Bird diversity in a montane cloud forest reserve, Costa Rica

Effects of forest succession stages on bird diversity

by
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Front page picture: Male Resplendent Quetzal (*Pharomachrus mocinno*) in Cloudbridge Reserve, Costa Rica (picture by Harold van Riessen)

Effects of forest succession stages on bird diversity in Cloudbridge Reserve, Costa Rica

An undergraduate thesis for the degree

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Preface

Ever since I was a child, I was fascinated by the natural world. This became a fascination especially for tropical nature and over the years I've travelled to some of the most stunning tropical destinations, like Malaysian Borneo and the Amazon rainforest in Peru. As these places almost felt like home to me and I saw the degradation and destruction of these beautiful forests with my own eyes, I wanted to contribute to a more sustainable tropical environment myself. I decided to start studying again in 2017 after a career as a mechanical engineer. From the start, I was determined to study International Forest and Nature Management with a specialization in Tropical Forestry at Van Hall Larenstein in Velp. I have always been interested in tropical wildlife, particularly in snakes and poison dart frogs but during this study I became more enthusiastic about birds then I already was and when the option of studying bird diversity at Cloudbridge Reserve in Costa Rica came up, I didn't hesitate to take this opportunity. This was my chance to contribute to a sustainable tropical environment with a subject that I really liked.

I would like to use this section to express my gratitude to several people who supported and helped me during this period of my study. Foremost I would like to thank my wife Karito and my two children, Eliseo and Ariana, for their patience when being alone at home without their husband/father for almost two months. Their support has been of great value for me during this study and especially during my thesis. I am also thankful to my mother Jenny, who supported my family during my stay at Cloudbridge with cooking, baby-sitting and cleaning. Moreover, I would like to thank supervisor Dr. Ir. Paula Pebsworth, scientific coordinator at Cloudbridge, for her encouragement, knowledge and enthusiasm during my fieldwork at Cloudbridge. She always made sure there was a field assistant available at 6AM in the morning and helped me out when I was in need of any equipment. She herself has also been a great field assistant to me.

Furthermore, I would like to thank Kees Evers for working together on the vegetation sampling with me and exchange thoughts on how to get all the sampling done in one week. I also would like to thank Eddo, Seamus, Jann Erik, Haydn, Anna-Lena, Nina and all other field assistants for helping me during my bird observations and vegetation measurements. They have been of great help as an extra pair of eyes and ears. Climbing up and down the mountain early in the morning made it less exhaustive with their companionship. And I am thankful to Haydn West for making a short film about my activities during vegetation sampling, as it is of great value for promotion material.

Finally, I would like to thank supervisor Dr. Ir. Peter van der Meer, Associate lector at Van Hall Larenstein, for his guidance, encouragement, and knowledge during my thesis.

Abstract

Tropical deforestation is one of the main causes for habitat destruction and fragmentation for bird communities worldwide, but Costa Rica is one of the few countries where forest cover increased. Biodiversity in Costa Rica is astonishing, especially in the isolated cloud forests of the ecoregion 'Talamancan Montane Forests', which contain high endemism. Reforestation and natural regeneration of forests are one of the solutions to tackle the loss of bird diversity by creating different forest succession stages, which provide important habitat for many forest-depending species. Cloudbridge Nature Reserve actively engages in reforestation projects and the natural regeneration of disturbed forests and although their forest is relatively well protected, the isolated position and short-term human impact and climatic variations still makes them vulnerable. This study aims to gather information if different succession stages affect local bird diversity in order to get a better understanding of the protection and restoration of cloud forests. This resulted in the main research question 'What effect does forest succession stage has on the bird species diversity at Cloudbridge Nature Reserve, Costa Rica?'.

To see if there is a difference in bird diversity between different succession stages, bird diversity and vegetation variables were measured. For bird diversity, the point count method was used and in each of the bird stations birds were counted by sight and sound. These bird stations were divided among four different succession stages: planted forest, secondary forest younger than 30 years, secondary forest older than 30 years and primary forest. This study also examines if certain bird species have a preference for succession stage and if this affects diversity. Furthermore, the relationship between forest structure and bird diversity is explored.

Although species accumulation curves in each succession stage did not reach a horizontal asymptote, younger secondary forest was richest in both bird species richness and diversity. The chi-square test shows that the Common Bush Tanager and Elegant Euphonia have a significant preference for planted forest. The relation between forest structure and bird diversity is unclear, despite there is a similarity between bird diversity and planted forest, younger secondary forest and older secondary forest. This study shows that there is an effect of the aging of secondary forest and primary forest on bird species diversity. The high conservation value of younger secondary forest for species richness is clear as richness and diversity are highest here. Extension of this research on bird diversity and especially on vegetation variables is recommended in order to get a better understanding of the relationship between forest structure and bird diversity in the Cloudbridge Reserve.

Key words: *birds, diversity, richness, succession stage, cloud forest*

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1. Introduction

The first chapter describes the background of this research project, followed by the problem description. In addition, the research objective and research questions are described.

1.1 Background

Worldwide, tropical deforestation continues at alarming rates as forests are logged for timber and fuelwood or are converted to cattle ranches, large scale commodity crop plantations or for agricultural purposes. This has resulted in devastating consequences for critical ecosystem services, like carbon storage and habitat for an innumerable amount of flora and fauna species. Forest conversion for commercial agriculture accounts for 68% of deforestation in Latin America (Hosonuma et al., 2012). The tropics alone, accounted for a tree cover loss of 11,9 million hectares in 2019 of which nearly a third (3,8 million hectares) occurred in primary rainforests. Primary forest loss was 2,8% higher than in 2018. The 2010s started with a collective goal to reduce tropical deforestation rates by 2020 to combat climate change, stabilizing forest-dependent livelihoods and ecosystem services and reducing species extinction rates. This goal failed to meet its basic target as deforestation rates exceeded tropical forest loss in the 2000s, rising at least 30% (Tropical forests' lost decade: the 2010s, 2019).

As many poor tropical countries still face alarming rates of deforestation, a positive trend is slowly becoming visible on a global scale as deforestation has slowed, and afforestation increased in the period 1990-2015 (Sloan & Sayer, 2015). A significant forest increase of 379 million ha in tropical protected areas since 1990 is one of the positive results. Although, forest gain often occurs at higher latitudes in richer countries, some middle-income tropical countries are now also transitioning to forest gain. Costa Rica harbors an astonishing biodiversity, estimating the total expected world diversity at 3,6% (Kohlmann, 2011). It is one of the middle-income countries that changed its forest management approach in the 1980s and is well-known for its progressive approach in nature conservation (Conservation International, 2021). Forest cover increased by 21% in 1987 and up to 50% in 2005. Today, Costa Rica is at the forefront of acting as a role model for future green political actions around the world, with over 30% of its territory marked for conservation (Earth Law Center, 2019). And it has proven to be successful as it has become one of the world leaders in ecotourism.

A mountain range crosses the nation from the northwest to the southeast, dividing the Caribbean and Pacific coastal plains and is covered by the 'Talamancan Montane Forests', an ecoregion which occurs between 1.000m–3.000m above sea level (World Wildlife Fund, 2021). When altitude increases, vegetation patterns change, mean air temperature decreases and cloud formation increases, as moisture from the Pacific slope is lifted upwards, creating a misty, lush and perpetually dripping cloud forest. Cloud forests are rare and fragile ecosystems, which only make up 2,5% of tropical forests worldwide (Bubb, May, Miles, & Sayer, 2004). The cloud forests of Cordillera de Talamanca, where Cloudbridge is situated, are extremely rich in biodiversity and contain high endemism. It is estimated that 30–40% of all tree species in this region are endemic (Kappelle, 2016) as with over 50% of all bird species (World Wildlife Fund, 2021). This is because cloud forests are often isolated areas and comprise significant changes in elevation and climatic variations in a relatively small area which causes various microclimates. Cloud forests are rare and vulnerable ecosystems (Bubb, May, Miles, & Sayer, 2004) and they provide habitat for many forest-depending birds species. The isolated mountainous areas of

Costa Rica, together with the Panama highlands, are one of the Endemic Bird Areas (EBAs) in Central America. EBAs are further explained in Box 1.

Box 1: Endemic Bird Areas (EBAs)

Most bird species in the world are widespread and have a large range in which they find their habitat. However, over 2.500 bird species have a restricted range no larger than 50.000 km^2. Endemic Bird Areas are defined as areas where the distribution of two or more restricted range species overlap (BirdLife International, 2021). The complete range of these species should be entirely included in the boundary of the EBA. A total of 218 EBAs occur all over the world but most of them (77%) are located in the (sub)tropics. The EBA that was established in the highlands of Costa Rica and Panama comprises an area of only 23.000 km^2 but it contains 52 restricted range species. Most of these species were forest dependent, one of the highest numbers of any EBA in a study by Stattersfield, Crosby, Long, & Wege (1998). Restricted range species are extremely vulnerable to habitat degradation and fragmentation, not only due to climate change (Liu, Sandoval, Sherman & Wilson, 2020), but also due to deforestation, as most restricted range species are forest dependent (Oostra, Gomes, & Nijman, 2008). EBAs could be a solution in tackling the decline of endemic bird species as these approaches, together with biodiversity hotspots, and ecoregions are used by international organizations to prioritize conservation efforts globally (Wilson. McBride, Bode, & Possingham, 2006).

Text Box 1: Endemic Bird Areas (EBAs)

Many of the bird species in the Cordillera de Talamanca are vulnerable to climatic variations in a short timeframe, especially forest dependent species, as their habitat is quite small compared to non-forest dependent species with a larger range. According to Şekercioğlu, Schneider, Fay, & Loarie (2008), species found at elevations of more than 500 m are more susceptible to warming temperatures, due to their low basal metabolic rates and they experience limited temperature variation within their habitat. A study by Chen, Hill, Ohlemüller, Roy, & Thomas (2011) concluded that birds, on average, change their range upslope at around 11 m every decade. The upward shift is supposed to be faster for tropical bird species as compared to temperate regions (Freeman & Class Freeman, 2014). As they move further upslope, there could be a moment in time when they simply run out of suitable habitat and become extinct (Freeman, Scholer, Ruiz-Gutierrez, & Fitzpatrick, 2018). The causal relationships behind these shifts are not yet well understood but a reason could be that, as birds are quite mobile, prey abundance is not able to make this upward shift in a short amount of time as birds do. Adapting by changing their range latitudinal is not an option, as forested areas in the immediate surroundings are at low elevation for several hundred kilometers (Barrantes, 2009).

Human landscape alterations are also a threat to bird species. Due to local deforestation for development, infrastructure or shifting agriculture, small but significant habitat fragmentation prevent the connection of adjacent habitat blocks within the ecoregion and connectivity to other ecoregions. Therefore, important wildlife corridors can be diminished or even split and prevent species from migrating to other forest reserves. Bird species that are patchily distributed, or very specialized and intolerant to forest fragmentation are particularly prone to local extinction (Turner, 1996). Also, endemic species that are intolerant to conditions outside the forest are vulnerable. Despite the fact that many of the forest-dependent species in the Cloudbridge reserve are not at risk, some species are near threatened or even vulnerable according to the IUCN Red List (IUCN, 2021). A study by O’Dea and Whittaker (2007) in Andean montane forests indicated that species richness is lowest in agricultural land, but in some measures equally low as in primary forests. This study also showed that richness peaked in secondary forest and edge habitat so, disturbed forests might be of great conservation value, as other studies indicate that species richness in older secondary forests is comparable to that of primary forests (Sodhi et al., 2005; Schulze et al., 2004). Results in a study by Blake & Loiselle (2001) show that several threatened species are common in second growth but were not found in primary forests. This indicates that different forest succession stages, especially younger secondary forest, could be of great importance for bird diversity. According to Swanson et al. (2010) post-disturbance ecosystems are often rich in biological legacies which provide resources that attract and sustain high species diversity. The same study states that early forest succession is the only period when tree canopies do not dominate the forest. Therefore, there is high productivity of plant species, complex food webs, large nutrient fluxes and high structural and spatial complexity.

1.2 Problem description

Despite the fact that the montane cloud forests of the Cordillera de Talamanca are relatively well protected, the isolated position in the landscape still makes them vulnerable to human impact and climatic variations in a short period of time. Although Cloudbridge actively engages in reforestation projects and the natural regeneration of disturbed forests, bird communities are particularly vulnerable here, as a considerable part of the bird population consists of restricted range species. These species are often not able to change their latitudinal range, due to the fact that similar habitat types are interrupted by unsuitable lowland forest for several hundred kilometers (Barrantes, 2009). Small scale agriculture and deforestation could lead to habitat fragmentation which often leads to a severe decline in bird species richness and abundance (Fujita, Prawiradilaga, & Yoshimura, 2014; Kupsch et al., 2019; Dunn, 2004). Reforestation and natural regeneration of degraded forests might help to mitigate the loss of bird species and habitat fragmentation. Several studies suggest the relationship between bird species richness and diversity and habitat variables (Rajpar & Zakaria, 2015; Santamaría-Rivero, Leyequién, Hernández-Stefanoni, & Wood, 2016). The increase in natural regenerated forest cover can provide habitat for many bird species (Acevedo-Charry & Aide, 2019) and reforestation and natural forest regeneration create different succession stages with unique structures on which many specialist bird species depend. Birds are a relatively well studied object, but the effect of different forest succession stages on bird diversity is not yet well understood in the area.

1.3 Research objective and research questions

This study aims to gather information if different forest succession stages affect local bird communities and if so, in what way are they affected. This in order to better understand the bird diversity in different forest succession stages and therefore provide a better understanding of the importance of the protection of secondary and primary cloud forests and restoration of degraded cloud forests. Therefore, the main research question is formulated as:

- *<u>What effect does forest succession stage has on the bird species diversity at Cloudbridge Nature Reserve, Costa Rica?</u>*

This research question is split into three sub-questions:

1. *Is there a difference in species richness and diversity between the different succession stages?*
2. *Do dominant forest-depending bird species have a preference for certain landscape and does this affect diversity?*
3. *What is the relation between vegetation structure and bird species diversity in planted, naturally regenerated and primary forest?*

2. Methodology

The following chapter describes the study area and the four forest succession stages used in this research. This is followed by the methodology of bird surveys and vegetation surveys. Finally, the methodology of data analysis is described.

2.1 Study area

Data collection for this research was conducted from 15 March 2021 until 5 May 2021 in the Cloudbridge Nature Reserve, Costa Rica. This privately owned reserve, established in 2002, is located on the Pacific slopes of the Talamancan mountains in the Perez Zeledon region and covers an area of just over 280 ha. The reserve is characterized by a mosaic of different forest succession stages, such as primary forest, natural regenerating secondary forest with different age classes, riparian forest and reforested pastureland. Reforestation of degraded agricultural land began in 2002.

The reserve is divided by the Uran River in a northern and southern part (Figure 1) of which the southern part is most visited by researchers and tourists. This is also the part where most of the reforestation and natural regeneration of forests is realized and where data collection for this study was conducted. The northern part is characterized by steep inclines and most of the area is dominated by primary forest which is mostly impermeable. Altitude ranges between 1550 m and 2600 m above sea level with precipitation of around 4300 mm per year (Giddy, 2006). Temperatures vary with altitude but are generally mild with average high at around 23,1^{o}C and average low at around 13,4^{o}C.

The area is extremely rich in floral and faunal biodiversity. Just over 300 mid- and high-elevation bird species have been recorded within the boundaries of the reserve. Not all of these bird species occur in large numbers or throughout the whole year as some of the species are migrants and some are only encountered occasionally. Chirripó National Park borders the reserve on the east. Relatively intact forested areas border the northside and to the west the landscape is characterized by villages and agricultural fields.

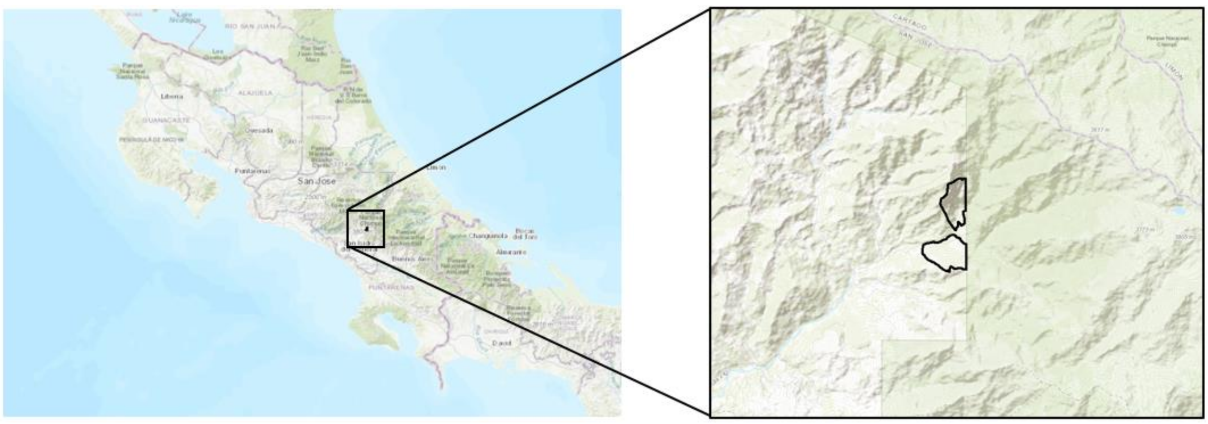


Figure 1: Location Cloudbridge Reserve

This study focusses on four categories of forest succession stages (Figure 2): planted forest, younger secondary forest under 30 years, older secondary forest over 30 years and primary forest. The division of secondary forest into younger and older than 30 years was based on the coverage of secondary forest throughout the reserve. In this way, younger and older secondary forest were more or less evenly distributed.

