0.016 | 0.9 | n.s. | 2.3 | n.s. | 0.15 | n.s. | n.s. | n.s. | n.s. |
| **Diet** | | | | | | | | | | | |
| Insectivore Richness | 60.5 | <0.005 | 2.5 | n.s. | 4.6 | 0.005 | 0.48 | n.s. | n.s. | n.s. | n.s. |
| **Composition** | | | | | | | | | | | |
| PCA Axis 1 | 66.3 | <0.005 | 8.2 | <0.005 | 5.1 | 0.003 | 0.55 | 0.27 a | -0.05 a | -0.56 b | 0.34 a |
| PCA Axis 2 | 0.1 | n.s. | 0.4 | n.s. | 10.2 | <0.005 | 0.27 | n.s. | n.s. | n.s. | n.s. |

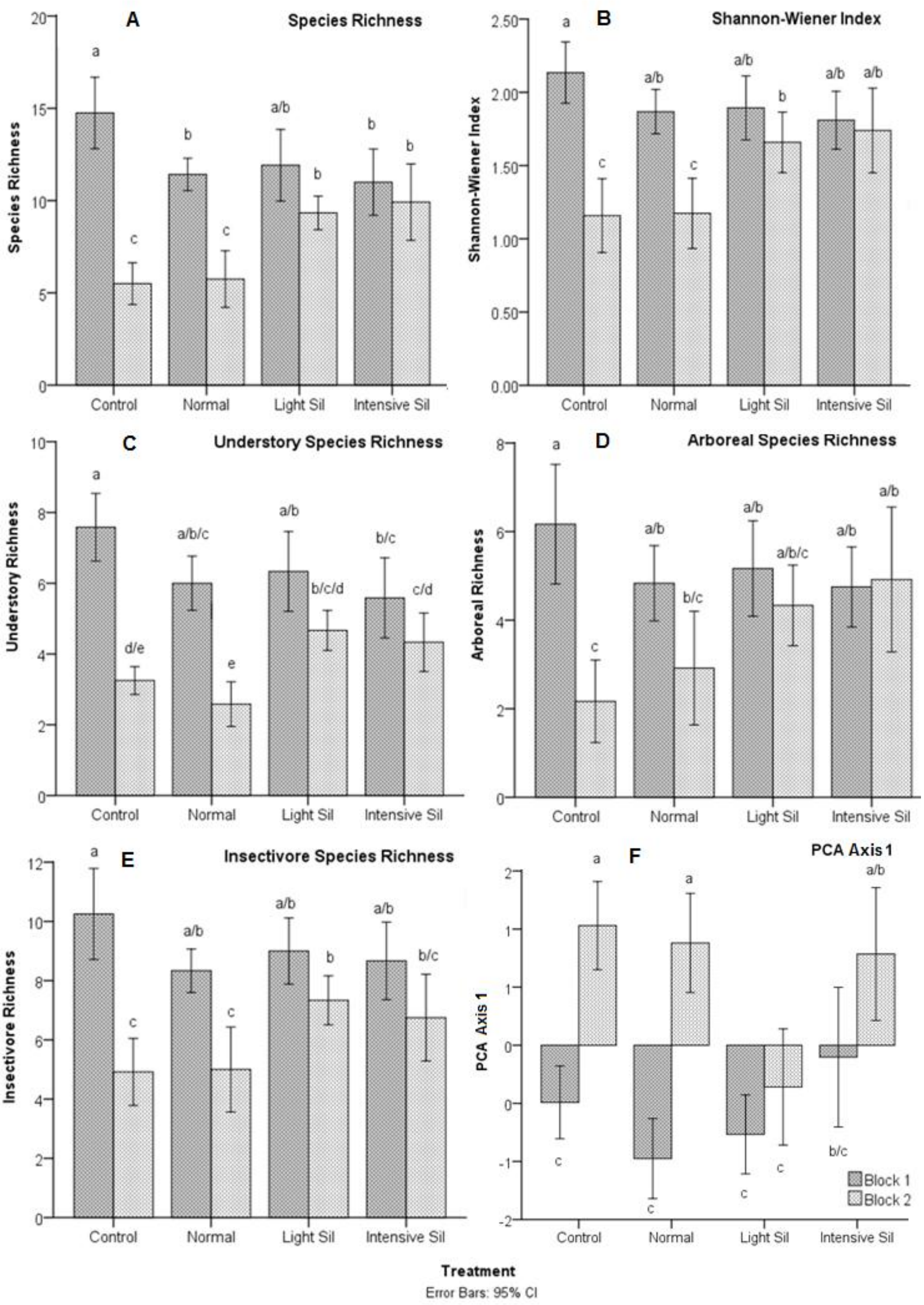


Figure 4: Means and 95% confidence interval are shown for Species Richness (A), Shannon-Wiener Index (B), Understory Richness (C), Arboreal Richness (D), Insectivore Richness (E) and PCA Axis 1 (F). Comparisons are made between the two different blocks (block 1 dark grey bars, block 2 light grey bars) and the treatments. Treatments differ in intensity from unlogged mature forest (control) to logged (normal) with additional silvicultural measures (light and intensive silviculture) and higher logging rates (intensive silviculture). Bars accompanied by a different letter are significantly different at $p < 0.05$ (Tukey post-hoc test).

Differences in treatment effect has been compared for each block separately, analysing the avian parameters that do not follow a normal distribution (Table 5). Important diet types (like Frugivores) that thought to be positively related to forest disturbance show a surprisingly higher richness in the less and undisturbed plots in block 1 (Fig. 5A). Nectarivores appear to be more associated to the highest disturbed plot in block 2 (Fig. 5B). Of the two most species rich guilds (Understory and Bark-gleaning Insectivores), the Understory Insectivores show higher number of species in the light silviculture plots in block 2 and no significant difference in block 1. Bark-gleaning Insectivores have a significant higher richness in the light silviculture plot in block 1 (Fig. 5C,D).

Table 5: Output of the nonparametric Kruskal Wallis test (d.f. 3) of avian parameters that do not follow a normal distribution. These avian parameters are compared between treatment for each block separately. Treatments differ in intensity from unlogged mature forest (control) to logged (normal) with additional silvicultural measures (light and intensive silviculture) and higher logging rates (intensive silviculture). (Arb/Und) Arboreal/Understory; (Und) Understory.

| | **Block 1** | | **Block 2** | |
|---|---|---|---|---|
| | $X^2$ | p | $X^2$ | p |
| **Diet** | | | | |
| Frugivores | 8.9 | 0.030 | 2.4 | n.s. |
| Nectarivores | 4.9. | n.s. | 11.4 | 0.010 |
| Insect/Frugivores | 7.4. | n.s. | 22.5 | <0.001 |
| Omnivores | 12.8 | 0.005 | 3.8 | n.s. |
| **Specific Guilds** | | | | |
| Arboreal Frugivores | 3.5 | n.s. | 2.4 | n.s. |
| Arboreal Insectivores | 3.6 | n.s. | 4.3 | n.s. |
| Arboreal Insect/frugivores | 15.6 | 0.001 | 24.2 | <0.001 |
| Arboreal Omnivores | 12.8 | 0.005 | n.s. | n.s. |
| Bark-gleaning Insectivores (Arb/Und) | 8.3 | 0.040 | n.s. | n.s. |
| Sallying Insectivores (Arb/Und) | 3.9 | n.s. | 6.4 | n.s. |
| Insect/Nectarivores (Und) | 4.9 | n.s. | 11.4 | 0.010 |
| Understory Frugivores | 12.8 | 0.005 | 0 | n.s. |
| Understory Insectivores | 2.1 | n.s. | 18.3 | <0.001 |
| Understory Insect/Frugivores | 3.8 | n.s. | 0 | n.s. |
| Terrestrial Frugivores | 4.7 | n.s. | 0 | n.s. |
| Terrestrial Frugi/insectivores | 3.4 | n.s. | 5.7 | n.s. |
| Terrestrial Insectivores | 11.1 | 0.011 | 0 | n.s. |