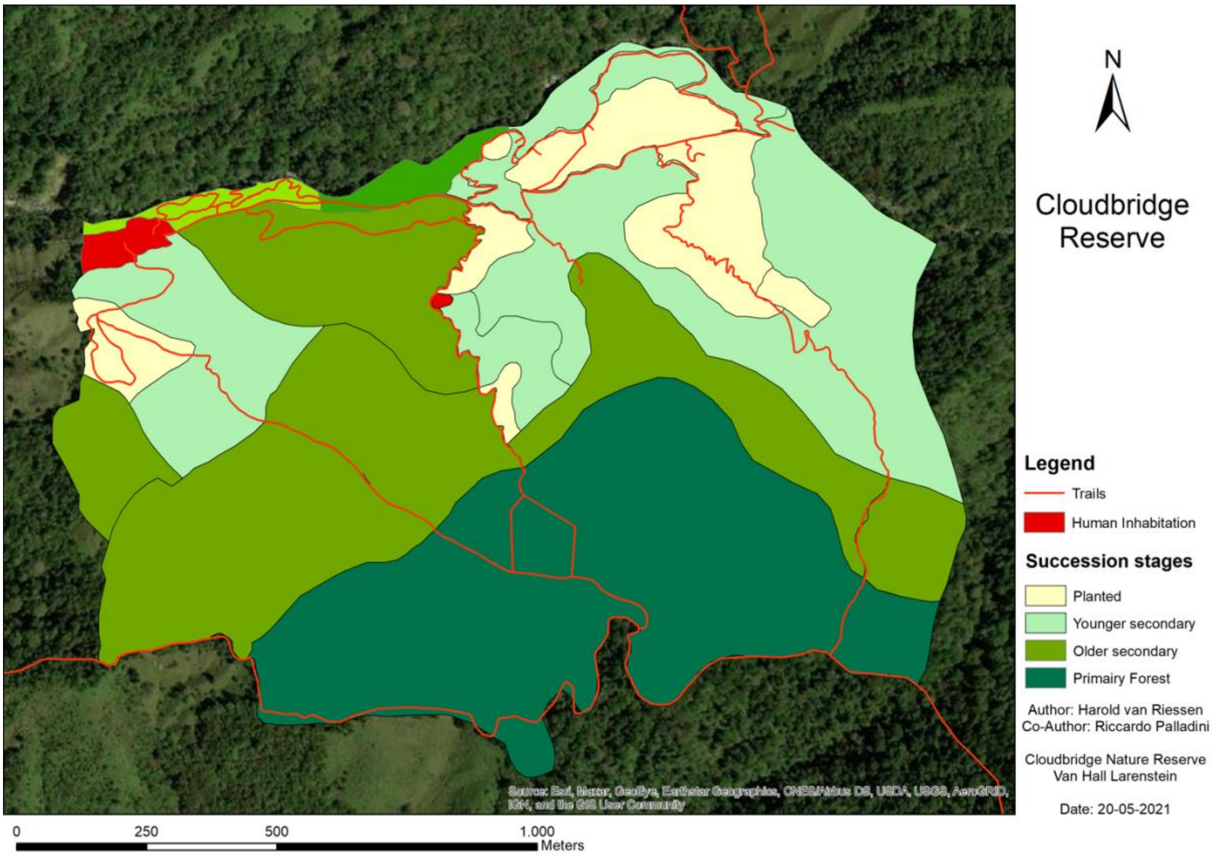


Figure 2: Map of the Cloudbridge study area with the four different forest succession stages

2.1.1 Planted forest

Reforestation of degraded agricultural fields began in 2002 with both local and international consultants (Cloudbridge, 2021). Over the years, a number of agricultural fields have been replanted with different levels of success, but with the help of the local community, volunteers and researchers, planting techniques have improved a lot since then. Initially, a few species were selected for potential sustainable forestry, such as the non-native Cypress (*Cupressus lusitanica*, although common in the area) and the native Alder (*Alnus acuminata*). Nowadays, after sustainable forestry for commercial use was not considered viable, the non-native Cypress is slowly being weeded out for use as building material in the reserve. And instead of planting entire hillsides, ridge lines are now planted to help spread the seeds downhill. Pioneer species, like the sun loving Cecropia (*Cecropia angustifolia*) are planted to create shade for shade-bearing Oak (*Quercus spp.*) species. Over time, when trees start to grow and other pioneer species start to return, planted forests are still characterized by low canopy. In some cases, depending on planting technique, understory vegetation is still absent. Nightshade (*Solanum aphyodendron*) is one of the most common plant species found in planted forests (Hoving, 2019).

2.1.2 Secondary forest

Before Cloudbridge Nature Reserve was established, the area was characterized by agricultural fields. Probably due to shifting agriculture or timber harvesting, several forest patches were left abandoned and started regenerating naturally. The first forests that started to regenerate are between 30 and 45 years old, dating back to 1986 and 1991, which in this study are defined as older secondary forest. Other forests, between 13 and 19 years old, started regenerating in 2002, 2006 and 2008, which in this study are defined as younger secondary forest. Nowadays, the most common plant and tree species are Leathery Colicwood (*Myrsine coriacea*) and Nightshade (*Solanum aphyodendron*) (Hoving, 2019). Only a few individuals of Cecropia are still present in the area. Cloudbridge actively promotes sustainable forest health by mimicking natural succession of forest growth, which is done by enhancement planting (Cloudbridge, 2021). Shady areas are cleared of herbs and shrubs, so shade loving tree species of primary forests can take root. In this way, natural regeneration is supported in order to reach a climax state as soon as possible and tree stock will also be diversified.

2.1.3 Primary forest

Primary forest only makes up 28 ha of the total nature reserve. Primary forest is defined as forest that hasn't been harvested since the turn of the 20th century (Cloudbridge, 2021). Protecting these primary forests is one of the main focus points of Cloudbridge. The largest primary forest area is situated in the northern part of the reserve but due to steep inclines this part is mostly impermeable. A smaller portion of primary forest is situated in the southern end of the reserve and borders Chirripó NP. The primary forests of the Talamancan Mountain Range are characterized by a staggering floristic diversity but are often dominated by oak forests, often with dense '*Chusquea'* bamboo stands in the understory (Kappelle, 2016). Costa Rica's 'Instituto Nacional de Biodiversidad' reports a total of over 1700 plant species, many of which are endemic, and many more species are expected to be discovered in the near future. Due to the moisture from cloud formation, epiphytes, mosses, fungi and lichens also dominate the primary forests. The canopy reaches its maximum height here and forest structure is generally less dense as in secondary forests as most pioneer species have disappeared and climax species persist.

2.2 Bird surveys

Although I do have quite some knowledge about the local birds, as I have been observing birds in the area before, identification of some bird species can be difficult, especially in poor light conditions. Prior to my field visit, I used training material provided by Cloudbridge to learn most of the species that occur within the boundaries of the reserve. In addition, the first week of field visit was used to familiarize myself with the area and the local birds. During this week, from 14 March to 21 March 2021, I explored the different trails and bird stations. I also saw and heard a large proportion of the most common bird species that I was expecting to encounter during this research and in this way, I prepared myself for identification. During this week, I also tested my method for bird observations which is explained in the following paragraphs.

2.2.1 Point count selection and transects

In 2013, a bird monitoring project was started at Cloudbridge to monitor the diversity and presence of birds in the reserve and also, to build a species list. In 2016, the observation method for this monitoring project was standardized. In order to contribute to this project with my thesis, this method was followed as much as possible. Currently, a total of 29 bird stations have been established along a number of existing trails, which run through different succession stages. Unfortunately, not all of these stations were usable for this study, as some of these stations are established on the border between different forest succession stages. Also, some of the existing bird stations are located near the river and could not be used due to the noise from the water as this would influence sound recording. For this reason, only twelve of the existing bird stations could be used. In order to maximize data collection, another twenty bird stations were established along the trails creating a total of 32 bird stations, with eight bird stations in each forest succession stage. The bird stations are situated along the Principal trail, Heliconia trail, El Jilguero trail and Montaña trail. Most of the bird stations in primary forest are situated around the Smithsonian Plot, a hectare of primary forest which is used for scientific research. Figure 3 shows the southern part of the reserve, where all of the bird stations are located, together with the existing trails, observation points and forest succession stages. Appendix 1 shows the bird stations in more detail along the different trails.

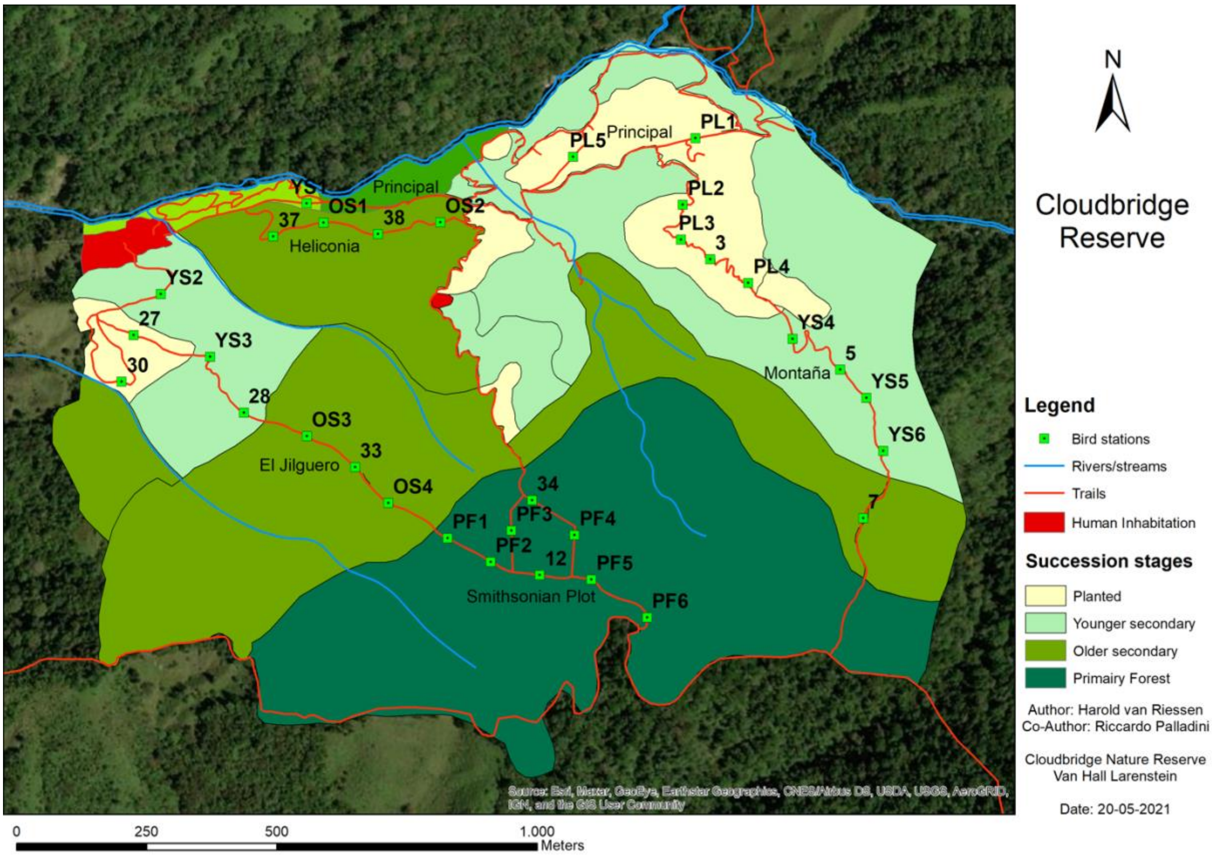


Figure 3: Map of the Cloudbridge study area with the bird stations, main waterways, main trails and succession stages

All bird stations are located in the southern part of the reserve. Every bird station was visited once a week according to a fixed schedule (Appendix 4), with a total of six visits for each bird station. Every day a transect was walked covering more than one forest succession stage in order to minimize time-of-day bias (Bibby, Burges, Hill, & Mustoe, 2000). Six bird stations were visited on Monday, Wednesday and Friday and seven on Tuesday and Thursday.

2.2.2 Point count method

Bird species diversity was measured using the point count method at set locations throughout the reserve. The point count technique is a powerful method to measure bird diversity as data collection can be directly related to habitat (Bibby, Burges, Hill, & Mustoe, 2000). Bird identification was done by sight and sound. Swarovski 10x30 binoculars were used for sightings and a field guide (Garrigues & Dean, 2014) was used to support identification. The latest version of the IOC World Bird List (2021) was used for current scientific names and classification. Sounds were recorded by using the standard 'Dictaphone' app on a mobile phone and later identified by comparing the sounds with a database downloaded from https://www.xeno-canto.org, which is an open-source website with bird sounds. The existing bird stations are marked with a small sign and the newly established bird stations were marked with blue flagging tape. This small sign or flagging tape acted as the center point of an imaginary cylinder with a horizontal radius of 25m and that extends all the way to the top of the canopy (Figure 4). Within a timeframe of 15 minutes, all birds seen and heard that utilized the area within this cylinder for at least 5 seconds were recorded. So, birds passing through or flying over were not recorded. At the start of each observation the Dictaphone app was activated, and a field assistant simultaneously used a stopwatch to check the time. The field assistant wrote down every observation using a field form (Appendix 5). Species were identified onto species level and if uncertain, species were identified onto the highest identifiable taxon possible. Observations were conducted between 6:00 AM and 10:00 AM, times when birds are most active. Observations were done under fair weather conditions as much as possible (no or light winds, no rain or mist). GPS coordinates were taken using a Garmin 64x GPS tracker (Appendix 3).

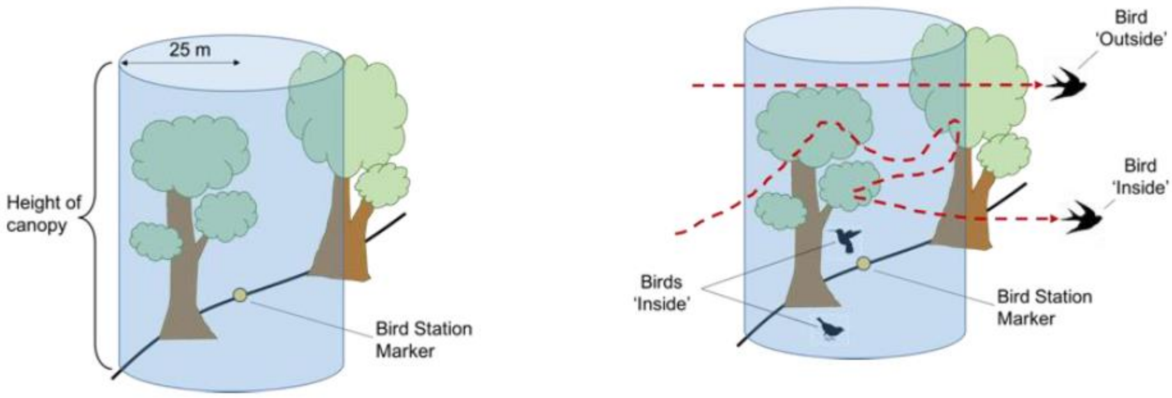


Figure 4: Illustrative representation of the point count survey area (Powell & Spooner, 2018)

2.3 Vegetation survey

Vegetation structure was surveyed to answer sub-question 3. For this study, forest succession stages within the reserve are divided into four categories: planted forest, secondary forest younger than 30 years, secondary forest older than 30 years and primary forest (Figure 2). Location of the plots were determined in the field according to accessibility, as the area is dominated by steep inclines (Appendix 2). GPS coordinates were taken using a Garmin 64x GPS tracker (Appendix 3). In each succession stage, three plots were established, resulting in a total of 12 plots. Vegetation variables were measured inside 20x20m plots. DBH was measured of trees >=10cm, using a DBH measuring tape and tree height was estimated. If tree height was unsure, a clinometer was used to measure the exact tree height. Along the centerline of the main plot, canopy cover was measured at 5m intervals. At every 5m a picture was taken, and canopy cover was measured by making use of the CanopyApp. This app, developed by the University of New Hampshire (2018), allows the user to calculate the percentage of canopy cover according to the picture taken. The average percentage of the three pictures was used as percentage of canopy cover for the main plot.

Understory coverage was measured in four plots with dimensions of 4x4m. Plots were established on each outer corner of the main plot. Understory vegetation coverage was measured by estimating the coverage of all woody vegetation with a height >=1m. The average of the four plots was used as the average understory coverage for the 20x20m plot.

Herb coverage was measured inside four 1x1m plots. Plots were established on the outer corner of each 4x4m plot. Herb coverage was measured by estimating the coverage of all vegetation with a height of <1m. An example of the plot design is illustrated in Figure 5. In addition, a field form was used to record all the vegetation data (Appendix 6).