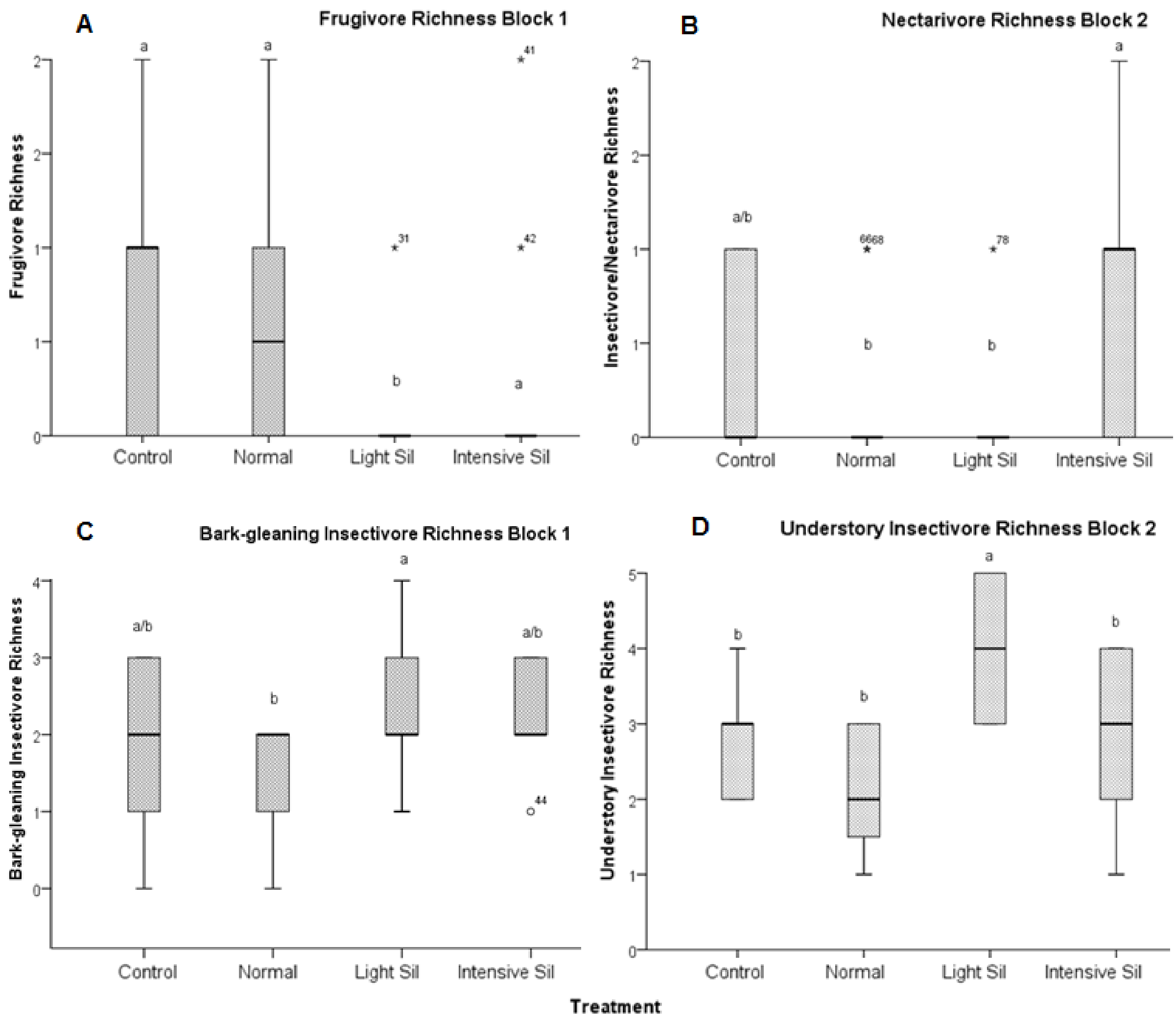


Figure 5: Boxplot are shown for Frugivore Richness block 1 (A), Nectarivore Richness block 2 (B), Bark-gleaning Insectivore Richness block 1 (C) and Understory Insectivore Richness (D). Grey box showing the likely range of variation including the median and bars representing the minimum and maximum numbers of this functional group. These richness's are compared between the different treatments for each block separately. Treatments differ in intensity from unlogged mature forest (control) to logged (normal) with additional silvicultural measures (light and intensive silviculture) and higher logging rates (intensive silviculture). Bars accomplished by a different letter are significantly different at $p < 0.05$.

## 4. Results: Avian community response over time

*4.1 Description of avian community structure*

A total of 889 individuals belonging to 51 species have been observed within the point-transect measurements over the seven studied compartments. The avian community structure was comparable to those of the LTSRP plots. Again more than 50% of the avian community feeds on insects, with 47% foraging in the canopy and 45% in the understory of the forest (Table 6). The two most common species are again the Fawn-breasted Wren (*Cantorchilus guarayanus*) and Bolivian Slaty Antshrike (*Thamnophilus sticturus*), measured in each sample point. Other abundant species are Tropical Parula (*Setophaga pitiayumi*), Olivaceous Woodcreeper (*Sittasomus griseicapillus*), Black-capped Antwren (*Herpsilochmus atricapillus),* Buff-throated Woodcreeper (*Xiphorhynchus guttatus*), White-backed Fire-eye (*Pyriglena leuconota)*, Guira Tanager (*Hemithraupis guira)* Golden Crowned Warbler (*Basileuterus culicivorus*) and Hummingbird spec. (*Trochilidae spec.).*

Table 6: Percentage and total number (between brackets) of species and composition measured during point-transect sampling of 84 sample points (12 sample points per compartment) within the compartments logged by INPA. Total richness indicates all the different species observed all compartments and total observations are the sum of all individual species observed in all compartments. Other totals are all the different species belonging to that diet and foraging layer observed in all compartments.

| Years post-logging | 1 | 2 | 4 | 6 | 8 | 10 | Mature | Total |
|---|---|---|---|---|---|---|---|---|
| **Species** | | | | | | | | |
| Richness | 27 | 29 | 25 | 25 | 31 | 27 | 31 | 51 |
| Observations | 130 | 133 | 133 | 119 | 118 | 129 | 127 | 889 |
| **Diet** | | | | | | | | |
| % Frugivores | 3,7 (1) | 6,9 (2) | 8 (2) | 8 (2) | 9,7 (3) | 7,4 (2) | 3,2 (1) | 9,8 (5) |
| % Insectivores | 66,7 (18) | 58,6 (17) | 60 (15) | 68 (17) | 61,3 (19) | 63 (17) | 61,3 (19) | 54,9 (28) |
| % Insect/Frugivores | 18,5 (5) | 24,1 (7) | 20 (5) | 20 (5) | 19,4 (6) | 14,8 (4) | 22,6 (7) | 21,6 (11) |
| % Insect/Nectarivores | 11,1 (3) | 10,3 (3) | 12 (3) | 4 (1) | 6,5 (2) | 14,8 (4) | 9,7 (3) | 11,8 (6) |
| % Omnivores | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 3,2 (1) | 0 (0) | 3,2 (1) | 2 (1) |
| **Foraging Layer** | | | | | | | | |
| % Understory Species | 51,9 (14) | 48,3 (14) | 44 (11) | 44 (11) | 38,7 (12) | 48,1 (13) | 48,4 (15) | 45,1 (23) |
| % Arboreal Species | 40,7 (11) | 44,8 (13) | 48 (12) | 52 (13) | 48,4 (15) | 40,7 (11) | 41,9 (13) | 47,1 (24) |
| % Terrestrial Species | 7,4 (2) | 6,9 (2) | 8 (2) | 4 (1) | 12,9 (4) | 11,1 (3) | 9,7 (3) | 7,8 (4) |

The avian community is dominated by Insectivore species (55% of all species) divided over three dominant guilds; Sallying Insectivores (19.6 %), Bark-gleaning Insectivores (17.6 %) and Understory Insectivores (15.7 %) (Table 7). Sallying Insectivores consist mainly of Flycatchers, Bark-gleaning Insectivores of Woodpeckers and Woodcreepers and Understory Insectivores of small understory passerines.