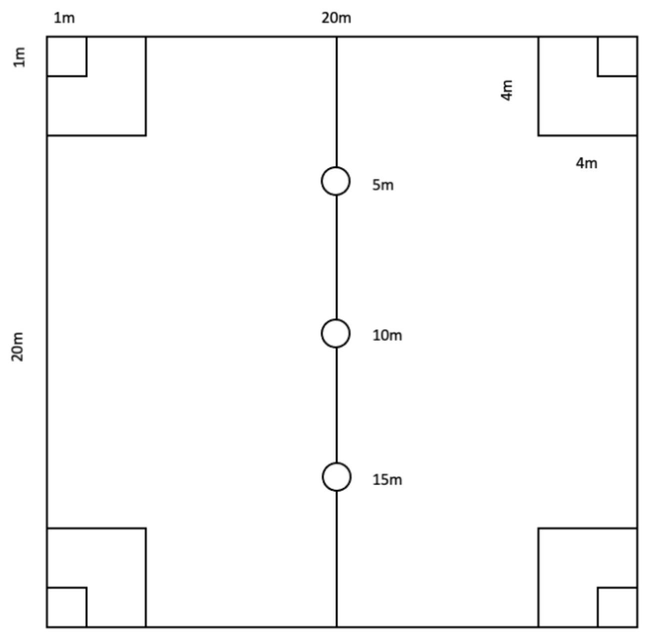


Figure 5: Plot lay-out vegetation survey

2.4 Data analysis

In order to answer the main research question and sub-research questions, data was analyzed according to the following methods. A complete bird species list was made with all the species encountered during this research (Appendix 7). This database includes family name, common English name and scientific name. Endemic species are marked with (e). Also, total number of individuals for each species as well as IUCN status, feeding guild and level of forest specialization are listed in this database. Information was retrieved from the database of Birdlife International (2021) and the IOC World Bird List (2021). This species list was not used for further analysis.

Species accumulation curves

Species accumulation curves were made to illustrate the accumulation of new species in every succession stage. Species accumulation curves are a good indicator to see if more samples are needed. When the curve reaches a horizontal asymptote, it means that enough samples are taken as the line would not further increase (Davidar, Yoganand, & Ganesh, 2001). If the line still shows a little inclining curve, more samples are needed (Figure 6).

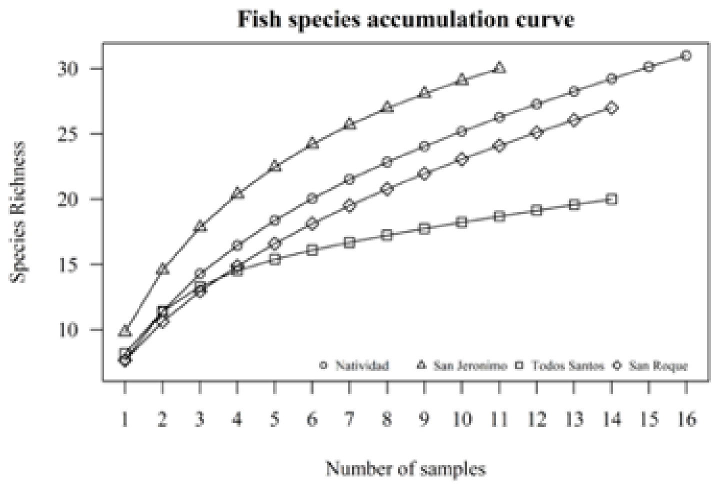


Figure 6: Example of species accumulation curve (Reprinted from 'Do marine reserves increase prey for California sea lions and Pacific harbor seals?' by Arias-Del-Razo et al. (2019)

Bird richness and diversity

As complexity of habitat increases, species diversity also increases (Bibi & Ali, 2013). Species richness and evenness are two components of diversity and evenness is a measure of the relative abundance of different species making up the richness of an area. Species richness and relative abundance in relation to succession stage were used to calculate the Shannon Index (sub-question 1). Shannon Index is one of the most common methods for analyzing species diversity. The Shannon index is illustrated by graphs. The equation for calculating the Shannon Index is:

$$H' = -\sum_{i=1}^{S}(p_i \ln p_i)$$

Equation 1: Equation for calculating Shannon Index

Landscape preference

The chi-squared test was carried out to see if specific succession stages are preferred by certain dominant forest-dependent species (sub-question 2). High abundance of a specific forest-depending species affects evenness and results in lower biodiversity between ecological groups. This test indicates if specific dominant forest-depending species affect diversity among succession stages. This test has been used in a study by Peterson, Ball, & Cohoon (2002) to predict the distribution of Mexican birds. The equation for calculating the chi-square test is:

$$\chi^2 = \sum \frac{(O-E)^2}{E}$$

Equation 2: Equation for calculating chi-square test

Forest-dependency is classified in three categories: low, medium and high forest-dependency and level of forest-dependency was retrieved from the database of Birdlife International (2021). The chi-squared test compares the actual observed species in each habitat (*O*) with the null-hypothesis (*E*), which indicates that each specie is distributed evenly among the succession stages (Glen, n.d.). Significance level (*P-value*) is set at 5% (0,05) and degrees of freedom (*df*) was set on 3. This leads to a critical X^2 value of 7,815, any value higher than the critical value is considered significant. Results are presented in a table and the results from the chi-square test are shown in Appendix 10.

Relation between forest structure and species diversity

In order to examine if species diversity varies between forest succession stages (sub-question 3), a comparison between Shannon Index and the different aspects of forest structure was made. The aspects of forest structure are canopy cover, understory vegetation cover and herb cover. Also, average DBH for trees >=10cm, basal area, average tree height and stem density (trees/ha) were taken into account. The values of each aspects are derived from vegetation measurements. Several studies show that there is a relationship between forest structure and bird diversity (Poulsen, 2002; Castaño-Villa, Ramos-Valencia, & Fontúrbel, 2014; Munro et al., 2011).

3. Results

Results that are derived from data collection and data analysis are presented in the following chapter. Results consists of species accumulation curves, bird species richness, bird species diversity, landscape preference and finally the relation between forest structure and bird diversity.

3.1 Species accumulation curves

Figure 7 illustrates the bird species accumulation curves for each of the four forest succession stages. None of the four curves shows a horizontal asymptote on the last sampling day. The curve for planted forest shows a horizontal asymptote on the second-last sampling day, but due to the discovery of two new species on the last sampling day the curve still shows an incline. The same applies to the younger secondary curve, but on the last sampling day only one new specie was discovered. Also, the primary forest curve shows a horizontal asymptote from sampling day 14-16 but three new species were discovered on the last sampling day. The curve for older secondary shows no horizontal asymptote in the last few sampling days. Primary forest shows less sampling days due to the fact that bird stations were visited in fewer days as compared to other succession stages (Appendix 4).

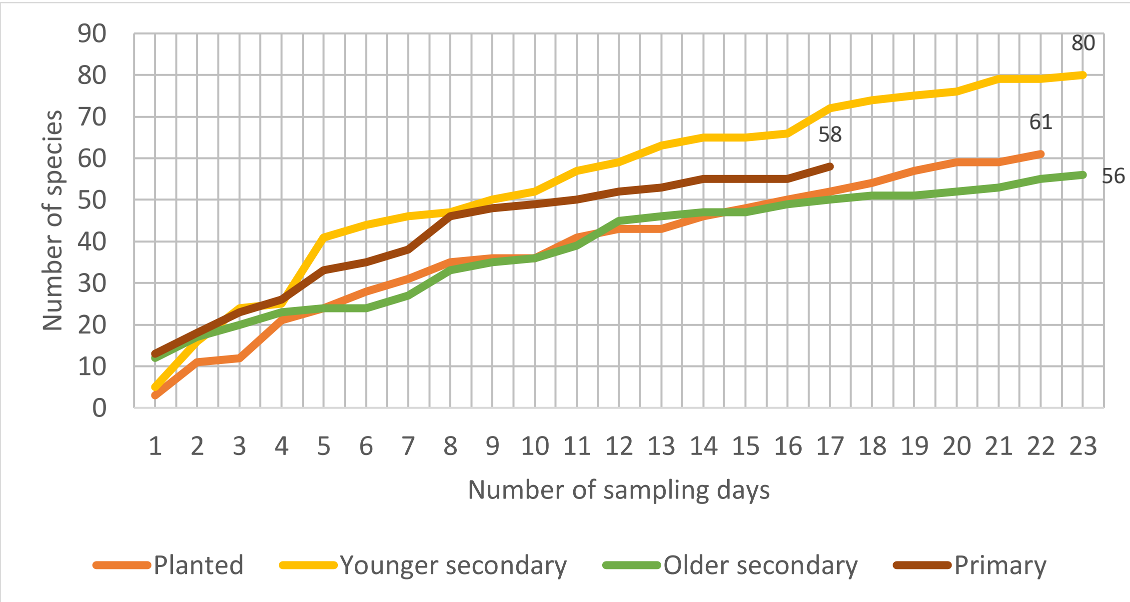


Figure 7: Species accumulation curves for each succession stage

3.2 Bird species richness

During bird observations a total of 1017 individual bird were encountered, covering 111 species from 23 families. 61 species with 249 individuals were observed in planted forest, 80 species with 300 individuals in younger secondary forest, 56 species with 228 individuals in older secondary forest and 58 species with 243 individuals were observed in primary forest (Figure 8). Younger secondary forest is richest in both number of species and individuals. Planted forest and primary forest are comparable in both number of species and individuals. Older secondary forest has the least number of species and individuals, but number of species is slightly lower than primary forest. Total species list for each succession stage is illustrated in Appendix 8.

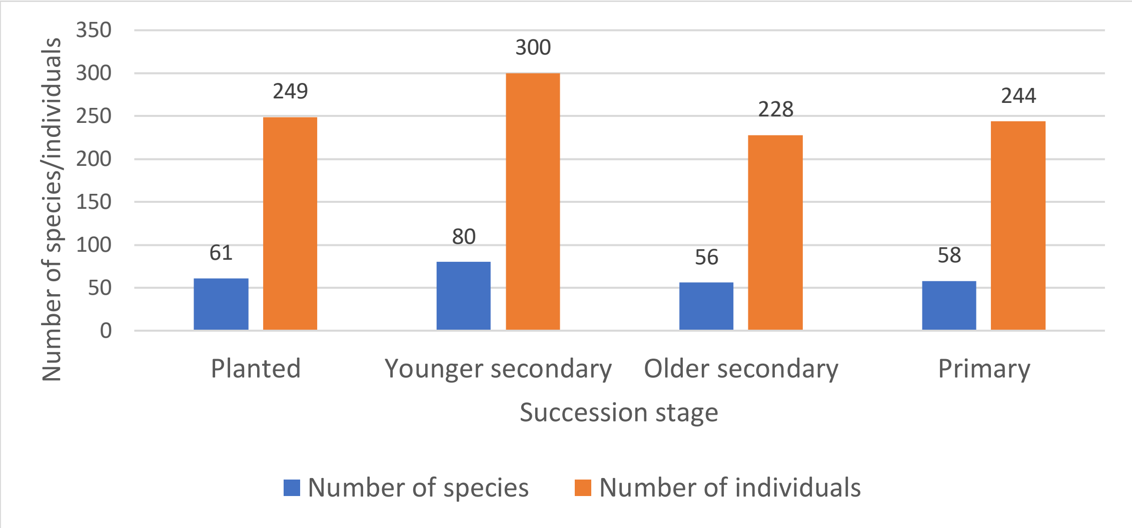


Figure 8: Bird species richness, with total number of species and total number of individuals in each succession stage

Two bird species are listed as near threatened (NT) according to the IUCN Red List (2021), the Golden-winged Warbler (*Vermivora chrysoptera*) with 1 individual and the Resplendent Quetzal (*Pharomachrus mocinno*) with 3 individuals. Only the Ruddy Pigeon (*Patagioenas subvinacea*), with 1 individual is listed as vulnerable (VU) (Appendix 7). The rest of the observed species are listed as least concern (LC). Table 1 shows the three bird species and in which succession stage they were seen. Only the Ruddy Pigeon was observed in all four succession stages.

Table 1: Near threatened and vulnerable bird species

Species	Planted	Younger secondary	Older secondary	Primary
Golden-winged Warbler (NT)	X			
Resplendent Quetzal (NT)				X
Ruddy Pigeon (VU)	X	X	X	X

3.2.1 Species without overlap

As some of the bird species encountered during this study are widespread and common, there are also species that are less common and only found in a certain succession stage. Table 2 shows an overview of the four succession stages and bird species that were observed only in that specific succession stage. It also shows the number of endemic species and number of species that are defined as high forest dependent. Younger secondary shows the greatest number of species (20 species), followed by planted forest (13 species), older secondary (6 species) and primary forest (5 species). Number of species that are highly forest dependent are the same in planted forest, older secondary and primary forest (3 species). Only older secondary has one specie that is highly forest dependent.

Table 2: Overview of number of bird species that have no overlap among the succession stages

Succession stage	# of species	# of endemics	# of highly forest dependent species
Planted	13	5	3
Young secondary	20	3	3
Old secondary	6	0	1
Primary forest	5	1	2

3.2.2 Feeding guilds

Of the 111 bird species observed during this research, 61 species are defined as insectivore which makes up the largest portion of all the species (55%). 28 species are defined as omnivore (25%). 11 species are defined as frugivore (10%) and 11 species are defined as nectarivore (10%), which are all hummingbirds. The distribution of the different feeding guilds between the four succession stages can be seen in Figure 9. Younger secondary forest is richest as regards to feeding guilds. 40 of the 61 insectivores were present in this succession stage as well as 18 omnivore species, 10 frugivore species and 10 nectarivore species (all but one hummingbird species).

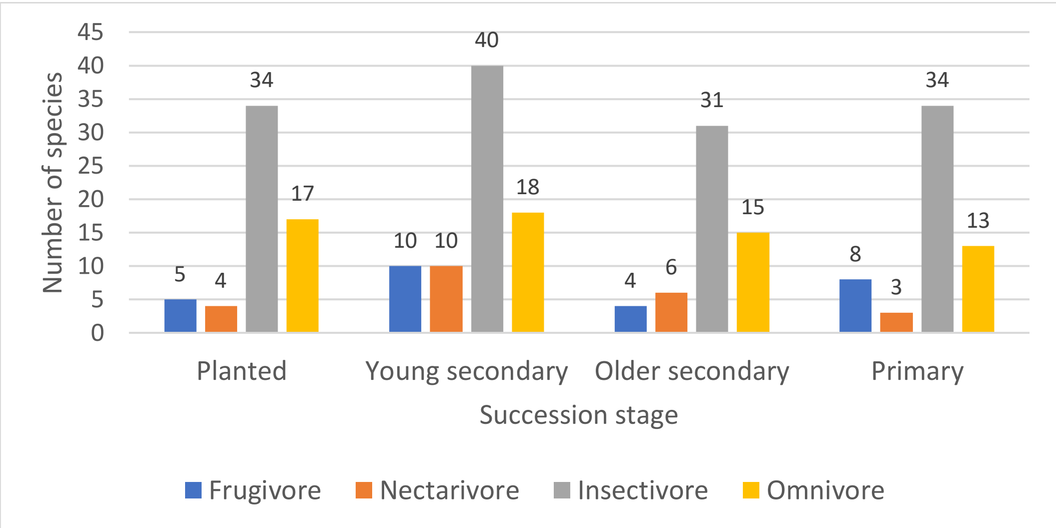


Figure 9: Representation of the different feeding guilds observed in each succession stage

3.3 Bird species diversity

Figure 10 illustrates the total Shannon Index for each of the different succession stages. Shannon Index (*H-value*) is highest in younger secondary with 3,699. Older secondary and primary forest show a lower *H-value* compared to younger secondary but are almost similar to each other with 3,646 and 3,629. Planted forest has the lowest *H-value* of the four succession stages with 3,308. Shannon Index for each succession stage is shown in Appendix 9.

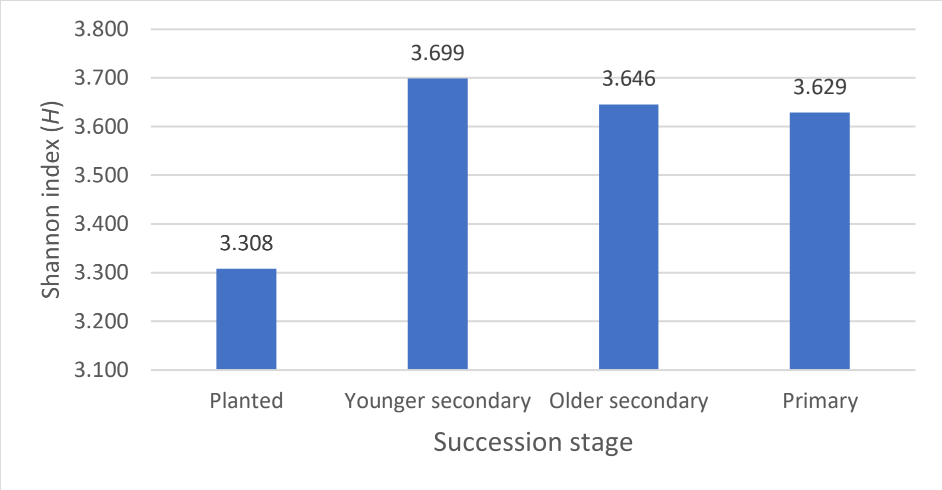


Figure 10: Total Shannon Index for each succession stage

Figure 11 illustrates the *H-value* for each separate bird station for planted and younger secondary forest. *H-value* for each separate bird station in planted forest differs from 1,889 in plot PL4 to 2,939 in plot 30. *H-value* for each separate bird station in younger secondary is slightly higher than in planted forest with 2,246 in plot YS2 to 3,141 in plot 28. Difference between lowest and highest *H-value* is slightly higher in planted forest compared to younger secondary.

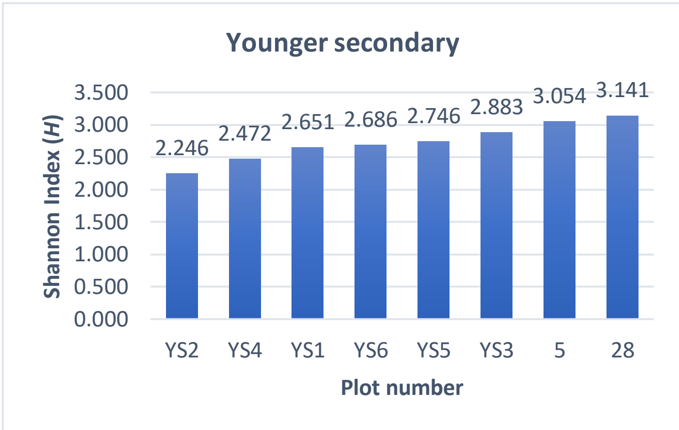
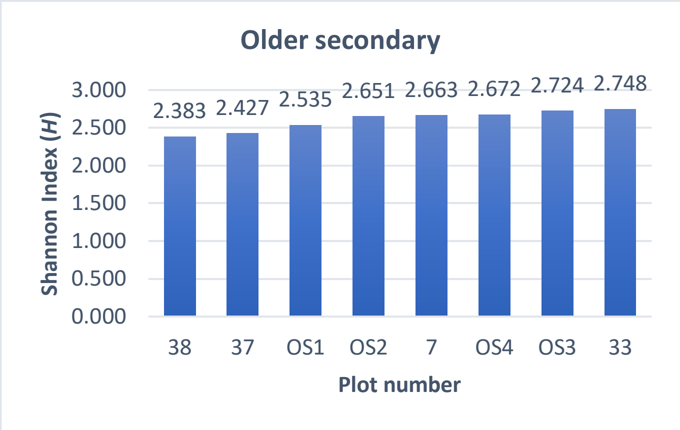


Figure 11: Shannon Index for each separate bird station in planted (left) and younger secondary (right) forest

H-value for older secondary and primary forest is illustrated in Figure 12. The difference between separate bird stations in older secondary is lowest of all four succession stages with lowest value at 2,383 in plot 38 and highest value at 2,748 in plot 33. The *H-value* between the separate bird stations in primary forest differ slightly more than in older secondary, but not as much as in planted or younger secondary. Lowest value was found in plot 12 at 2,487 and highest value in plot PF1 at 2,996. Lowest value of all plots was found in planted forest in plot PL4 with an index of 1,889 and highest value was found in younger secondary plot 28 with 3,141.



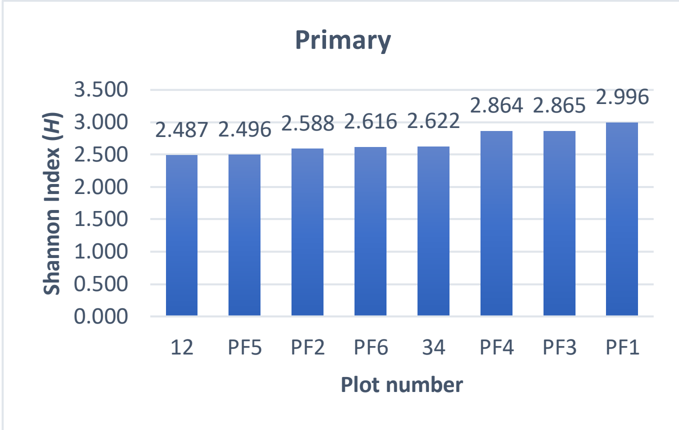


Figure 12: Shannon Index for each separate bird station in older secondary (left) and primary (right) forest

3.4 Landscape preference

The most common forest-depending bird species are defined as bird species that are medium or high forest-dependent, according to BirdLife International (2021), and that have a share which is >2,5% of the total number of individuals. This gives a total of seven medium or high forest-depending bird species, which are the Common Bush Tanager (*Chlorospingus flavopectus, N=134*), the Slate-throated Whitestart (*Myioborus miniatus, N=85*), the Swainson's Thrush (*Catharus ustulatus, N=47*), the Brown-capped Vireo (*Vireo leucophrys, N=41*), the Elegant Euphonia (*Euphonia elegantissima, N=34*), the Yellowish Flycatcher (*Empidonax flavescens, N=33*) and the Silver-throated Tanager (*Tanagara icterocephala, N=33*). The Swainson's Thrush is the only specie which is defined as high forest dependent (H). All the other species are defined as medium forest dependent (M). The chi-square test that was calculated for the observed bird species (Table 3) shows that the Common Bush Tanager and the Elegant Euphonia have a significant preference for planted forest as *P-value* for these species is <0,05. The Common Bush Tanager has a strong preference for planted forest with a *P-value* of 4,1867E-06 and the preference of Elegant Euphonia is less strong with a *P-value* of 0,0101. The other four species show no preference for a specific landscape as *P-value* is >0,05.

Table 3: P-value of chi-square test for the six most common bird species in each succession stage (CBT = Common Bush Tanager, STW = Slate-throated Whitestart, SWT = Swainson's Thrush, BCV = Brown-capped Vireo, ELE = Elegant Euphonia, YFC = Yellowish Flycatcher, STT = Silver-throated Tanager)

	CBT (M)	STW (M)	SWT (H)	BCV (M)	ELE (M)	YFC (M)	STT (M)
Planted	56	18	13	15	14	3	3
Young secondary	39	28	15	14	12	9	9
Older secondary	17	21	5	7	7	9	9
Primary	22	18	14	5	1	12	12
Total (N)	**134**	**85**	**47**	**41**	**34**	**33**	**33**
P-value	**4,1867E-06**	**0,3632**	**0,1544**	**0,0576**	**0,0101**	**0,1463**	**0,1463**

3.5 Relation of forest structure to bird diversity

Figure 13 shows the forest structure for each of the succession stages. For each succession stage, average canopy cover, average understory cover and average herb cover was measured. The figure indicates that no big differences in average canopy cover, understory cover and herb cover in each succession stage were found.

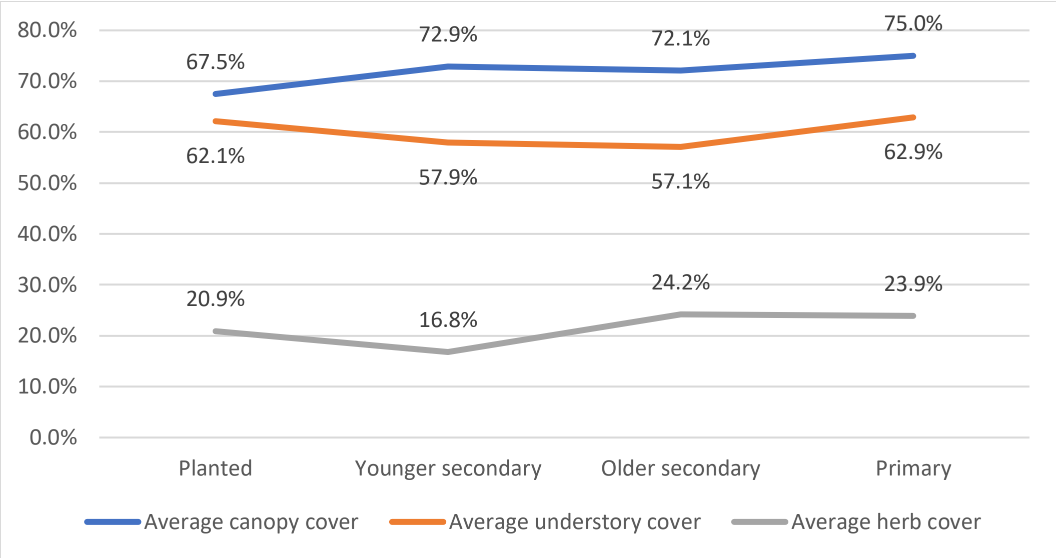


Figure 13: Average canopy cover, understory cover and herb cover in each succession stage

Figure 14 shows the average canopy cover and Shannon Index for each succession stage. Planted forest has a relatively low average canopy coverage (67,5%), as well as a relatively low Shannon Index (3,308). Younger secondary forest shows an increased average canopy cover (72,9%) and Shannon Index is also higher in younger secondary (3,699). Older secondary has a slightly lower average canopy cover (72,1%) than younger secondary, the same applies for Shannon Index (3,646). Primary forest shows the highest average canopy cover with 75%, yet here Shannon Index is almost similar to older secondary with 3,638.

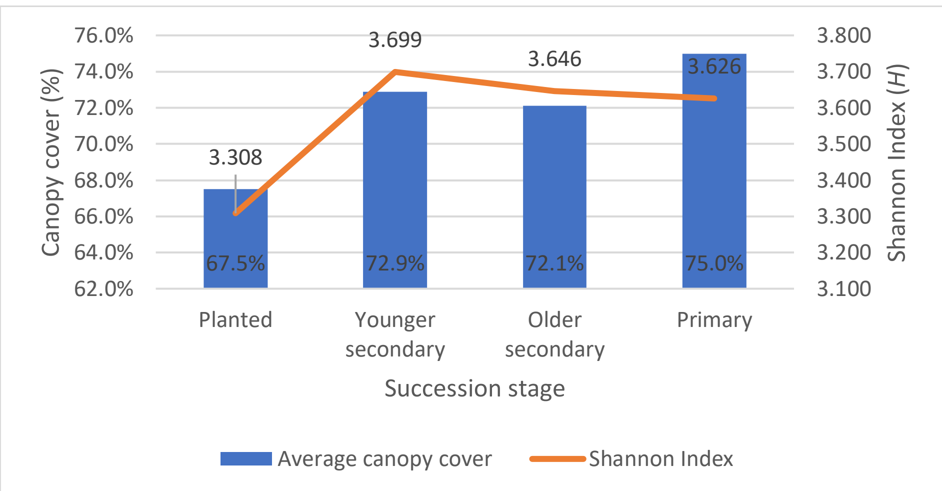


Figure 14: Average canopy cover and total Shannon Index for each succession stage

The basal area for each succession stage is illustrated in Figure 15. Basal area shows the same trend as Shannon Index for planted forest, younger and older secondary, with lowest basal area in planted forest (0,025 m^2) and highest in younger secondary (0,041 m^2). Basal area in primary forest is slightly higher than older secondary (0,038 m^2), yet Shannon Index is slightly lower.

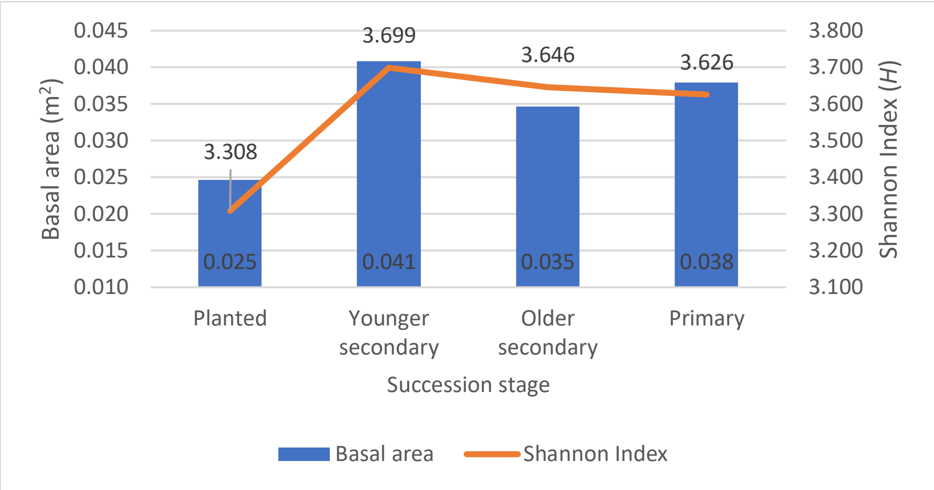


Figure 15: Basal area and Shannon Index for each succession stage

4. Discussion

The discussion of the results is described in this chapter. The discussion chapter is divided into a section which discusses the interpretation of the results as well as a section in which the limitations of this research are discussed.

4.1 Interpretation of the results

Is there a difference in species richness and diversity between the different succession stages?

Results for sub-question 1 show that there is a difference in species richness between the four succession stages (Figure 8). Young secondary forest has the highest species richness of all succession stages with 80 species and 300 individuals. Several studies argue that bird species richness peaks in younger secondary forest and thus found similar results. O'Dea & Whittaker (2007) found most species in secondary forest with an age of 15-20 years old, as well as a study by Stanley (2012) in Cloudbridge Reserve. Highest species richness was also found in young secondary forest in a study by Blake & Loiselle (2001) in Costa Rica, although here young secondary forest started regenerating in 1981. Contrary to these findings and results from this study, other studies found no peak in species richness in secondary forest. Results from a study by Barlow, Mestre, Gardner & Peres (2007), in lowland tropical rainforest in Brazil, found highest richness in primary forest. Species richness also peaked in primary forest in a study by Sodhi et al. (2005) in a montane and sub-montane forest reserve in Sulawesi, Indonesia. Thierry (2016) found no differences in species richness between different habitat types such as planted, young secondary, older secondary and primary forest in Cloudbridge Reserve. Reasons for these contradictory results could be differences in geographical changes, timeframe of research or quality of collected data.

Three bird species are listed as some form of vulnerability according to the IUCN Red List (2021) (Table 1). The Golden-winged Warbler and Resplendent Quetzal are listed as near threatened (NT). The population of the Golden-winged warbler has rapidly declined mainly due to habitat loss in its breeding and wintering grounds (Cornell University, 2021). As a migratory species, Costa Rica is its wintering ground and prevention of habitat loss is key to preserve this species. The Resplendent Quetzal was only observed in primary forest, so this would indicate the importance of preserving primary forests for this species. Not only because of the iconic status in Central American culture, but also because it is a secondary cavity nester and modifies abandoned woodpecker nest site in dead tree trunks (Siegfried, Linville, & Hille, 2010). The Ruddy Pigeon is the only species listed as vulnerable (VU), mainly due to the ongoing deforestation in the Amazon basin (BirdLife International (2021). Although this species is highly forest dependent, it was observed in all four succession stages. Despite this species is likely to be relatively safe in Costa Rica, preserving natural forests is important for this species.

This study shows that diversity also peaks in younger secondary forest (Figure 9). Similar results were found by Hanle, Duguid & Ashton (2020). Younger secondary forest has a Shannon Index of 3,699 (Figure 10). When looking at the separate values for each bird station, the two highest values were found in younger secondary (bird station 5 and 28) (Figure 11). This might have to do with the open forest structure of young secondary forest. Bird station 28 has the highest Shannon Index of all bird stations (3,141). This bird station was characterized by a half open forest structure where the canopy was not entirely closed. Swanson et al. (2010) argues that such a forest structure contains high species diversity due to the richness in resources. However, the value between the different bird stations differed almost as much as in planted forest. Planted forest shows the lowest overall Shannon Index of all succession stages, but when looking at the separate bird stations, the highest value was found in bird station 30 with 2,939. This was higher than any of the Shannon Indexes in older secondary and almost as high as the highest value found in primary forest found (Figure 12). Shannon Index for each separate bird station in older secondary differed the least from each other with lowest value of 2,383 and highest value of 2,748. The reason for this could be that forest structure resembles that of primary forest, where Shannon Index also differed less between separate bird stations compared to planted and younger secondary forest.

Forty-four of the 111 bird species were found only in a specific succession stage (Table 2), of which almost half of them (20 species) were found in younger secondary forest. As planted forests do not harbor most species without overlap, it is remarkable that five endemic bird species were only found here. Yet, three of these endemic species were only observed once (Volcano Hummingbird, Rufous-winged Woodpecker and Silvery-fronted Tapaculo). That the Silvery-fronted Tapaculo was only found in planted forest is noteworthy, as Stanley (2012) found most individuals of this species in primary forest and some individuals in secondary and planted forest in the same study area. Table 1 also shows that primary forest contains only six species without overlap, but two of them (40%) are highly forest dependent (Black-breasted Wood-Quail and Resplendent Quetzal). This could indicate the importance of primary forest for sensitive species like the Resplendent Quetzal, a large frugivore which is more intolerant to medium and severe habitat disturbance in comparison to small and medium sized frugivores like the Chestnut-capped Brushfinch (*Atlapetes brunneinucha*) and the Swainson's Thrush (*Catharus ustulatus*) (Kappelle, 2016).