Table 7: Percentage and total number (between brackets) of the guild composition measured during point-transect sampling of 84 sample points (12 sample points per compartment) within the compartments logged by INPA. Total are all the different species belonging to that guild observed in all compartments.

| Years post-logging | 1 | 2 | 4 | 6 | 8 | 10 | Mature | Total |
|---|---|---|---|---|---|---|---|---|
| % Arboreal Frugivores | 0 (0) | 6,9 (2) | 4 (1) | 4 (1) | 6,5 (2) | 3,7 (1) | 3,2 (1) | 5,9 (3) |
| % Arboreal Insectivores | 14,8 (4) | 10,3 (3) | 8 (2) | 12 (3) | 9,7 (3) | 14,8 (4) | 12,9 (4) | 7,8 (4) |
| % Arboreal Insect/Frugivores | 7,4 (2) | 6,9 (2) | 8 (2) | 12 (3) | 6,5 (2) | 7,4 (2) | 9,7 (3) | 7,8 (4) |
| % Arboreal Omnivores | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 3,2 (1) | 0 (0) | 3,2 (1) | 1,9 (1) |
| % Bark-gleaning Insectivores | 14,8 (4) | 17,2 (5) | 20 (5) | 24 (6) | 16,1 (5) | 14,8 (4) | 9,7 (3) | 17,6 (9) |
| % Insect/Nectarivores | 11,1 (3) | 10,3 (3) | 12 (3) | 4 (1) | 9,7 (3) | 14,8 (4) | 9,7 (3) | 11,8 (6) |
| % Sallying Insectivores | 22,2 (6) | 13,8 (4) | 16 (4) | 16 (4) | 12,9 (4) | 7,4 (2) | 19,4 (6) | 19,6 (10) |
| % Terrestrial Frugivores | 3,7 (1) | 0 (0) | 4 (1) | 0 (0) | 3,2 (1) | 3,7 (1) | 0 (0) | 1,9 (1) |
| % Terrestrial Frugi/Insectivores | 3,7 (1) | 6,9 (2) | 4 (1) | 4 (1) | 6,5 (2) | 3,7 (1) | 6,5 (2) | 3,9 (2) |
| % Terrestrial Insectivores | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 3,2 (1) | 3,7 (1) | 3,2 (1) | 1,9 (1) |
| % Understory/Frugivores | 0 (0) | 0 (0) | 0 (0) | 4 (1) | 0 (0) | 0 (0) | 0 (0) | 1,9 (1) |
| % Understory Insectivores | 22,2 (6) | 24,1 (7) | 24 (6) | 20 (5) | 19,4 (6) | 22,2 (6) | 19,4 (6) | 15,7 (8) |
| % Understory Insect/Frugivores | 0 (0) | 3,4 (1) | 0 (0) | 0 (0) | 3,2 (1) | 3,7 (1) | 3,2 (1) | 1,9 (1) |

### *4.2 Response of the avian community over time*

There are no significant differences in Species Richness and Shannon-Wiener diversity among the six logged and the mature forest compartments (One-way ANOVOA, Table 8 & Fig. 6A,B). The variation in bird species composition is explained by the first and second component of the Principal Component Analysis, which separates the two oldest logged compartment from the most recently logged compartments (annex 2B), although no clear trend is visible. Understory and insectivore species declined significantly over time (Regression analysis, p=0.045 and p=0.042 respectively). However mature forest stands had again a higher understory and insectivore species richness, which is comparable to the most recently logged forest stands (Fig. 6C,E). Other avian parameters like Nectarivore species and Arboreal Insectivore species declined after logging to increase again in the later logged stands (Fig. 6D,F). Bark-gleaning Insectivores like Woodcreepers (*Dendrocolaptinae*) and Woodpeckers (*Picidae*) significantly decreased over time and maintained low values in mature forest stands (Fig. 6H). Only Arboreal Insect/Frugivores tend to increase over time though having lower numbers in mature forest stands (Fig. 6G).

Table 8: Output of One-way ANOVA (d.f. 6) and Regression results of avian parameters that are normally distributed (except for the Nectarivore, Arboreal Insectivore, Arboreal Insect/Frugivore, Bark-gleaning Insectivore, Terrestrial Frugivore and Terrestrial Insectivore richness's) based on the 84 sample points (12 sample points per compartment). Regression analysis was carried out using all 6 logged compartments, thus excluding the mature forest plot. Trend lines were tested for the best explaining fit, either following a linear trend or an optimum trend (quadratic).

| | **One-way ANOVA** | | **Regression** | | | |
|---|---|---|---|---|---|---|
| | F | p | F | p | $R^2$ | Trend |
| **Species** | | | | | | |
| Species Richness (S) | 0.5 | n.s. | - | - | - | - |
| Shannon-Wiener (H') | 0.6 | n.s. | - | - | - | - |
| **Foraging Layer** | | | | | | |
| Understory Richness | 1.8 | n.s. | 4.2 | 0.045 | 0.058 | Linear |
| Arboreal Richness | 0.3 | n.s. | - | - | - | - |
| **Diet** | | | | | | |
| Insectivore Richness | 1.3 | n.s. | 4.3 | 0.042 | 0.056 | Linear |
| Nectarivore Richness | - | - | 3.4 | 0.037 | 0.092 | Quadratic |
| **Specific Guilds** | | | | | | |
| Arboreal Insectivores | - | - | 3.9 | 0.025 | 0.080 | Quadratic |
| Arboreal Insect/Frugivores | - | - | 14.2 | <0.001 | 0.168 | Linear |
| Bark-gleaning Insectivores | - | - | 8.2 | 0.006 | 0.105 | Linear |
| Terrestrial Frugivores | - | - | 5.9 | 0.018 | 0.078 | Linear |
| Terrestrial Insectivores | - | - | 6.5 | 0.013 | 0.085 | Linear |
| **Composition** | | | | | | |
| PCA Axis 1 | 11.8 | <0.001 | - | - | - | - |
| PCA Axis 2 | 3.0 | 0.010 | - | - | - | - |

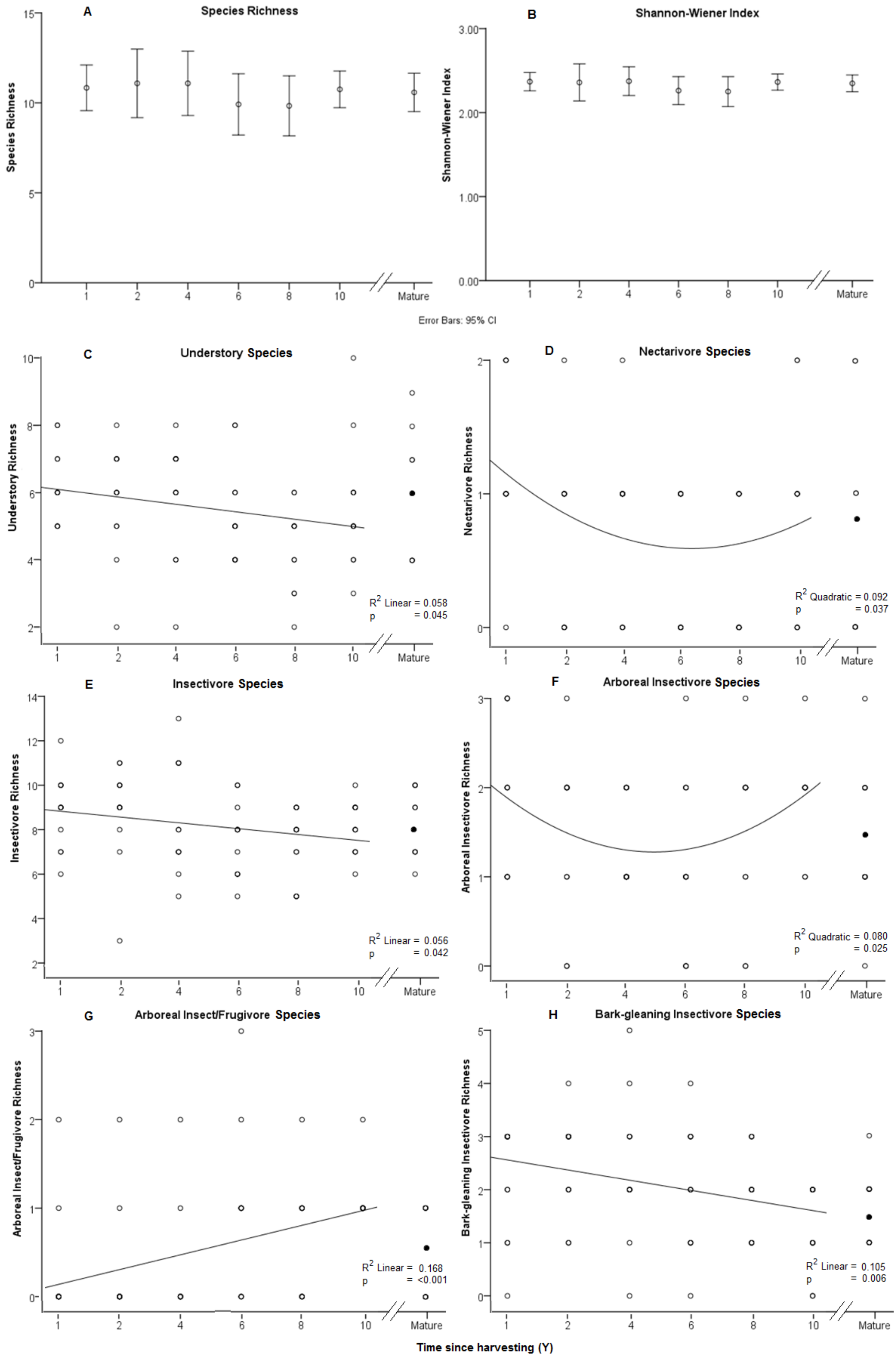


Figure 6: Development of richness of species and guilds with time after logging. Mature forest (Mature) was included as a reference. For species richness (A) and diversity (B) means and confidence interval are shown based on 12 sample point per compartment. For the other response variables (C-H) a regression analysis was done based on 12 sample points per compartments. Not all sample points are visible as some do overlap in numbers. Black points are average richness for the mature forest compartment.

When looking at individual species responses towards logging, only 5 out of the 51 evaluated species (10 %) show a significant response. Hummingbird spec. (*Trochilidae spec.*) Buff-throated Woodcreeper (*Xiphorhynchus guttatus*) and White-backed Fire-eye (*Pyriglena leuconota*) show a decreasing trend over time, while two flycatcher species, Fuscous Flycatcher (*Cnemotriccus fuscatus*) and Southern Antpipit (*Corythopis delalandi*) show an increasing trend over time (Table 9).

Table 9: Output of binary regression results of individual species that do show a significant response bases on the presence and absence data of the 84 sample points (12 sample points per compartment).

| Species | Wald | p |
|---|---|---|
| Hummingbird spec. | 6.6 | 0.010 |
| Buff-throated Woodcreeper | 12.4 | <0.000 |
| White-backed Fire-eye | 6.9 | 0.009 |
| Fuscous Flycatcher | 4.6 | 0.032 |
| Southern Antpipit | 4.5 | 0.034 |

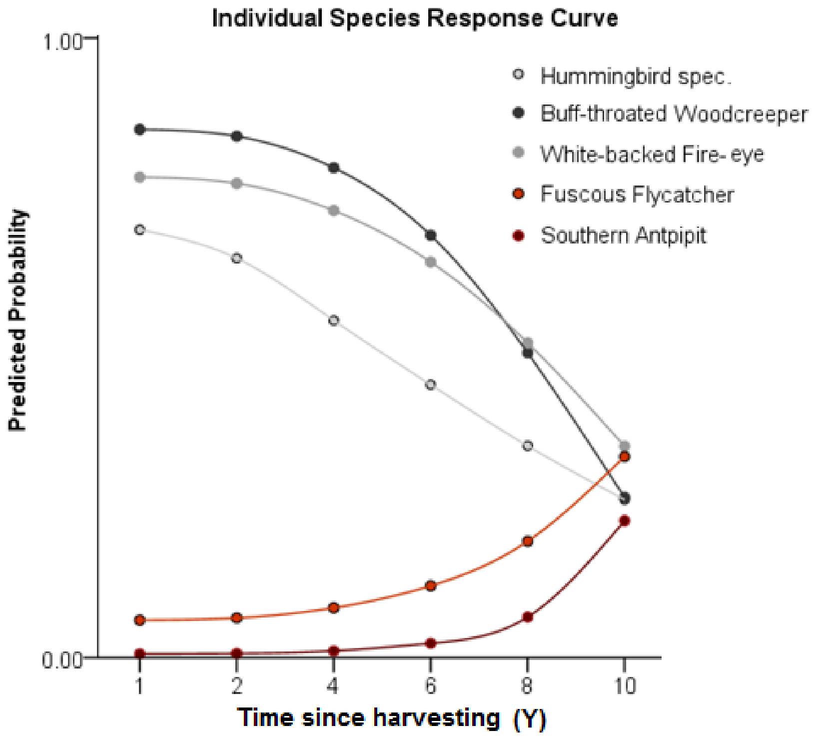


Figure 7: Individual response curves of the predicted probability of species that do show a significant response bases on the presence and absence data of the 84 sample points (12 sample points per compartment).

## 5. Discussion: Treatment effects on the avian community structure

In this study we focused on the effect of different logging intensities and silvicultural treatments on avian community composition looking at a variety of avian parameters (richness, diversity, abundance and composition). It was hypothesised that these differences in intensities and treatments create different microhabitats and increases food availability for birds. This results in an overall higher richness, however, this increase in richness goes accompanied with a shift in composition where some functional groups benefit (nectarivores and frugivores) and others loose (insectivores). It was expected that especially understory insectivore species would suffer from the increase in logging intensity as this group is highly susceptible to changes caused by logging. The main results of this study in the Long-term Silvicultural Research plots showed that there is a clear difference in total richness and functional group richness's between the two different studied blocks and that the treatment effect itself showed little influence on the avian community. When separating the two areas, logging intensity and different silvicultural treatments do have an effect on the avian community though showing opposite trends between blocks.

*5.1 Treatment effects on the avian community*

*5.1.1 Species richness & diversity*

The most striking difference in species richness and diversity was found between the two different studied blocks, with a significant higher richness and diversity in block 1 compared to block 2 (Table 2). Possible causes that explain these differences will be addressed later. Looking at just the effect of different treatments (Table 3), species richness as well as Shannon-Wiener diversity are significantly lower in the 'normal logging' plot, harvested according the Bolivian forestry law using RIL techniques. Richness in plots with additional silvicultural treatments (LS, IS) and increased logging intensity (IS) were comparable and even higher than the undisturbed control plot (Table 4). A clearer treatment effect was visible when separating the two areas. Species richness increased with disturbance intensity in block 2, like we expected, however decreased in block 1.

Different logging intensities and additional silvicultural measures therefore appear to have little effect on total richness 10 years post logging in the Chiquitano dry forest. Although a higher richness and diversity was observed in the more disturbed plots in block 2, coinciding with the stated hypothesis that disturbance creates more habitats for a larger range of species (de Iongh & van Weerd 2006), an opposite trend was witnessed in block 1. The significant lower numbers of species in the 'normal logged' plot cannot be explained solely by the effect of logging as 'LS' and 'IS' plots are two logging treatments with comparable richness levels as the unlogged control plot (Table 4).

*5.1.2 Functional groups*

As with total species richness, also the richness's of several functional groups (understory, arboreal, terrestrial and insectivore richness) showed a prominent difference between blocks. Only understory species showed a significantly lower richness in the 'normal logged' plot when looking at just treatment effect itself. Again a clearer treatment effect was visible when separating the two blocks. Significantly higher numbers of understory, arboreal and insectivore species were witnessed in the unlogged control plot compared to the logged plots in block 1. Completely opposite results were observed in block 2, with the highest numbers in either 'LS' or 'IS' plots (Fig. 4C,D,E).

We hypothesised that avian nectarivores and frugivores would increase with an increased logging intensity, due to a raise in flower and fruit availability of mainly vines that react positively to an opened forest structure after logging (Thiollay 1992; Mason 1996; Mason & Thiollay 2001; Meijaard et al. 2005). However, we found this trend only in block 2, with a significant higher number of nectarivores in the most disturbed plot (IS). No significant differences were seen in block 1 (Table 5). An opposite result was observed for frugivores, with significant higher numbers in the un-logged and normal plot (Table 5). It was also hypothesised that insectivore species are affected negatively by logging, as logging alters the preferred foraging habitat (Thiollay 1992; Thiollay 1997; Mason & Thiollay 2001). However only block 2 demonstrates a significant higher number of insectivore species in the light silviculture treatment compared to the un-logged and normal plot (Table 5).