Another remarkable finding is the absence of granivores like the Rufous-collared Sparrow (*Zonotrichia capensis*), Yellow-faced Grassquit (*Tiaris olivaceus*) and the Lesser Goldfinch (*Spinus psaltria*). Although these birds were not observed anywhere during this research, a study by Marcy in 2004 showed that these species were dominant at bird station 3. On the other hand, the same study claims that the Common Bush Tanager was not seen here. Yet, it was the dominant species in this study. Granivores were also encountered during a study by Stanley in 2012, although to a lesser extent. As granivores favor more open countryside habitat like gardens, pastures and fields, the absence of these species could indicate that the planted forest around these bird stations is aging and attracting more forest depending species like the Common Bush Tanager and Rudy-capped Nightingale-Thrush (Garrigues & Dean, 2014).

Do dominant forest-depending bird species have a preference for certain landscape and does this affect diversity?

Results from sub-question 2 show that only two dominant forest-depending species have a preference for a specific landscape (Table 3). The most dominant forest depending species observed is the Common Bush Tanager with 134 individuals and has a preference for planted forest (P = 4,1867E-06). This species, with an extremely large range, is often core member of mixed-species feeding flocks (eBird, 2021) and was most the abundant species in three of the four succession stages. Only the Slate-throated Whitestart was more abundant in younger secondary forest. Reason for this abundancy could be that, as this species is medium forest dependent, it favors a range of habitat types such as heavily degraded former forest and high altitude shrubland (BirdLife International, 2021). Main habitat type is cloud forest and Cloudbridge provides ample supply of cloud forest. As this species favors a range of habitats, it could be considered as a pioneer or generalist species. This could explain the preference for planted forest. Powell (2016) found similar results in the same study site, where this species was most abundant in planted, younger secondary and primary forest except for older secondary forest. This species was also most dominant in studies by Marcy in 2007 and Slifkin in 2019, both studies also conducted at Cloudbridge. The Elegant Euphonia, like the Common Bush Tanager, has a preference for planted forest, although less evident (P = 0,0101). It was less dominant overall with 34 individuals. This frugivorous species also favors cloud forest and heavily degraded former forest what could explain the preference for planted forest as well.

The effect of these dominant forest depending species on species diversity is unclear. There seems to be an effect when looking at total Shannon Index for each succession stage as Common Bush Tanager was most dominant in planted forest and planted forest shows lowest diversity (Figure 10). But when looking at separate bird stations, the effects seems to be less obvious (Figure 11 and 12). Bird station 27 had no observations of the Common Bush Tanager, but Shannon Index (2,375) is similar to bird station PL1 (2,449) where it was the dominant species. Although the Common Bush Tanager is a widespread species and it is most likely the most common species found in similar habitats, scientific evidence of any effect of this species on diversity is missing. However, Hillebrand, Bennett, & Cadotte (2008) claim that regional dominance of species leads to low beta diversity and reducing regional coexistence.

What is the relation between vegetation structure and bird species diversity in planted, naturally regenerated and primary forest?

If there is a statistically significant relation between forest structure and bird diversity is hard to tell due to the lack of vegetation data. Terrain characteristics were the main cause of the limited dataset. Further analysis of understory cover, herb cover, stem density and tree height data did not lead to a relationship with bird diversity. Despite the limited dataset, there seems to be a resemblance between average canopy cover and three succession stages (planted, younger and older secondary), as both Shannon Index and average canopy cover show a similar trend (Figure 14). The same applies for Shannon Index and basal area in planted forest (Figure 15), younger and older secondary forest. But, again, the small vegetation data size makes it hard to prove if there is indeed a relationship. However, several studies emphasize the importance of large trees (Lutz et al., 2018; Stagoll, Lindenmayer, Knight, Fischer, & Manning, 2012) while others suggest the relationship between forest structure and bird diversity. In a study conducted in Danish temperate forests, Poulsen (2002) came to the conclusion that bird diversity positively correlates with the increase of old trees, tree species and DBH classes. Castaño-Villa, Ramos-Valencia, & Fontúrbel (2014) suggest that bird diversity for insectivorous species also positively correlates with the variety in basal area, stem density and stem diameter. Over half of the bird species in this study are insectivores (55%), this could explain the similarity in Shannon Index and basal area, based on the results by Castaño-Villa, Ramos-Valencia, & Fontúrbel (2014). Another study (However, studies that indicate the direct relation between DBH, canopy cover and bird diversity are scarce.

Bird station PL4 (planted forest) has the lowest Shannon Index of all bird stations (1,189) (Figure 11). The forest structure around this bird station differed substantially from all other bird stations in planted forest. Canopy was low and very dense and there was a complete lack of understory vegetation. Bird station 3, around 150m downhill from PL4, showed a similar forest structure and a low Shannon Index (although a little higher than PL4 with 2,111). According to Tom Gode (personal communication, 20 May 2021), former director at Cloudbridge, this area was part of a weed suppression project in 2002 and was solely planted with Oak trees. Trees were planted much closer to each other than usual, which explains the lack of understory vegetation. The poor structural forest complexity could be the reason of a low diversity, as Munro et al. (2011) suggest, where species richness was lower in 'woodlot plantings' (plantings with homogenous structure) compared to plantings with a diverse tree, understory and shrub composition. Marcy found similar results in this area in 2004. Most observed species in this study were the Common Bush Tanager and the Ruddy-capped Nightingale-Thrush (*Catharus frantzii*), a species which is mostly found in humid pine-oak forests (eBird, 2021). Of all observations of this species, with 6 individuals it was most frequently observed in bird station PL4. The abundance of Oak trees in this area could explain the dominance of this species.

4.2 Limitations of this research

Methodology of bird surveys were partly based on the methods of the bird monitoring project that Cloudbridge started in 2013. This method uses an imaginary 25m radius cylinder in which all bird seen and heard are recorded. As the forests in Cloudbridge can be quite dense and canopy height can be as high as 35-40m, it was sometimes hard to determine if a bird was in or outside of the cylinder, especially with bird sounds. Also, birds are not always visible or audible. This makes silent birds that reside high in the canopy hard to detect. Another point of attention is that a standard sound recording app was used to record bird sounds and calls during observations. Although the quality of the recordings was mostly sufficient for identifying bird sounds, in some cases it was insufficient, especially in combination with background noise such as the river or people moving around in the proximity of the recorder. Softer bird calls or calls that were quite similar to other bird species could hardly be identified in this way.

The species accumulation curves for all four succession stages showed no horizontal asymptote. This was mainly due to a lack of time. With over 300 confirmed bird species recorded in the Cloudbridge Reserve, of which a portion are migratory birds that are not present throughout the year, it was not expected to reach a horizontal asymptote in short amount of time. Also, this study did not cover all of the Cloudbridge Reserve. E.g., the area closer to the main river and a number of existing bird stations across different trails were not included in this study (Don Victor, Sentinel and Gavilan trail). Hence, more sampling days are needed in order to record all, or most of the bird species that occupy the reserve and to get a full horizontal asymptote.

Vegetation sampling was conducted on a smaller scale than expected. The limiting factors were that the terrain was often rocky and steep, and vegetation was sometimes impermeable. Finding suitable terrain for setting out 20x20m plots was a challenge and this resulted in a restricted data set. The main reason for this approach was that bird stations were established on existing trails. Before fieldwork it was not yet clear to what extend these trails would affect forest structure. It was expected that these trails would indeed affect forest structure and therefore create a biased dataset. Reflecting on vegetation surveys, the trails did affect herb cover and to a lesser extent understory cover, but it did not affect canopy cover. Initially, the relation would be demonstrated through a regression analysis but due to limited dataset this method was found to be unsuitable.

5. Conclusion and recommendations

In this chapter, first the conclusion for each sub-question is described, followed by the main conclusion to the research question 'What effect does forest succession stage has on the bird species diversity at Cloudbridge Nature Reserve, Costa Rica?'. In response to the discussion (Chapter 4) and conclusions, a number of recommendations are presented to Cloudbridge Nature Reserve.

5.1 Conclusion

Species richness and diversity between the different succession stages

Results show that there is a clear difference in bird species richness between the succession stages. Species richness peaks in younger secondary forest which is followed by planted forest, primary forest and older secondary forest. Shannon Index shows that bird diversity also peaks in younger secondary forest. This is followed by older secondary forest, primary and planted forest. For species that are highly forest dependent and under threat, like the Resplendent Quetzal, the protection of primary forest is important.

Landscape preference for dominant forest-depending species

The chi-square test shows that from the six most dominant medium and high forest-depending species, the Common Bush Tanager and the Elegant Euphonia have a significant preference for planted forest. The Common Bush Tanager has the strongest preference for planted forest but the effect of dominance on bird diversity is unclear. Other dominant species show no preference for a specific landscape.

Relation between forest structure and bird diversity

There is no conclusive evidence that there is a relation between forest structure and bird diversity. Yet, there seems to be a resemblance between canopy cover, basal area and species diversity. The low diversity around bird station PL4 could be explained by the lack of understory vegetation due to tree planting techniques in the past.

Main conclusion

This study demonstrates that there is an effect of the aging of secondary forests and primary forest on bird species diversity. The high conservation value of younger secondary forest is clear as bird species diversity peaks here. Species diversity gradually declines in older secondary and primary forest. Planted forests show the lowest diversity and have a less positive effect. Planted forests harbor less species and certain species are more dominant like the Common Bush Tanager, which has a strong preference for planted forest. There is an indication that structural complexity causes this lower diversity although there is no conclusive evidence.

5.2 Recommendations

Resulting from the results and findings in this study, a number of recommendations for Cloudbridge are presented in this section. Recommendations are based on further research and forest management practices.

- The limited timeframe of this study was the most restricting factor of gathering sufficient data. As shown in sub-section 3.1, species accumulation curves did not reach a horizontal asymptote. Also, vegetation dataset for this study was very limited. It is therefore recommended to extend this research in the near future. More bird stations could be added throughout the reserve or more existing bird stations could be used, especially around the main river and on Don Victor trail. As discussed in sub-section 4.2, noise from the river was a reason for not using some of the existing bird stations close to the main river and on Sentinel trail. These bird station could be used if an advanced sound recording device is used. Noise from the river can be filtered out and bird songs and calls become much easier to identify. However, advanced sound recording devices could be expensive and filtering out background noise requires substantial computer knowledge and specialized software.

- Results of this study show that bird diversity flourishes in younger secondary forest. As mentioned in Chapter 4, several studies found similar results. As younger secondary forests are of great conservation value to bird diversity it is therefore recommended to keep at least a part of the reserve as young secondary forest. This could be accomplished by local thinning and weed suppression practices. This can create habitat for pioneer species and slow or stop the succession process going into mature forest.
- As discussed in sub-section 4.1, bird station PL4 shows the lowest Shannon Index of all bird stations. The forest structure around bird station PL4 shows poor structural diversity, due to a weed suppression project in 2002. In order to enhance species diversity and bird occurrence, it is recommended to improve forest structure. This could be accomplished by removing a part of the planted Oak trees (thinning), to ensure that sunlight is able to penetrate the canopy and reaches the forest floor. It is also recommended to diversify tree species, by enhancement planting. Thinning and enhancement planting could help stimulate natural regeneration of this forest section and become structurally more diverse. In the long term, this would enhance bird diversity. External experts, forestry interns or independent forestry researchers could be a solution for starting this project.
- Sub-question 3 could not be answered by the use of statistical analysis due to a lack of vegetation data. Terrain characteristics like steepness and the presence of cliffs made it hard to conduct vegetation research with the selected methods. Examining the relation between vegetation structure and bird diversity by making use of the regression analysis, which was the initial plan, was not possible. Hence, other methods for vegetation sampling are recommended to use during further research. Vegetation variables like canopy cover, understory vegetation cover and herb cover can be measured at the location of the bird stations. In this way, vegetation variables can be directly linked to bird diversity (Bibby, Burges, Hill, & Mustoe, 2000). But, as discussed in sub-section 4.2, the trails had some effect on understory coverage and affected herb cover on a larger extend. The same plot lay-out used in this research could be used, with the bird station as center point of the plot. Other vegetation variables could be taken into account as well, such as tree density, shrub density and vertical vegetation density.

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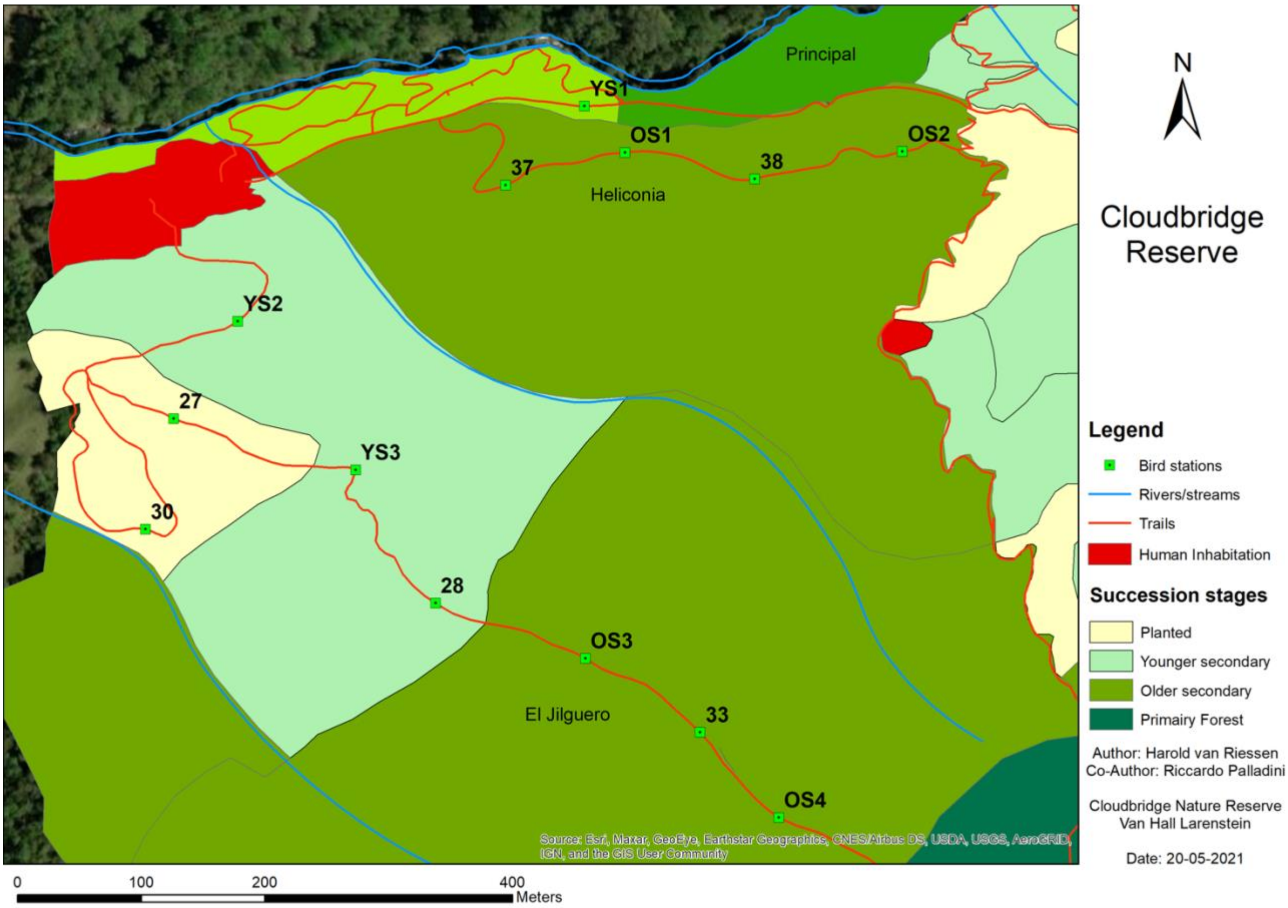
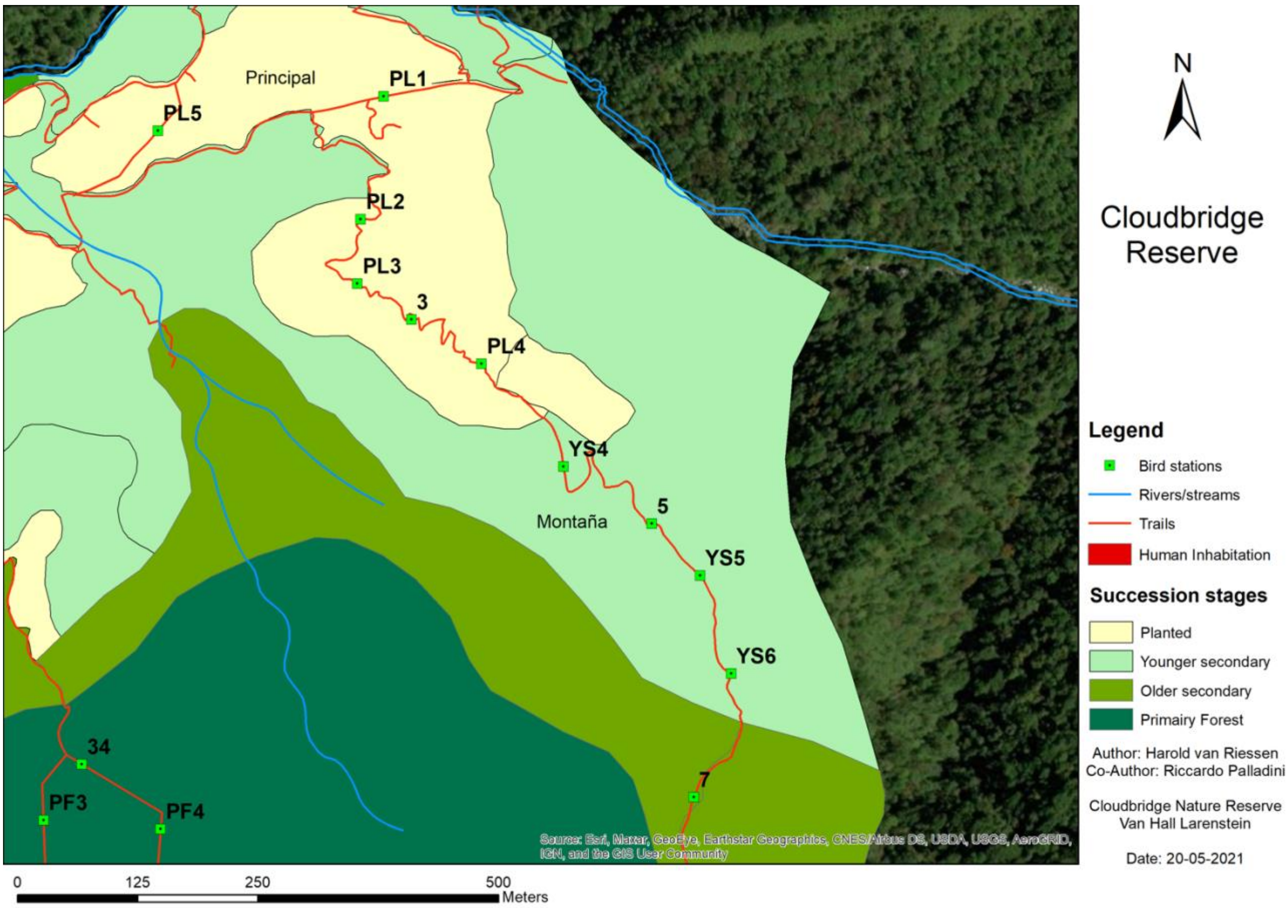
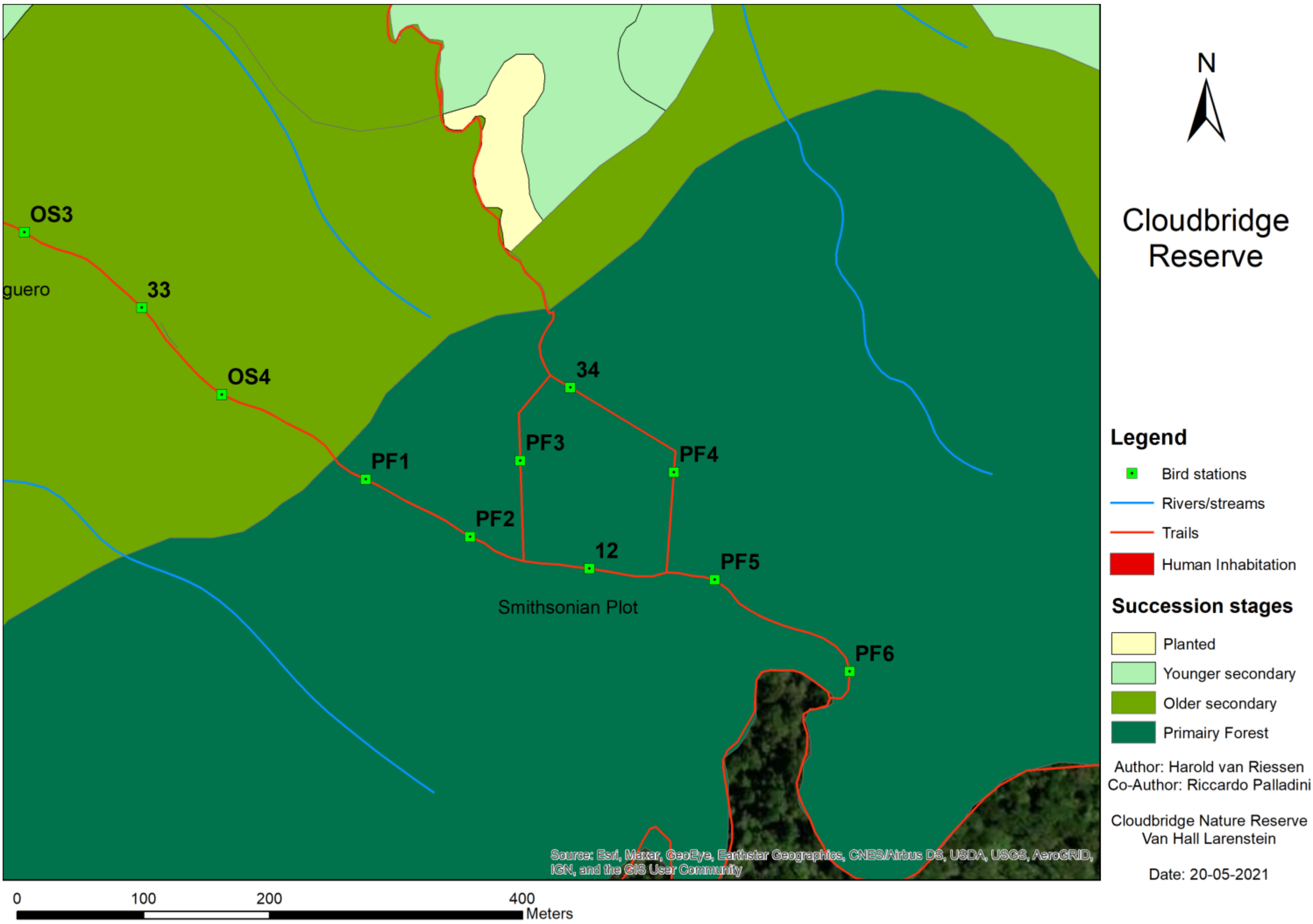
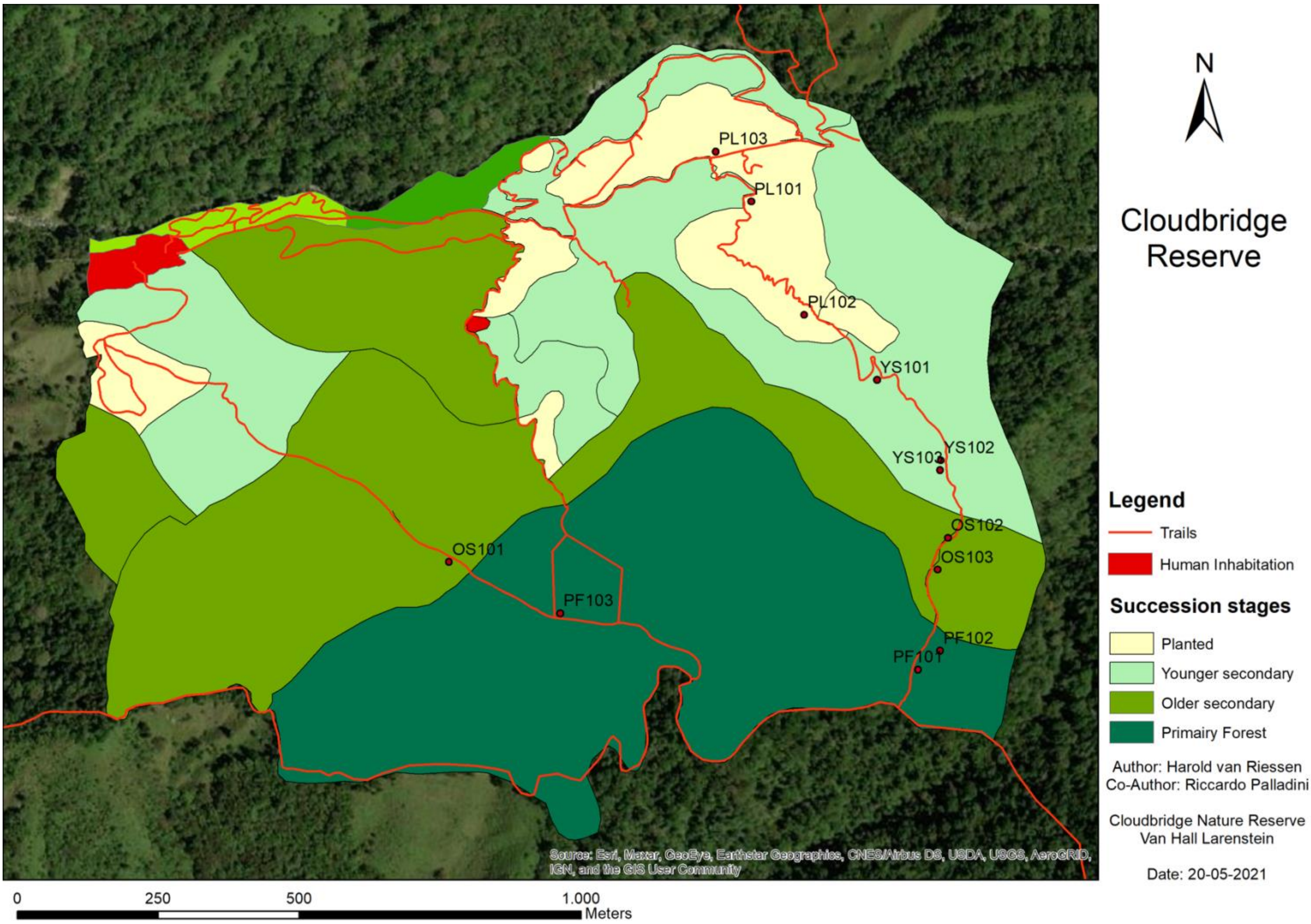
Appendix 1: Detailed location bird stations






OS3
guero
33
OS4
34
PF1
PF3
PF4
PF2
12
PF5
Smithsonian Plot
PF6
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
N
Cloudbridge Reserve
Legend
Bird stations
Rivers/streams
Trails
Human Inhabitation
Succession stages
Planted
Younger secondary
Older secondary
Primairy Forest
Author: Harold van Riessen
Co-Author: Riccardo Palladini
Cloudbridge Nature Reserve
Van Hall Larenstein
Date: 20-05-2021
0
100
200
400
Meters

Appendix 2: Location vegetation plots



Appendix 3: GPS location bird stations and vegetation plots

Bird stations

Planted		Younger secondary		Older secondary		Primary	
3	0218025, 1048046	5	0218254, 1047840	7	0218316, 1047559	12	0217678, 1047459
27	0216967, 1047884	28	0217160, 1047742	33	0217357, 1047628	34	0217704, 1047573
30	0216910, 1047848	YS1	0217223, 1048150	37	0217203, 1048094	PF1	0217472, 1047545
PL1	0217997, 1048280	YS2	0216972, 1047996	38	0217432, 1048100	PF2	0217554, 1047481
PL2	0217974, 1048164	YS3	0217054, 1047854	OS1	0217310, 1048121	PF3	0217639, 1047527
PL3	0217941, 1048098	YS4	0218204, 1047876	OS2	0217495, 1048128	PF4	0217743, 1047441
PL4	0218075, 1048000	YS5	0218312, 1047725	OS3	0217316, 1047674	PF5	0217771, 1047401
PL5	0217759, 1048245	YS6	0218335, 1047635	OS4	0217427, 1047569	PF6	0217813, 1047358

Vegetation plots

Planted		Younger secondary		Older secondary		Primary	
PL101	0217981, 1048184	YS101	0218209, 1047869	OS101	0217453, 1047554	PF101	0218271, 1047353
PL102	0218075, 1047981	YS102	0218319, 1047715	OS102	0218325, 1047583	PF102	0218310, 1047385
PL103	0217923, 1048262	YS103	0218316, 1047708	OS103	0218299, 1047533	PF103	0217643, 1047449

Appendix 4: Schedule bird surveys

Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Heliconia + El Jilguero	El Jilguero	Principal + Montaña	El Jilguero	Principal + Montaña
37	YS2	YS1	27	PL5
38	30	PL1	28	PL2
34	YS3	PL3	33	3
12	OS3	PL4	PF1	YS4
OS2	OS4	5	PF3	YS5
OS1	PF2	YS6	PF4	7
	PF5		PF6	

Appendix 5: Field form bird observations

Date		Bird station #	
Start time		GPS coordinates	
End time		Observer name(s)	

Species	Time	# Ind.	Certain?	Seen/heard	Remarks

Appendix 6: Field form vegetation measurements

Date		Succession stage	
Plot number		GPS coordinates	

Canopy cover (%)

5m		15m	
10m		Average	

Trees (DBH >10cm) in 20x20m plot

Tree #	DBH (cm)	Height (m)

Vegetation coverage 4x4m plots (%)

Subplot1	
Subplot2	
Subplot3	
Subplot4	
Average	

Herb coverage 1x1m plots (%)

Subplot 1A	
Subplot 2A	
Subplot 3A	
Subplot 4A	
Average	

Appendix 7: Species list

Family	English name	Scientific name	# individuals	IUCN status	Feeding guild	Forest specialization
Cracidae	Black Guan (e)	*Chamaepetes unicolor*	11	LC	Frugivore	Medium
Odontophoridae	Black-breasted Wood-Quail (e)	*Odontophorus leucolaemus*	2	LC	Omnivore	High
	Spotted Wood-Quail	*Odontophorus guttatus*	18	LC	Omnivore	High
Trochilidae	Violet Sabrewing	*Campylopterus hemileucurus*	2	LC	Nectarivore	Medium
	Green Hermit	*Phaethornis guy*	6	LC	Nectarivore	Medium
	Green-crowned Brillant	*Heliodoxa jacula*	6	LC	Nectarivore	High
	Fiery-throated Hummingbird (e)	*Panterpe insignis*	3	LC	Nectarivore	Medium
	Purple-crowned Fairy	*Heliothryx barroti*	2	LC	Nectarivore	High
	Stripe-tailed Hummingbird	*Eupherusa eximia*	2	LC	Nectarivore	High
	Rufous-tailed Hummingbird	*Amazilia tzacatl*	5	LC	Nectarivore	Medium
	Lesser Violetear	*Colibri cyanotus*	1	LC	Nectarivore	Low
	Grey-tailed Mountaingem (e)	*Lampornis cinereicauda*	15	LC	Nectarivore	Medium
	Scintillant Hummingbird (e)	*Selasphorus scintilla*	15	LC	Nectarivore	Low
	Volcano Hummingbird (e)	*Selasphorus flammula*	1	LC	Nectarivore	Low
Columbidae	Ruddy Pigeon	*Patagioenas subvinacea*	6	VU	Frugivore	High
Psittacidae	Brown-hooded Parrot	*Pyrilia haematotis*	8	LC	Frugivore	High
Cuculidae	Squirrel Cuckoo	*Piaya cayana*	3	LC	Insectivore	Medium
Trogonidae	Collared Trogon	*Trogon collaris*	5	LC	Omnivore	High
	Resplendent Quetzal	*Pharomachrus mocinno*	2	NT	Omnivore	High
Capitonidae	Red-headed Barbet	*Eubucco bourcierii*	9	LC	Frugivore	High
Ramphastidae	Blue-throated Toucanet	*Aulacorhynchus caeruleogularis*	23	LC	Omnivore	Medium
Picidae	Red-crowned Woodpecker	*Melanerpes rubricapillus*	4	LC	Insectivore	Medium
	Golden-olive Woodpecker	*Colaptes rubiginosus*	5	LC	Insectivore	Medium
	Hairy Woodpecker	*Leuconotopicus villosus*	2	LC	Insectivore	High
	Rufous-winged Woodpecker (e)	*Piculus simplex*	1	LC	Insectivore	High
	Olivaceous Piculet	*Picumnus olivaceus*	1	LC	Insectivore	Medium
Furnariidae	Streaked Xenops	*Xenops rutilans*	1	LC	Insectivore	High
	Olivaceous Woodcreeper	*Sittasomus griseicapillus*	1	LC	Insectivore	Medium
	Wedge-billed Woodcreeper	*Glyphorynchus spirurus*	2	LC	Insectivore	Medium
	Spotted Woodcreeper	*Xiphorhynchus erythropygius*	6	LC	Insectivore	Medium
	Streak-headed Woodcreeper	*Lepidocolaptes souleyetii*	11	LC	Insectivore	Medium
	Spot-crowned Woodcreeper	*Lepidocolaptes affinis*	21	LC	Insectivore	Medium
	Brown-billed Scythebill	*Campylorhamphus pusillus*	3	LC	Insectivore	High
	Tawny-throated Leaftosser	*Sclerurus mexicanus*	1	LC	Insectivore	High
	Scaly-throated Foliage-gleaner	*Anabacerthia variegaticeps*	5	LC	Insectivore	High
	Buff-fronted Foliage-gleaner	*Dendroma rufa*	4	LC	Insectivore	High
	Ruddy Treerunner	*Margarornis rubiginosus*	1	LC	Insectivore	High
	Buffy Tuftedcheek	*Pseudocolaptes lawrencii*	1	LC	Insectivore	Medium
	Lineated Foliage-gleaner	*Syndactyla subalaris*	17	LC	Insectivore	High
	Streak-breasted Treehunter (e)	*Thripadectes rufobrunneus*	4	LC	Insectivore	High
Thamnophilidae	Slaty Antwren	*Myrmotherula schisticolor*	14	LC	Insectivore	High
Rhinocryptidae	Silvery-fronted Tapaculo (e)	*Scytalopus argentifrons*	1	LC	Insectivore	Medium
Tyrannidae	White-fronted Tyrannulet	*Phyllomyias zeledoni*	3	LC	Omnivore	High
	Mistletoe Tyrannulet	*Zimmerius parvus*	12	LC	Omnivore	Medium
	Mountain Elaenia	*Elaenia frantzii*	2	LC	Omnivore	Medium
	Yellow-olive Flatbill	*Tolmomyias sulpherescens*	1	LC	Insectivore	Medium
	Olive-striped Flycatcher	*Mionectes olivaceus*	5	LC	Frugivore	Medium
	Slaty-capped Flycatcher	*Leptopogon superciliaris*	2	LC	Omnivore	High
	Scale-crested Pygmy Tyrant	*Lophotricus pileatus*	6	LC	Insectivore	Medium
	Eye-ringed Flatbill	*Rhynchocyclus brevirostris*	3	LC	Insectivore	High
	Eastern Wood Pewee	*Contopus virens*	1	LC	Insectivore	Medium
	Yellow-bellied Flycatcher	*Empidonax flaviventris*	15	LC	Insectivore	Medium
	Least Flycatcher	*Empidonax minimus*	1	LC	Insectivore	Medium
	Yellowish Flycatcher	*Empidonax flavescens*	33	LC	Insectivore	Medium
	Black-capped Flycatcher (e)	*Empidonax atriceps*	1	LC	Insectivore	Medium
	Northern Tufted Flycatcher	*Mitrephanes phaeocercus*	4	LC	Insectivore	Medium
	Boat-billed Flycatcher	*Megarynchus pitangua*	2	LC	Insectivore	Low