#### *5.1.3 Understory insectivores*

The most susceptible group to logging is likely to be the understory insectivores (Johns 1991, Thiollay 1992; Gray et al. 2007; Felton et al. 2008). We hypothesized significant lower numbers of understory insectivores in plots with higher logging rates and additional silvicultural measures, because understory insectivore species tend to need open understory under a closed canopy as the most ideal foraging habitat (Mason & Thiollay 2001; de Iongh & van Weerd 2006). Logging generates the opposite conditions, creating a dense understory of regenerating trees and fast growing vines under an open canopy (Mason & Thiollay 2001; Putz et al. 2008). Contrary to this hypothesis, understory insectivore species seemed not to be affected by this change in forest structure as numbers were significantly higher in the 'LS' plot (Fig. 5D). Logging seems not to be the explaining factor as it would be expected that also other logging treatments would promote the presence of this functional group.

A study on understory insectivore species carried out in the same area in 2005, showed that a higher richness was found in the unlogged control plot, though higher abundances in the most disturbed (IS) plot (Flores & Martinez 2007). These results coincide with the results of this study, when only taking block 1 into account. In the study of 2005 a total of 13 understory species in all the sample points were observed compared to 21 species during this study. This large difference in understory richness suggest that species numbers and composition may vary from year to year.

### *5.2 Explaining factors*

#### *5.2.1 Differences in microhabitat*

The explanation of differences in richness and diversity among the two blocks could be because block 2 is located 20.7 km north of block 1, comprising of a different floristic composition as it is drier and located at a higher altitude than block 1. There also might have been presence of fire in the past (Lourens Poorter, personal communication, September 2012). As logging seems not to be the explaining factor for differences in community structures and richness, other factors could explain differences among treatments. Different microhabitats between plots within a single block can explain the presence or absence of functional groups and individual species. Therefore species are unevenly distributed over the area. The presence of a creek in the unlogged control plot in block 1 can explain the higher richness of understory and insectivore species, as more food will be available as many insects use water bodies to reproduce (Ghazoul & Hill 2001). A difference in altitude and steepness of the hills observed in the intensive silviculture plot in block 2, create different habitats possibly positively affecting the distribution of different bird species. But also the presence and absence of fruiting trees will affect the distribution of many frugivore species. Another explanation for the unexpected distribution of frugivores as well as nectarivores could be that the boom of flowering and fruiting of trees and vines is not as prolific 10 years post-harvesting.

### *5.2.2 Forest structure*

The forest matrix is largely maintained as the executed logging activities minimally fragment the continuity of the forest, therefore little affecting this mobile class of species (Johns 2001). The low intensity of the executed selective logging in the INPA concession (4-6 trees $ha^{-1}$) can be an explaining factor for the little effect it has on the bird community, as logging does not clearly change the conditions of the forest structure. The difference in understory denseness with regenerating trees and woody vines do not differ much between logged and unlogged stands (personal observation). Furthermore logging little changes the openness of the canopy by tree removal, as the canopy opens each dry season as trees shed their leaves in this period (Villegas et al. 2009). These harsh conditions possibly make this avian community less responsive to changed caused by logging.

## *5.3 Supporting results*

In a resent meta-analysis on the effect of selective logging on tropical forest ecosystems and biodiversity based on 36 papers concerning birds globally, Putz et al. (2012) also state that selective logging has little effect on the avian community, with an average loss of 15% of avian species richness. In this study an average decrease of 9% was found comparing the normal logged plot to the undisturbed control plot (with a decrease of 23% in block 1 and an increase of 5% in block 2). According to most of the studies, functional groups like (understory) insectivores are affected negatively while frugivores and nectarivores are affected positively. This is confirmed by studies executed in the CELOS Management System situated in Suriname where approximately 30 $m^3$ $ha^{-1}$ is harvested (Werger 2011).

It is also stated that important (logging-related) threats to the avian community are most likely the higher risk of fire and hunting as the area is opened or when minimal harvest cycles/diameters are not respected, than by controlled selective logging itself (Putz et al. 2012). These threats do not affect the avian community in the INPA forest concession as it is protected and managed according FSC requirements.

## 6. Discussion: Avian community responses over time

This part of the study focuses on the responses of the avian community over time after logging and evaluates whether the avian community recovers towards its original state (unlogged mature forest). It is hypothesised that all tested avian parameters (richness, diversity, abundance and composition) will recover towards the original state over time, though different functional groups respond differently. It is expected that right after logging total species richness as well as some functional groups (nectarivores and frugivores) increase due to an increased food availability and creation of different microhabitats. On the other hand especially (understory) insectivores will respond negatively right after logging due to an in favourable forest structure for foraging. The most striking result of this study is that none of the 6 logged forest stands differ in any of the parameters from a unlogged mature forest stand. Some functional groups like understory species, insectivore species and bark-gleaning insectivore species show a significant decreasing trend over time since logging.

*6.1 Avian community responses*

Selective logging executed in the Chiquitano dry forest according to FSC requirements and the adherence to the Bolivian forestry law, using RIL techniques has no to very little impact on the avian community. Total richness as well as other important avian parameters do not differ among compartments logged at different years (Table 8). Slight differences in richness, diversity and abundances can be explained by differences in microhabitats from compartment to compartment, as the forest as a whole is not homogenous. The presence of small water bodies as well as geographical differences alter the abundance of food and specific niches (Ghazoul & Hill 2001). Also differences in floristic composition between compartments can explain this differences in avian abundance and richness.

When looking at specific functional groups, some significant trends were visible over time. Understory as well as insectivores showed a significant decrease (Fig. 6C,E), though having similar numbers right after logging compared to mature forest stands. This decrease can be explained by the fact that right after logging the understory is still open. This will change as the understory will become more dense in upcoming years, affecting understory and insectivore species negatively as foraging habitat alters (Johns 1988; Mason & Thiollay 2001; Putz et al. 2008). Focussing on even more specific functional groups, bark-gleaning insectivores like Woodcreepers (*Dendrocolaptinae*) and Woodpeckers (*Picidae*) also showed this decreasing trend over time. Logging itself causes damage to standing trees resulting in a higher mortality of trees (Johns 1988; Mason & Thiollay 2001). This positively affects species that forages on dead trees. Over time, numbers of dead trees will decrease towards a more natural amount present in mature forests. This trend was also visible when looking at the level of individual species within this group. Buff-throated Woodcreeper (*Xiphorhynchus guttatus)* as well as Pale-crested Woodpecker (*Celeus lugubris*) tend to increase straight after logging, plummeting in numbers the following years.

Arboreal insect/frugivores were positively affected over time post logging. These species are more generalist as they forage on a broader scale of diets (Meijaard et al. 2005). Logging positively affects the fruiting of lianas as well as trees, therefore creating a higher abundance of food for this functional group (Meijaard et al. 2005). This trend was not visible for species solely feeding on fruits.

Nectarivores are thought to be positively affected by logging but showed a decrease over time in this study. Having highest numbers right after logging, possibly due to an increase in flowering of trees and vines, numbers plummet in the following years. This could be explained by the fact that the abundant flowering only last a couple of years.

Other changes in individual species and functional group responses were negligible. The little effect of logging can be explained by the harsh conditions of this forest type. Understory is dense and canopy experiences annual opening as trees shed their leaves in the dry period (Villegas et al. 2009). This might minimise the effect of logging itself on the avian community as logging does not dramatically change the conditions compared to the natural dynamics in a mature forest.

Overall these results coincide with previous executed studies (Johns 1991, Thiollay 1992; Gray et al. 2007; Felton et al. 2008), where understory as well as insectivore species tend to be effected negatively. But also supporting the view that selective logging can be seen as being sustainable as little of the avian community is affected (Putz et al. 2012). These forest can be of high conservation value when logged sustainably, respecting minimum harvesting cycles and cutting diameters, prevention of land-use conversion, fire and hunting. Selective logging following FSC requirements is a possible sustainable way of extracting timber with a minimum effect on the ecosystem in the Chiquitano dry forest.

## 7. Recommendations

*7.1 Strengths and limitations*

As little is known about the effect of logging on the avian community in the Chiquitano dry tropical forest, this study strengthened the knowledge of the influence of logging on this ecosystem. The implemented experimental set-up with different logging intensities creates a great opportunity to measure the influence of logging intensities and silvicultural treatments on the environment. This is of high importance in order to reach the point where economic goals can be met with the least negative influence on the ecosystem. Also the site of the INPA Parket (Ltda) concession is a unique setting to assess the effect of implemented logging techniques on avian community responses. As this forest is harvested over a time span of 25 years, it provides a great experiment to evaluate bird responses over time.

As little is known about avian community responses in dry tropical forests, most hypothesis were based on logging effects in moist tropical forests. It is therefore important to gather data in this ecosystem because we assume that the environmental conditions of the dry tropical forest in INPA are not comparable to those of moist tropical forest types. Also the avian community did not respond as we expected, assuming that avian community responses to logging are not comparable to those in moist/wet tropical forest types.

Limitations of this study were that it would have been preferable to have more experimental set-ups with different logging intensities distributed over the concession in order to have more data-points. By comparing only two areas, many other factors can blur the actual effect of logging when it is there. This was visible in this study, where the two different blocks show opposite results. Due to logistic and economic boundaries, the implantation of more experimental set-ups was not possible. It is also uncertain whether birds, due to their mobility, were affected by changes caused by logging in an area of approximately 21 ha, as this plot is surrounded by a logging compartment logged 10 years ago.

When looking at the chronosequence study, we compared 6 logged stand to a 1 unlogged (mature) forest stand. It could be possible that this unlogged stand by chance was not comparable to an actual mature forest stand in the Chiquitano dry forest. It would therefore be preferable to have more unlogged control stand as well as logged stands of similar ages. Though it was preferable to have more sample points in similar forest stand distributed over a larger area, multiple compartments of similar ages are not present in the INPA concession.

*7.2 Recommendation for future studies*

When logging was not the explaining factor for changes in bird community structures between different treatments and different logged stands, which factor do explain these changes? In order to evaluate other environmental factors influencing bird community structure, additional data should be gathered on floristic composition and microhabitat structures. A comparison of floristic composition, standing basal area and possible geographical factors explaining these differences between blocks was beyond the scope of this study, but will be addressed in future analysis.

Beside this additional data, it is preferable to increase sample points or distribute sample points over a larger area in plots and compartments with similar logging intensities and age. In this study we measure avian community changes over a time span of 10 years. This should be continued as it is necessary to see the effect of logging over a full cycle of 25 years. But also additional data should be gathered in the Long-term Silvicultural research Plots in order to see the bird responses over time related to different logging intensities.

## 8. Conclusion

The main questions for this study were, (1) how does different logging intensities and silvicultural treatments (normal reduced impact logging, additional light silvicultural measures and additional intensive silvicultural measures) affect the avian community structure; (2) How does the avian community responses en recovers over time since logging and (3) which avian functional groups can be used as possible indicators for sustainable harvesting.

It appears that difference in logging intensity and additional silvicultural measures has little effect on the avian community 10 years post logging in the Chiquitano dry forest. Also the executed selective logging in the INPA concession following FSC requirements and the adherence to the Bolivian forestry law, using RIL techniques has no to very little impact on the avian community. Differences in richness, diversity, abundance and composition cannot solely be explained by logging. Possible other factors like floristic composition, presence or absence of fruiting trees, geographical differences, plot specific differences, presence of water bodies and other microhabitat differences explain the avian distribution over the area. To see which other factors explain the differences in avian community structures in the Chiquitano dry forest was beyond the scope of this study but will be addressed in future analysis. As no clear avian functional group responses were observed, little can be stated on the use of functional groups as indicators for sustainable harvesting in the Chiquitano dry forest.

## Acknowledgement

I owe special thanks to my supervisors Lourens Poorter and Betty Flores in order to make this thesis project in Bolivia possible. But also for all the help in the field, coaching in all phases of this study and financial support. This is very much appreciated.

I would like to thank Luz Natalia Mercado, Marisol Toledo and Alfredo Alarcon from the Instituto Boliviano de Investigacion Forestal (IBIF), which supported me during my stay in Santa Cruz, Bolivia. They made it possible to use their equipment and logistic arrangements were made by them in order to conduct fieldwork in their field station in the INPA Parket (Ltd) concession.

Many thanks go out to the owner of INPA Parket (Ltd) Paul Rozenboom, to make my stay in their concession possible and comfortable. Furthermore thanks go out to Urbano Choque Lopez and Daniel Belasques, to support me with necessary information and maps as well as with the logistics to enter the field station.

In the field I was greatly assisted by Marcellino, Victor Hugo Hurtado and Ricardo Mendes. Many thanks for all the kilometres of transects they have cut and for all their great stories. Furthermore I would like to thank Estela Quintero Vallejo for the good times and all the useful information she gave me to spent time in the field. Thanks also go out to Jan van den Hoeven for using his field recorder to record all the hours of bird sounds.

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## Appendix 1: Bird species observed in INPA Parket (Ltda) Concession

Appendix 1: All bird species observed in the INPA Parket (Ltda) Concession. This table includes scientific, English and Spanish nomenclature, as well as species red list IUCN status (LC: Least Concern), country endemism and whether the birds were observed in sample points of the Long-Term Silvicultural Research Program or in Sample points of the compartments harvested annually by INPA.

| Scientific name | English name | Nobre Espaniol | IUCN Status | Country Endemic | Observed in plots LTSRP | Observed in plots COMP. |
|---|---|---|---|---|---|---|
| ***Tinamidae*** | **Tinamous** | | | | | |
| *Crypturellus undulatus* | Undulated Tinamou | Tinamú Ondulado | LC | No | X | X |
| *Crypturellus tataupa* | Tataupa Tinamou | Tinamú Tataupá | LC | No | X | X |
| ***Anhingidae*** | **Anhingas & Darters** | | | | | |
| *Anhinga anhinga* | Anhinga | Anhinga Americana | LC | No | - | - |
| ***Ardeidae*** | **Herons & Bitterns** | | | | | |
| *Pilherodius pileatus* | Capped Heron | Garza Capirotada | LC | No | - | - |
| *Butorides striata* | Striated Heron | Garcita Azulada | LC | No | - | - |
| ***Anhimidae*** | **Screamers** | | | | | |
| *Chauna torquata* | Southern Screamer | Chajá Común | LC | No | - | - |
| ***Anatidae*** | **Ducks, Geese & Swans** | | | | | |
| *Cairina moschata* | Muscovy Duck | Pato Criollo | LC | No | - | - |
| ***Cathartidae*** | **New World Vultures** | | | | | |
| *Cathartes melambrotus* | Greater Yellow-headed Vulture | Aura Selvática | LC | No | - | - |
| *Cathartes aura* | Turkey Vulture | Aura Gallipavo | LC | No | - | - |
| *Sarcoramphus papa* | King Vulture | Zopilote Rey | LC | No | - | - |
| ***Accipitridae*** | **Kites, Hawks & Eagles** | | | | | |
| *Elanoides forficatus* | Swallow-tailed Kite | Elanio Tijereta | LC | No | - | - |
| *Ictinia plumbea* | Plumbeous Kite | Elanio Plomizo | LC | No | - | - |
| *Chondrohierax uncinatus* | Hook-billed Kite | Milano Pico de Garfio | LC | No | - | - |
| *Buteo magnirostris* | Roadside Hawk | Busardo Caminero | LC | No | - | - |
| *Buteogallus urubitinga* | Great Black Hawk | Busardo-negro Urubitinga | LC | No | - | - |
| ***Falconidae*** | **Caracaras & Falcons** | | | | | |
| *Falco sparverius* | American Kestrel | Cernícalo Americano | LC | No | - | - |
| ***Cracidae*** | **Chachalacas, Curassows & Guans** | | | | | |
| *Penelope superciliaris* | Rusty-margined Guan | Pava Yacupemba | LC | No | X | X |