	Bright-rumped Attila	*Attila spadiceus*	2	LC	Omnivore	Medium
	Grey-capped Flycatcher	*Myiozetetes granadensis*	1	LC	Insectivore	Low
	Golden-bellied Flycatcher (e)	*Myiodynastes hemichrysus*	7	LC	Omnivore	Medium
Tityridae	Barred Becard	*Pachyramphus versicolor*	1	LC	Insectivore	Medium
	Masked Tityra	*Tityra semifasciata*	1	LC	Omnivore	Medium
Turdidae	Ruddy-capped Nightingale-Thrush	*Catharus frantzii*	20	LC	Omnivore	Medium
	Slaty-backed Nightingale-Thrush	*Catharus fuscater*	5	LC	Omnivore	High
	Swainson's Thrush	*Catharus ustulatus*	47	LC	Omnivore	High
	Black-faced Solitaire (e)	*Myadestes melanops*	2	LC	Frugivore	High
	Sooty Thrush (e)	*Turdus nigrescens*	1	LC	Omnivore	Low
	Clay-colored Thrush	*Turdus grayi*	2	LC	Omnivore	Low
	White-throated Thrush	*Turdus assimilis*	1	LC	Omnivore	Medium
Troglodytidae	Rufous-breasted Wren	*Pheugopedius rutilus*	24	LC	Insectivore	Medium
	Isthmian Wren (e)	*Cantorchilus elutus*	4	LC	Insectivore	Medium
	Ochraceous Wren (e)	*Troglodytes ochraceus*	13	LC	Insectivore	High
	Grey-breasted Wood Wren	*Henicorhina leucophrys*	11	LC	Insectivore	High
	Southern Nightingale-Wren	*Microcerculus marginatus*	7	LC	Insectivore	High
Vireonidae	Yellow-throated Vireo	*Vireo flavifrons*	1	LC	Insectivore	Medium
	Yellow-winged Vireo (e)	*Vireo carmioli*	8	LC	Insectivore	Medium
	Brown-capped Vireo	*Vireo leucophrys*	41	LC	Insectivore	Medium
	Lesser Greenlet	*Hylophilus decurtatus*	17	LC	Insectivore	Medium
	Rufous-browed Peppershrike	*Cyclarhis gujanensis*	3	LC	Insectivore	Medium
Parulidae	Golden-winged Warbler	*Vermivora chrysoptera*	1	NT	Insectivore	Medium
	Black-and-white Warbler	*Mniotilta varia*	1	LC	Insectivore	Medium
	Tennessee Warbler	*Leiothlypis peregrina*	19	LC	Insectivore	Medium
	Flame-throated Warbler (e)	*Oreothlypis guttaralis*	3	LC	Insectivore	Medium
	Tropical Parula	*Setophaga pitiayumi*	13	LC	Insectivore	Medium
	Chestnut-sided Warbler	*Setophaga pensylvanica*	1	LC	Insectivore	Low
	Blackburnian Warbler	*Setophaga fusca*	14	LC	Insectivore	Medium
	Townsend's Warbler	*Setophaga townsendi*	4	LC	Insectivore	Medium
	Black-throated Green Warbler	*Setophaga virens*	1	LC	Insectivore	Medium
	Wilson's Warbler	*Cardellina pusilla*	11	LC	Insectivore	Medium
	Slate-throated Whitestart	*Myioborus miniatus*	85	LC	Insectivore	Medium
	Black-cheeked Warbler (e)	*Basileuterus melanogenys*	4	LC	Insectivore	High
	Golden-crowned Warbler	*Basileuterus culicivorus*	22	LC	Insectivore	Medium
Thraupidae	Blue-grey Tanager	*Thraupis episcopus*	3	LC	Frugivore	Low
	Silver-throated Tanager	*Tangara icterocephala*	33	LC	Omnivore	Medium
	Speckled Tanager	*Ixothraupis guttata*	2	LC	Frugivore	Low
	Golden-hooded Tanager	*Stilpnia larvata*	2	LC	Omnivore	Low
	Spangle-cheeked Tanager (e)	*Tangara dowii*	6	LC	Omnivore	Medium
	Bay-headed Tanager	*Tangara gyrola*	2	LC	Omnivore	Medium
	Scarlet-thighed Dacnis	*Dacnis venusta*	10	LC	Omnivore	Medium
	Buff-throated Saltator	*Saltator maximus*	3	LC	Frugivore	Medium
Emberizidae	Yellow-thighed Brushfinch (e)	*Atlapetes tibialis*	7	LC	Omnivore	Medium
	Chestnut-capped Brushfinch	*Arremon brunneinucha*	16	LC	Insectivore	Medium
	White-naped Brushfinch	*Atlapetes albinucha*	1	LC	Omnivore	Medium
	Black-eared Warbler (e)	*Basileuterus melanotis*	9	LC	Insectivore	Medium
	Common Bush Tanager	*Chlorospingus flavopectus*	134	LC	Omnivore	Medium
Cardinalidae	Tooth-billed Tanager	*Piranga lutea*	2	LC	Insectivore	Medium
	Summer Tanager	*Piranga rubra*	1	LC	Insectivore	Medium
	Flame-colored Tanager	*Piranga bidentata*	6	LC	Omnivore	Medium
	White-winged Tanager	*Piranga leucoptera*	3	LC	Omnivore	Medium
Fringilidae	Golden-browed Chlorophonia (e)	*Chlorophonia callophrys*	3	LC	Frugivore	Medium
	Elegant Euphonia	*Euphonia elegantissima*	34	LC	Frugivore	Medium

Appendix 8: Species list for each succession stage

Planted forest

Species	27	30	PL1	PL2	PL3	PL4	PL5	3	Total abundance (N)
Black Guan		1							1
Black-throated Green Warbler	1								1
Blackburnian Warbler				1	1				2
Boat-billed Flycatcher					2				2
Bright-rumped Attila	1						1		2
Brown-capped Vireo	5	4		3		2		1	15
Buff-throated Saltator		1							1
Chestnut-capped Brushfinch				4	1		1	1	7
Collared Trogon		1		1					2
Common Bush Tanager		2	11	11	9	6	7	10	56
Elegant Euphonia			3	6	3	1		1	14
Eye-ringed Flatbill		1							1
Flame-colored Tanager								1	1
Golden-bellied Flycatcher					1				1
Golden-crowned Warbler	1	2			1		2		6
Golden-hooded Tanager		2							2
Golden-olive Woodpecker					2				2
Golden-winged Warbler				1					1
Grey-breasted Wood Wren	1		1		2	1			5
Grey-tailed Mountaingem		1							1
Isthmian Wren				1	3				4
Lesser Greenlet		2							2
Mistletoe Tyrannulet		1		2					3
Mountain Elaenia								1	1
Red-crowned Woodpecker		1							1
Red-headed Barbet				1					1
Ruddy Pigeon			1						1
Ruddy-capped Nightingale-Thrush		1	1	3	1	6		2	14
Rufous-breasted Wren				1					1
Rufous-browed Peppershrike				1					1
Rufous-tailed Hummingbird		1							1
Rufous-winged Woodpecker	1								1
Scale-crested Pygmy Tyrant		1							1
Scarlet-thighed Dacnis			1						1
Scintillant Hummingbird	1	1	1				2		5
Silver-throated Tanager		1	1		3				5
Silvery-fronted Tapaculo								1	1
Slate-throated Whitestart	1	1	2	4		5	2	3	18
Slaty Antwren			1	1			2		4
Slaty-backed Nightingale-Thrush	1						1		2
Slaty-capped Flycatcher	1								1
Southern Nightingale-Wren							1		1
Spotted Wood-Quail					3				3
Spotted Woodcreeper			1						1
Squirrel Cuckoo			2						2
Streak-breasted Treehunter					1				1
Streak-headed Woodcreeper						1			1
Streaked Xenops			1						1
Swainson's Thrush	2	2	5	2			1	1	13
Tawny-throated Leaftosser				1					1
Tennessee Warbler			3	1		1	4		9
Tooth-billed Tanager					2				2
Townsend's Warbler								1	1

Tropical Parula	2								2
Volcano Hummingbird		1							1
White-tailed Emerald					1				1
White-winged Tanager	1								1
Wilson's Warbler			1			1		1	3
Yellow-bellied Flycatcher		2						1	3
Yellow-thighed Brushfinch			2	3	2				7
Yellowish Flycatcher				2	1				3
Total individuals	**19**	**30**	**38**	**50**	**39**	**24**	**24**	**25**	**249**

Younger secondary forest

Species	**YS1**	**YS2**	**YS3**	**YS4**	**YS5**	**YS6**	**5**	**28**	**Total abundance (N)**
Barred Becard							1		1
Bay-headed Tanager			2						2
Black Guan							1		1
Black-and-white Warbler			1						1
Black-capped Flycatcher							1		1
Black-cheeked Warbler				1		1			2
Black-faced Soltaire	1								1
Blackburnian Warbler	1		1		1				3
Blue-grey Tanager								3	3
Blue-throated Toucanet						2		1	3
Brown-billed Scythebill								1	1
Brown-capped Vireo			3	4	2	1	1	3	14
Brown-hooded Parrot				1					1
Buff-fronted Foliage-gleaner							1		1
Buff-throated Saltator		1						1	2
Buffy Tuftedcheek	1								1
Chestnut-capped Brushfinch	1				1				2
Common Bush Tanager	10	2	5	14	2	1	3	2	39
Elegant Euphonia	5		1	2	1			3	12
Fiery-throated Hummingbird	3								3
Flame-colored Tanager						1		1	2
Flame-throated Warbler							1		1
Golden-bellied Flycatcher	1		1					1	3
Golden-browed Chlorophonia				1	1				2
Golden-crowned Warbler					1				1
Green Hermit	1								1
Green-crowned Brillant	3								3
Grey-breasted Wood Wren				1		1		1	3
Grey-tailed Mountaingem								1	1
Hairy Woodpecker				1					1
Least Flycatcher	1								1
Lesser Elaenia							1		1
Lesser Violetear							1		1
Lineated Fioliage-gleaner					1		1		2
Mistletoe Tyrannulet		2	2	2					6
Mountain Elaenia							1		1
Ochraceous Wren							2		2
Olivaceous Piculet								1	1
Olive-striped Flycatcher	2								2
Purple-crowned Fairy	1							1	2
Red-crowned Woodpecker								1	1
Red-headed Barbet							1	2	3
Ruddy Pigeon							1		1
Ruddy Treerunner						1			1
Ruddy-capped Nightingale-Thrush					1				1
Rufous-breasted Wren	5		2	1	1	1	1	2	13
Rufous-browed Peppershrike								1	1

Rufous-tailed Hummingbird								1	1
Scale-crested Pygmy Tyrant								1	1
Scarlet-thighed Dacnis			5	2				2	9
Scintillant Hummingbird	1	2	2					3	8
Silver-throated Tanager	2	1		2			4	3	12
Slate-throated Whitestart	1	6	4	4	5	1	3	4	28
Slaty-backed Nightingale-Thrush	1								1
Sooty Thrush						1			1
Southern Nightingale-Wren		2							2
Spangle-cheeked Tanager							2		2
Speckled Tanager			2						2
Spot-crowned Woodcreeper				5	2	1			8
Spotted Wood-Quail		2	2		2		2		8
Spotted Woodcreeper						1			1
Squirrel Cuckoo								1	1
Streak-breasted Treehunter				1					1
Streaked Xenops					1				1
Stripe-tailed Hummingbird							1		1
Summer Tanager				1					1
Swainson's Thrush	2		2		3		1	7	15
Tennessee Warbler		2	1					6	9
Townsend's Warbler			1						1
Tropical Parula			4	1				1	6
Violet Sabrewing						1			1
White-naped Brushfinch			1						1
White-throated Thrush						1			1
White-winged Tanager								1	1
Wilson's Warbler	1		1		2				4
Yellow-bellied Flycatcher		2	2					2	6
Yellow-olive Flatbill		1							1
Yellow-throated Vireo							1		1
Yellow-winged Vireo					1		2		3
Yellowish Flycatcher				4	2	1	2		9
Total individuals	**44**	**23**	**45**	**48**	**30**	**16**	**36**	**58**	**300**

Older secondary forest

Species	OS1	OS2	OS3	OS4	7	33	37	38	Total abundance (N)
Black Guan				2					2
Black-eared Warbler	3							6	9
Blackburnian Warbler		1			3		2		6
Blue-throated Toucanet		2			3	3			8
Brown-billed Scythebill					1				1
Brown-capped Vireo	2		1		1	2		1	7
Chestnut-capped Bruschfinch	1	2				1	2		6
Chestnut-sided Warbler								1	1
Clay-colored Thrush		2							2
Collared Trogon			1	2					3
Common Bush Tanager	8	3		1		1		4	17
Elegant Euphonia		2	3			2			7
Flame-colored Tanager					2				2
Golden-bellied Flycatcher	1				1				2
Golden-crowned Warbler				3		3		4	10
Golden-olive Woodpecker			2						2
Green Hermit	3						2		5
Green-crowned Brilliant		1				1	1		3
Grey-breasted Wood Wren								2	2
Grey-capped Flycatcher								1	1
Grey-tailed Mountaingem	1			1					2
Lesser Greenlet		1	3	3				3	10

Lineated Foliage-gleaner		1	1	1	3	1			7
Mistletoe Tyrannulet			1	1					2
Ochraceous Wren					1				1
Olivaceous Woodcreeper			1						1
Red-headed Barbet								2	2
Ruddy Pigeon				2					2
Ruddy-capped Nightingale-Thrush					2		1		3
Rufous-breasted Wren			3			2	1	1	7
Rufous-tailed Hummingbird		1							1
Scale-crested Pygmy Tyrant				1					1
Scaly-throated Foliage-gleaner						1			1
Scintillant Hummingbird	1						1		2
Silver-throated Tanager		4	1	1	1				7
Slate-throated Whitestart	1	1	4		2	5	4	4	21
Slaty Antwren		1	2	1		2		3	9
Slaty-backed Nightingale Thrush	1						1		2
Slaty-capped Flycatcher					1				1
Southern Nightingale-Wren						1	3		4
Spot-crowned Woodcreeper			2		3	2			7
Spotted Wood-Quail			2				3		5
Spotted Woodcreeper						1			1
Streak-breasted Treehunter								1	1
Streak-headed Woodcreeper	1								1
Swainson's Thrush		1	2	1			1		5
Tennessee Warbler	1								1
Townsend's Warbler	1				1				2
Tropical Parula	2		1	1					4
Violet Sabrewing	1								1
Wedge-billed Woodcreeper						1			1
White-fronted Tyrannulet		1		1			1		3
White-winged Tanager					1				1
Wilson's Warbler	1					1			2
Yellow-bellied Flycatcher			2						2
Yellowish Flycatcher	1	2		2	2	2			9
Total individuals	**30**	**26**	**32**	**24**	**28**	**32**	**23**	**33**	**228**

Primary forest

Species	PF1	PF2	PF3	PF4	PF5	PF6	12	34	Total abundance (N)
Black Guan	1			2			4	1	8
Black-breasted Wood-Quail								2	2
Black-cheeked Warbler				2					2
Black-faced Solitaire	1								1
Blackburnian Warbler			1		1			1	3
Blue-throated Toucanet	2	1	1	4		4			12
Brown-billed Scythebill								1	1
Brown-capped Vireo				2	1	1	1		5
Brown-hooded Parrot		2				1		4	7
Buff-fronted Foliage-Gleaner			1	1			1		3
Chestnut-capped Brushfinch			1						1
Common Bush Tanager	1			6	5	7		3	22
Eastern Wood Pewee	1								1
Elegant Euphonia				1					1
Eye-ringed Flatbill	2								2
Flame-colored Tanager			1						1
Flame-throated Warbler						2			2
Golden-bellied Flycatcher						1			1
Golden-browed Chlorophonia						1			1
Golden-crowned Warbler		1	1	2				1	5
Golden-olive Woodpecker				1					1