| Scientific name | English name | Nobre Espaniol | IUCN Status | Country Endemic | Observed in plots LTSRP | Observed in plots COMP. |
|---|---|---|---|---|---|---|
| *Crax fasciolata* | Bare-faced Curassow | Pavón Muitú | LC | No | - | - |
| ***Eurypygidae*** | **Sunbittern** | | | | | |
| *Eurypyga helias* | Sunbittern | Tigana | LC | No | - | - |
| ***Aramidae*** | **Limpkin** | | | | | |
| *Aramus guarauna* | Limpkin | Carrao | LC | No | - | - |
| ***Rallidae*** | **Rails, Crakes & Coots** | | | | | |
| *Aramides cajaneus* | Grey-necked Wood Rail | Cotara Chiricote | LC | No | - | - |
| *Porphyrio martinicus* | Purple Gallinule | Calamoncillo Americano | LC | No | - | - |
| ***Jacanidae*** | **Jacanas** | | | | | |
| *Jacana jacana* | Wattled Jacana | Jacana Suramericana | LC | No | - | - |
| ***Columbidae*** | **Pigeons & Doves** | | | | | |
| *Columbina talpacoti* | Ruddy Ground Dove | Columbina Colorada | LC | No | - | - |
| *Claravis pretiosa* | Blue Ground Dove | Tortolita Azulada | LC | No | X | X |
| *Patagioenas speciosa* | Scaled Pigeon | Paloma Escamosa | LC | No | X | X |
| *Leptotila verreauxi* | White-tipped Dove | Paloma Montaraz Común | LC | No | X | - |
| ***Psittacidae*** | **Parrots** | | | | | |
| *Primolius auricollis* | Golden-collared Macaw | Guacamayo Acollarado | LC | No | - | - |
| *Pyrrhura molinae* | Green-cheeked Parakeet | Cotorra de Molina | LC | No | - | - |
| *Brotogeris chiriri* | Yellow-chevroned Parakeet | Catita Versicolor | LC | No | - | - |
| ***Cuculidae*** | **Cuckoos** | | | | | |
| *Coccyzus erythropthalmus* | Black-billed Cuckoo | Cuclillo Piquinegro | LC | No | - | - |
| *Coccyzus americanus* | Yellow-billed Cuckoo | Cuclillo Piquigualdo | LC | No | - | - |
| *Piaya cayana* | Squirrel Cuckoo | Cuco-ardilla Común | LC | No | X | X |
| *Crotophaga major* | Greater Ani | Garrapatero Mayor | LC | No | - | - |
| *Crotophaga ani* | Smooth-billed Ani | Garrapatero Aní | LC | No | - | - |
| ***Strigidae*** | **Owls** | | | | | |
| *Megascops choliba* | Tropical Screech Owl | Autillo Chóliba | LC | No | - | - |
| *Glaucidium brasilianum* | Ferruginous Pygmy Owl | Caburé | LC | No | - | - |
| ***Nyctibiidae*** | **Potoos** | | | | | |
| *Nyctibius griseus* | Common Potoo | Nictibio Urutaú | LC | No | - | - |
| ***Caprimulgidae*** | **Nightjars** | | | | | |
| *Nyctidromus albicollis* | Pauraque | Chotacabras Pauraque | LC | No | - | - |

| Scientific name | English name | Nobre Espaniol | IUCN Status | Country Endemic | Observed in plots LTSRP | Observed in plots COMP. |
|---|---|---|---|---|---|---|
| ***Apodidae*** | **Swifts** | | | | | |
| *Chaetura brachyura* | Short-tailed Swift | Vencejo de Cola Blanca | LC | No | - | - |
| ***Trochilidae*** | **Hummingbirds** | | | | | |
| *Phaethornis subochraceus* | Buff-bellied Hermit | Ermitaño Ocráceo | LC | No | X | X |
| *Thalurania furcata* | Fork-tailed Woodnymph | Zafiro Golondrina | LC | No | X | X |
| *Hylocharis cyanus* | White-chinned Sapphire | Zafiro Gorgiblanco | LC | No | X | X |
| *Chlorostilbon lucidus* | Glittering-bellied Emerald | Esmeralda Ventridorada | LC | No | - | X |
| *Hylocharis chrysura* | Gilded Hummingbird | Zafiro Bronceado | LC | No | - | X |
| *Anthracothorax nigricollis* | Black-throated Mango | Picaflor Vientre Negro | LC | No | - | - |
| *Heliomaster longirostris* | Long-billed Starthroat | Colibrí Piquilargo | LC | No | - | - |
| ***Trogonidae*** | **Trogons** | | | | | |
| *Trogon curucui* | Blue-crowned Trogon | Trogón Curucuí | LC | No | X | X |
| ***Alcedinidae*** | **Kingfishers** | | | | | |
| *Megaceryle torquata* | Ringed Kingfisher | Martín Gigante Neotropical | LC | No | - | - |
| ***Momotidae*** | **Motmots** | | | | | |
| *Momotus momota* | Amazonian Motmot | Momoto Común | LC | No | X | X |
| ***Bucconidae*** | **Puffbirds** | | | | | |
| *Monasa nigrifrons* | Black-fronted Nunbird | Monja Unicolor | LC | No | X | X |
| *Notharchus hyperrhynchus* | White-necked Puffbird | Bobo de collar | LC | No | - | - |
| *Nystalus striatipectus* | Chaco Puffbird | Buco Durmilí | LC | No | - | - |
| ***Galbulidae*** | **Jacamars** | | | | | |
| *Galbula ruficauda* | Rufous-tailed Jacamar | Jacamará Colirrufo | LC | No | X | - |
| ***Ramphastidae*** | **Toucans** | | | | | |
| *Pteroglossus castanotis* | Chestnut-eared Aracari | Arasarí Caripardo | LC | No | - | X |
| ***Picidae*** | **Woodpeckers** | | | | | |
| *Melanerpes cruentatus* | Yellow-tufted Woodpecker | Carpintero Azulado | LC | No | - | - |
| *Piculus chrysochloros* | Golden-green Woodpecker | Carpintero Verdiamarillo | LC | No | X | - |
| *Celeus lugubris* | Pale-crested Woodpecker | Carpintero Lúgubre | LC | No | X | X |
| *Dryocopus lineatus* | Lineated Woodpecker | Picamaderos Listado | LC | No | X | X |
| *Campephilus rubricollis* | Red-necked Woodpecker | Picamaderos Cuellirrojo | LC | No | X | X |
| ***Picumnus*** | **Picultes** | | | | | |
| *Picumnus spec.* | Piculet spec. | | | | - | X |

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|---|---|---|---|---|---|---|
| ***Furnariidae*** | **Ovenbirds** | | | | | |
| *Synallaxis scutata* | Ochre-cheeked Spinetail | Pijuí Canela | LC | No | X | X |
| *Xenops rutilans* | Streaked Xenops | Picolezna Rojizo | LC | No | X | X |
| *Sittasomus griseicapillus* | Olivaceous Woodcreeper | Trepatroncos Oliváceo | LC | No | X | X |
| *Dendroplex picus* | Straight-billed Woodcreeper | Trepatroncos Piquirrecto | LC | No | - | - |
| *Xiphorhynchus guttatus* | Buff-throated Woodcreeper | Trepatronco Pegón | LC | No | X | X |
| *Xiphocolaptes major* | Great Rufous Woodcreeper | Trepatroncos Colorado | LC | No | - | X |
| ***Thamnophilidae*** | **Antbirds** | | | | | |
| *Thamnophilus sticturus* | Bolivian Slaty Antshrike | Batará Pizarroso Boliviano | LC | No | X | X |
| *Herpsilochmus atricapillus* | Black-capped Antwren | Tiluchí Plomizo | LC | No | X | X |
| *Pyriglena leuconota* | White-backed Fire-eye | Ojodefuego Dorsiblanco | LC | No | X | X |
| *Dysithamnus mentalis* | Plain Antvireo | Batarito Cabecigrís | LC | No | X | X |
| ***Tyrannidae*** | **Tyrant Flycatchers** | | | | | |
| *Myiopagis viridicata* | Greenish Elaenia | Fiofío Verdoso | LC | No | X | X |
| *Leptopogon amaurocephalus* | Sepia-capped Flycatcher | Orejero Coronipardo | LC | No | X | - |
| *Tolmomyias sulphurescens* | Yellow-olive Flatbill | Picoplano Sulfuroso | LC | No | X | X |
| *Corythopis delalandi* | Southern Antpipit | Mosquero Terrestre Sureño | LC | No | X | X |
| *Cnemotriccus fuscatus* | Fuscous Flycatcher | Mosquero Parduzco | LC | No | X | X |
| *Casiornis rufus* | Rufous Casiornis | Burlisto Castaño | LC | No | X | X |
| *Myiarchus tyrannulus* | Brown-crested Flycatcher | Copetón Tiranillo | LC | No | - | X |
| *Sirystes sibilator* | Eastern Sirystes | Mosquero Silbador | LC | No | - | X |
| *Megarynchus pitangua* | Boat-billed Flycatcher | Bienteveo Pitanguá | LC | No | - | - |
| *Tyrannus melancholicus* | Tropical Kingbird | Tirano Melancólico | LC | No | - | X |
| *Myiodynastes maculatus* | Streaked Flycatcher | Bienteveo Rayado | LC | No | X | X |
| *Myiozetetes cayanensis* | Rusty-margined Flycatcher | Bienteveo Alicastaño | LC | No | X | - |
| ***Tityridae*** | **Tityras & Becards** | | | | | |
| *Tityra cayana* | Black-tailed Tityra | Titira Colinegro | LC | No | - | - |
| ***Pipridae*** | **Manakins** | | | | | |
| *Pipra fasciicauda* | Band-tailed Manakin | Saltarín Naranja | LC | No | - | X |
| ***Corvidae*** | **Crows & Jays** | | | | | |
| *Cyanocorax cyanomelas* | Purplish Jay | Chara Morada | LC | No | - | - |
| *Cyanocorax chrysops* | Plush-crested Jay | Chara Moñuda | LC | No | X | X |

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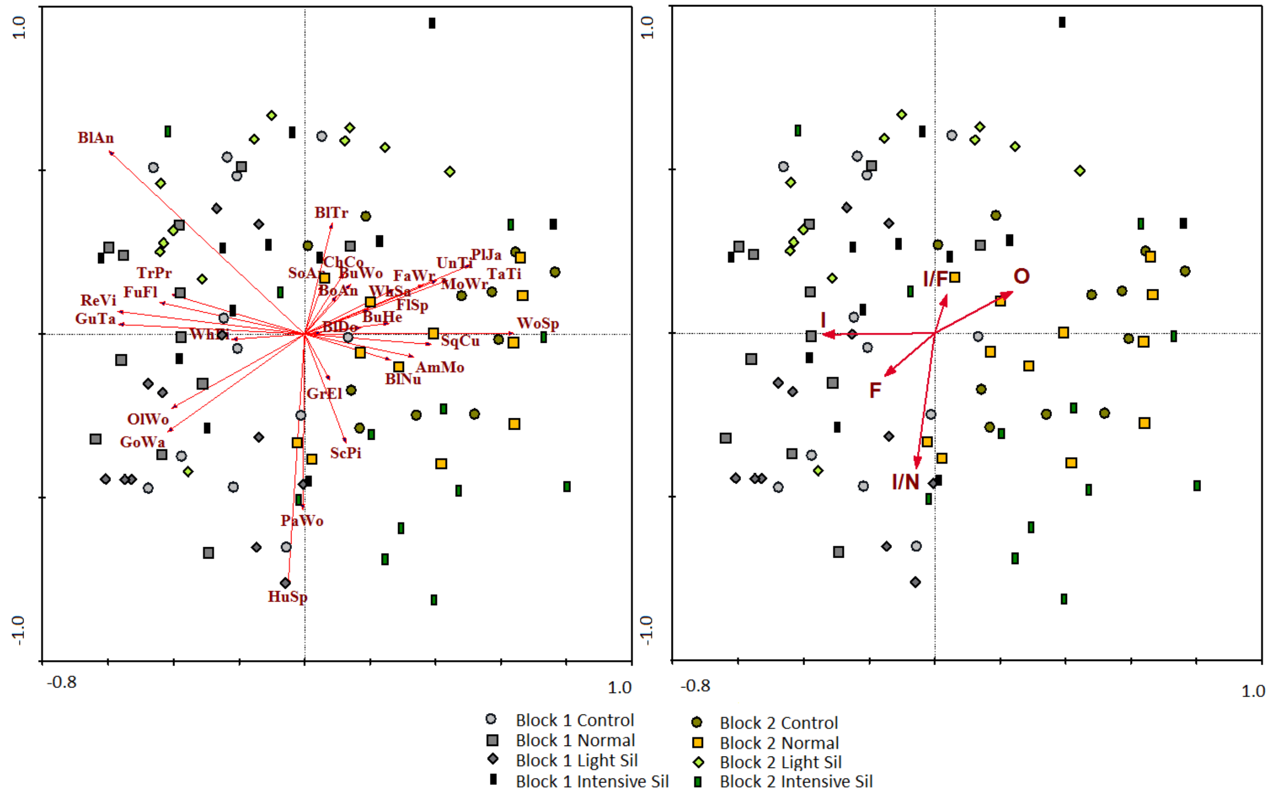
|---|---|---|---|---|---|---|
| ***Troglodytidae*** | **Wrens** | | | | | |
| *Campylorhynchus turdinus* | Thrush-like Wren | Ratona Tordo | LC | No | - | - |
| *Cantorchilus guarayanus* | Fawn-breasted Wren | Ratona de Pecho Crema | LC | No | X | X |
| *Pheugopedius genibarbis* | Moustached Wren | Ratona Bigotuda | LC | No | X | X |
| ***Turdidae*** | **Thrushes** | | | | | |
| *Catharus ustulatus* | Swainson's Thrush | Tordo Olivo | LC | No | - | - |
| *Turdus amaurochalinus* | Creamy-bellied Thrush | Tordo Sabiá | LC | No | X | - |
| *Turdus hauxwelli* | Hauxwell´s Thrush | Mirlo de Hauxwell | LC | No | X | - |
| ***Vireonidae*** | **Vireos & Greenlets** | | | | | |
| *Vireo olivaceus* | Red-eyed Vireo | Vireo de Ojos Rojos | LC | No | X | X |
| ***Parulidae*** | **New World Warblers** | | | | | |
| *Setophaga pitiayumi* | Tropical Parula | Párula Tropical | LC | No | X | X |
| *Basileuterus culicivorus* | Golden-crowned Warbler | Chiví Silvador | LC | No | X | X |
| ***Thraupidae*** | **Tanagers & Allies** | | | | | |
| *Conirostrum speciosum* | Chestnut-vented Conebill | Mielerito Azul | LC | No | X | X |
| *Hemithraupis guira* | Guira Tanager | Pintasilgo de Buche Negro | LC | No | X | X |
| *Eucometis penicillata* | Grey-headed Tanager | Sigua Hormiga Bachaquera | LC | No | X | X |
| ***Fringillidae*** | **Finches** | | | | | |
| *Euphonia chlorotica* | Purple-throated Euphonia | Fruterito Azuquero | LC | No | X | - |
| ***Icteridae*** | **Oropendolas, Orioles & Blackbirds** | | | | | |
| *Icterus croconotus* | Orange-backed Troupial | Matico | LC | No | - | - |
| *Cacicus cela* | Yellow-rumped Cacique | Arrendajo Común | LC | No | - | - |
| *Psarocolius decumanus* | Crested Oropendola | Conoto Yapú | LC | No | X | X |

## Appendix 2: PCA outputs

Appendix 2A: PCA output of the 96 sample points of the Long-Term Silvicultural Research Program. Block 1 is visualized with grey coloured figures while block 2 is visualized with coloured figures. Each symbol representing a different treatment. Species as well as diet groups were used to visualize their association to a specific treatment.

Appendix 2B: PCA output of the 84 sample points of the 6 logged compartments harvested by INPA and the unlogged control compartments. Each symbol represents a different compartments, harvested in a different year. Specific guild as well as species were used to visualize their association to a specific compartment.

**A**




**B**