Grey-breasted Wood Wren			1						1
Grey-tailed Mountaingem			1	4		4	1	1	11
Hairy Woodpecker								1	1
Lesser Greenlet	4	1							5
Lineated Foliage-gleaner	2	4	1				1		8
Masked Tityra					1				1
Mistletoe Tyrannulet								1	1
Northern Tufted Flycatcher				1		3			4
Ochraceous Wren	1	1	2	1			3	2	10
Olive-striped Flycatcher		1		2					3
Red-crowned Woodpecker		1					1		2
Red-headed Barbet				1	1	1			3
Resplendent Quetzal	1		1						2
Ruddy Pigeon	1	1							2
Ruddy-capped Nightingale-Thrush						1	1		2
Rufous-breasted Wren			1	1	1				3
Rufous-browed Peppershrike				1					1
Rufous-tailed Hummingbird				1			1		2
Scale-crested Pygmy Tyrant	1		1		1				3
Scaly-throated Foliage-gleaner	1			1	1			1	4
Silver-throated Tanager	2					5	2		9
Slate-throated Whitestart	1	2	3	3	2	2	4	1	18
Slaty Antwren							1		1
Spangle-cheeked Tanager					4				4
Spot-crowned Woodcreeper	1		2	2		1			6
Spotted Wood-Quail		2							2
Spotted Woodcreeper	1	2							3
Streak-breasted Treehunter					1				1
Streak-headed Woodcreeper	1	1	2	2	1	1		1	9
Stripe-tailed Hummingbird			1						1
Swainson's Thrush	4	3	2				5		14
Tropical Parula	1								1
Wedge-billed Woodcreeper							1		1
Wilson's Warbler	1				1				2
Yellow-bellied Flycatcher	1	2				1			4
Yellow-winged Vireo	2				1	1		1	5
Yellowish Flycatcher			2		2	1	4	3	12
Total individuals	**34**	**25**	**26**	**41**	**24**	**38**	**31**	**25**	**244**

Appendix 9: Shannon Index for each succession stage

Planted forest

Species	# individuals	p*i*	lnp*i*	p*i**lnp*i*
Black Guan	1	0,00401606	-5,5174529	-0,0221584
Black-throated Green Warbler	1	0,00401606	-5,5174529	-0,0221584
Blackburnian Warbler	2	0,00803213	-4,8243057	-0,0387494
Boat-billed Flycatcher	2	0,00803213	-4,8243057	-0,0387494
Bright-rumped Attila	2	0,00803213	-4,8243057	-0,0387494
Brown-capped Vireo	15	0,06024096	-2,8094027	-0,1692411
Buff-throated Saltator	1	0,00401606	-5,5174529	-0,0221584
Chestnut-capped Brushfinch	7	0,02811245	-3,5715427	-0,1004048
Collared Trogon	2	0,00803213	-4,8243057	-0,0387494
Common Bush Tanager	56	0,2248996	-1,4921012	-0,335573
Elegant Euphonia	14	0,0562249	-2,8783956	-0,1618375
Eye-ringed Flatbill	1	0,00401606	-5,5174529	-0,0221584
Flame-colored Tanager	1	0,00401606	-5,5174529	-0,0221584
Golden-bellied Flycatcher	1	0,00401606	-5,5174529	-0,0221584
Golden-crowned Warbler	6	0,02409639	-3,7256934	-0,0897757
Golden-hooded Tanager	2	0,00803213	-4,8243057	-0,0387494
Golden-olive Woodpecker	2	0,00803213	-4,8243057	-0,0387494
Golden-winged Warbler	1	0,00401606	-5,5174529	-0,0221584
Grey-breasted Wood Wren	5	0,02008032	-3,908015	-0,0784742
Grey-tailed Mountaingem	1	0,00401606	-5,5174529	-0,0221584
Isthmian Wren	4	0,01606426	-4,1311585	-0,066364
Lesser Greenlet	2	0,00803213	-4,8243057	-0,0387494
Mistletoe Tyrannulet	3	0,01204819	-4,4188406	-0,053239
Mountain Elaenia	1	0,00401606	-5,5174529	-0,0221584
Red-crowned Woodpecker	1	0,00401606	-5,5174529	-0,0221584
Red-headed Barbet	1	0,00401606	-5,5174529	-0,0221584
Ruddy Pigeon	1	0,00401606	-5,5174529	-0,0221584
Ruddy-capped Nightingale-Thrush	14	0,0562249	-2,8783956	-0,1618375
Rufous-breasted Wren	1	0,00401606	-5,5174529	-0,0221584
Rufous-browed Peppershrike	1	0,00401606	-5,5174529	-0,0221584
Rufous-tailed Hummingbird	1	0,00401606	-5,5174529	-0,0221584
Rufous-winged Woodpecker	1	0,00401606	-5,5174529	-0,0221584
Scale-crested Pygmy Tyrant	1	0,00401606	-5,5174529	-0,0221584
Scarlet-thighed Dacnis	1	0,00401606	-5,5174529	-0,0221584
Scintillant Hummingbird	5	0,02008032	-3,908015	-0,0784742
Silver-throated Tanager	5	0,02008032	-3,908015	-0,0784742
Silvery-fronted Tapaculo	1	0,00401606	-5,5174529	-0,0221584
Slate-throated Whitestart	18	0,07228916	-2,6270811	-0,1899095
Slaty Antwren	4	0,01606426	-4,1311585	-0,066364
Slaty-backed Nightingale-Thrush	2	0,00803213	-4,8243057	-0,0387494
Slaty-capped Flycatcher	1	0,00401606	-5,5174529	-0,0221584
Southern Nightingale-Wren	1	0,00401606	-5,5174529	-0,0221584
Spotted Wood-Quail	3	0,01204819	-4,4188406	-0,053239
Spotted Woodcreeper	1	0,00401606	-5,5174529	-0,0221584

Squirrel Cuckoo	2	0,00803213	-4,8243057	-0,0387494
Streak-breasted Treehunter	1	0,00401606	-5,5174529	-0,0221584
Streak-headed Woodcreeper	1	0,00401606	-5,5174529	-0,0221584
Streaked Xenops	1	0,00401606	-5,5174529	-0,0221584
Swainson's Thrush	13	0,05220884	-2,9525035	-0,1541468
Tawny-throated Leaftosser	1	0,00401606	-5,5174529	-0,0221584
Tennessee Warbler	9	0,03614458	-3,3202283	-0,1200083
Tooth-billed Tanager	2	0,00803213	-4,8243057	-0,0387494
Townsend's Warbler	1	0,00401606	-5,5174529	-0,0221584
Tropical Parula	2	0,00803213	-4,8243057	-0,0387494
Volcano Hummingbird	1	0,00401606	-5,5174529	-0,0221584
White-tailed Emerald	1	0,00401606	-5,5174529	-0,0221584
White-winged Tanager	1	0,00401606	-5,5174529	-0,0221584
Wilson's Warbler	3	0,01204819	-4,4188406	-0,053239
Yellow-bellied Flycatcher	3	0,01204819	-4,4188406	-0,053239
Yellow-thighed Brushfinch	7	0,02811245	-3,5715427	-0,1004048
Yellowish Flycatcher	3	0,01204819	-4,4188406	-0,053239
Total	**249**			**3,308482**

Younger secondary forest

Species	**# individuals**	**p*i***	**lnp*i***	**p*i**lnp*i***
Barred Becard	1	0,00333333	-5,7037825	-0,0190126
Bay-headed Tanager	2	0,00666667	-5,0106353	-0,0334042
Black Guan	1	0,00333333	-5,7037825	-0,0190126
Black-and-white Warbler	1	0,00333333	-5,7037825	-0,0190126
Black-capped Flycatcher	1	0,00333333	-5,7037825	-0,0190126
Black-cheeked Warbler	2	0,00666667	-5,0106353	-0,0334042
Black-faced Soltaire	1	0,00333333	-5,7037825	-0,0190126
Blackburnian Warbler	3	0,01	-4,6051702	-0,0460517
Blue-grey Tanager	3	0,01	-4,6051702	-0,0460517
Blue-throated Toucanet	3	0,01	-4,6051702	-0,0460517
Brown-billed Scythebill	1	0,00333333	-5,7037825	-0,0190126
Brown-capped Vireo	14	0,04666667	-3,0647251	-0,1430205
Brown-hooded Parrot	1	0,00333333	-5,7037825	-0,0190126
Buff-fronted Foliage-gleaner	1	0,00333333	-5,7037825	-0,0190126
Buff-throated Saltator	2	0,00666667	-5,0106353	-0,0334042
Buffy Tuftedcheek	1	0,00333333	-5,7037825	-0,0190126
Chestnut-capped Brushfinch	2	0,00666667	-5,0106353	-0,0334042
Common Bush Tanager	39	0,13	-2,0402208	-0,2652287
Elegant Euphonia	12	0,04	-3,2188758	-0,128755
Fiery-throated Hummingbird	3	0,01	-4,6051702	-0,0460517
Flame-colored Tanager	2	0,00666667	-5,0106353	-0,0334042
Flame-throated Warbler	1	0,00333333	-5,7037825	-0,0190126
Golden-bellied Flycatcher	3	0,01	-4,6051702	-0,0460517
Golden-browed Chlorophonia	2	0,00666667	-5,0106353	-0,0334042
Golden-crowned Warbler	1	0,00333333	-5,7037825	-0,0190126
Green Hermit	1	0,00333333	-5,7037825	-0,0190126

Green-crowned Brillant	3	0,01	-4,6051702	-0,0460517
Grey-breasted Wood Wren	3	0,01	-4,6051702	-0,0460517
Grey-tailed Mountaingem	1	0,00333333	-5,7037825	-0,0190126
Hairy Woodpecker	1	0,00333333	-5,7037825	-0,0190126
Least Flycatcher	1	0,00333333	-5,7037825	-0,0190126
Lesser Elaenia	1	0,00333333	-5,7037825	-0,0190126
Lesser Violetear	1	0,00333333	-5,7037825	-0,0190126
Lineated Fioliage-gleaner	2	0,00666667	-5,0106353	-0,0334042
Mistletoe Tyrannulet	6	0,02	-3,912023	-0,0782405
Mountain Elaenia	1	0,00333333	-5,7037825	-0,0190126
Ochraceous Wren	2	0,00666667	-5,0106353	-0,0334042
Olivaceous Piculet	1	0,00333333	-5,7037825	-0,0190126
Olive-striped Flycatcher	2	0,00666667	-5,0106353	-0,0334042
Purple-crowned Fairy	2	0,00666667	-5,0106353	-0,0334042
Red-crowned Woodpecker	1	0,00333333	-5,7037825	-0,0190126
Red-headed Barbet	3	0,01	-4,6051702	-0,0460517
Ruddy Pigeon	1	0,00333333	-5,7037825	-0,0190126
Ruddy Treerunner	1	0,00333333	-5,7037825	-0,0190126
Ruddy-capped Nightingale-Thrush	1	0,00333333	-5,7037825	-0,0190126
Rufous-breasted Wren	13	0,04333333	-3,1388331	-0,1360161
Rufous-browed Peppershrike	1	0,00333333	-5,7037825	-0,0190126
Rufous-tailed Hummingbird	1	0,00333333	-5,7037825	-0,0190126
Scale-crested Pygmy Tyrant	1	0,00333333	-5,7037825	-0,0190126
Scarlet-thighed Dacnis	9	0,03	-3,5065579	-0,1051967
Scintillant Hummingbird	8	0,02666667	-3,6243409	-0,0966491
Silver-throated Tanager	12	0,04	-3,2188758	-0,128755
Slate-throated Whitestart	28	0,09333333	-2,371578	-0,2213473
Slaty-backed Nightingale-Thrush	1	0,00333333	-5,7037825	-0,0190126
Sooty Thrush	1	0,00333333	-5,7037825	-0,0190126
Southern Nightingale-Wren	2	0,00666667	-5,0106353	-0,0334042
Spangle-cheeked Tanager	2	0,00666667	-5,0106353	-0,0334042
Speckled Tanager	2	0,00666667	-5,0106353	-0,0334042
Spot-crowned Woodcreeper	8	0,02666667	-3,6243409	-0,0966491
Spotted Wood-Quail	8	0,02666667	-3,6243409	-0,0966491
Spotted Woodcreeper	1	0,00333333	-5,7037825	-0,0190126
Squirrel Cuckoo	1	0,00333333	-5,7037825	-0,0190126
Streak-breasted Treehunter	1	0,00333333	-5,7037825	-0,0190126
Streaked Xenops	1	0,00333333	-5,7037825	-0,0190126
Stripe-tailed Hummingbird	1	0,00333333	-5,7037825	-0,0190126
Summer Tanager	1	0,00333333	-5,7037825	-0,0190126
Swainson's Thrush	15	0,05	-2,9957323	-0,1497866
Tennessee Warbler	9	0,03	-3,5065579	-0,1051967
Townsend's Warbler	1	0,00333333	-5,7037825	-0,0190126
Tropical Parula	6	0,02	-3,912023	-0,0782405
Violet Sabrewing	1	0,00333333	-5,7037825	-0,0190126
White-naped Brushfinch	1	0,00333333	-5,7037825	-0,0190126
White-throated Thrush	1	0,00333333	-5,7037825	-0,0190126
White-winged Tanager	1	0,00333333	-5,7037825	-0,0190126
Wilson's Warbler	4	0,01333333	-4,3174881	-0,0575665

Yellow-bellied Flycatcher	6	0,02	-3,912023	-0,0782405
Yellow-olive Flatbill	1	0,00333333	-5,7037825	-0,0190126
Yellow-throated Vireo	1	0,00333333	-5,7037825	-0,0190126
Yellow-winged Vireo	3	0,01	-4,6051702	-0,0460517
Yellowish Flycatcher	9	0,03	-3,5065579	-0,1051967
Total	**300**			**3,698972**

Older secondary forest

Species	**# individuals**	**p*i***	**lnp*i***	**p*i**lnp*i***
Black Guan	2	0,00877193	-4,7361984	-0,0415456
Black-eared Warbler	9	0,03947368	-3,2321211	-0,1275837
Blackburnian Warbler	6	0,02631579	-3,6375862	-0,095726
Blue-throated Toucanet	8	0,03508772	-3,3499041	-0,1175405
Brown-billed Scythebill	1	0,00438596	-5,4293456	-0,0238129
Brown-capped Vireo	7	0,03070175	-3,4834355	-0,1069476
Chestnut-capped Bruschfinch	6	0,02631579	-3,6375862	-0,095726
Chestnut-sided Warbler	1	0,00438596	-5,4293456	-0,0238129
Clay-colored Thrush	2	0,00877193	-4,7361984	-0,0415456
Collared Trogon	3	0,01315789	-4,3307333	-0,0569833
Common Bush Tanager	17	0,0745614	-2,5961323	-0,1935713
Elegant Euphonia	7	0,03070175	-3,4834355	-0,1069476
Flame-colored Tanager	2	0,00877193	-4,7361984	-0,0415456
Golden-bellied Flycatcher	2	0,00877193	-4,7361984	-0,0415456
Golden-crowned Warbler	10	0,04385965	-3,1267605	-0,1371386
Golden-olive Woodpecker	2	0,00877193	-4,7361984	-0,0415456
Green Hermit	5	0,02192982	-3,8199077	-0,0837699
Green-crowned Brilliant	3	0,01315789	-4,3307333	-0,0569833
Grey-breasted Wood Wren	2	0,00877193	-4,7361984	-0,0415456
Grey-capped Flycatcher	1	0,00438596	-5,4293456	-0,0238129
Grey-tailed Mountaingem	2	0,00877193	-4,7361984	-0,0415456
Lesser Greenlet	10	0,04385965	-3,1267605	-0,1371386
Lineated Foliage-gleaner	7	0,03070175	-3,4834355	-0,1069476
Mistletoe Tyrannulet	2	0,00877193	-4,7361984	-0,0415456
Ochraceous Wren	1	0,00438596	-5,4293456	-0,0238129
Olivaceous Woodcreeper	1	0,00438596	-5,4293456	-0,0238129
Red-headed Barbet	2	0,00877193	-4,7361984	-0,0415456
Ruddy Pigeon	2	0,00877193	-4,7361984	-0,0415456
Ruddy-capped Nightingale-Thrush	3	0,01315789	-4,3307333	-0,0569833
Rufous-breasted Wren	7	0,03070175	-3,4834355	-0,1069476
Rufous-tailed Hummingbird	1	0,00438596	-5,4293456	-0,0238129
Scale-crested Pygmy Tyrant	1	0,00438596	-5,4293456	-0,0238129
Scaly-throated Foliage-gleaner	1	0,00438596	-5,4293456	-0,0238129
Scintillant Hummingbird	2	0,00877193	-4,7361984	-0,0415456
Silver-throated Tanager	7	0,03070175	-3,4834355	-0,1069476
Slate-throated Whitestart	21	0,09210526	-2,3848232	-0,2196548
Slaty Antwren	9	0,03947368	-3,2321211	-0,1275837
Slaty-backed Nightingale Thrush	2	0,00877193	-4,7361984	-0,0415456

Slaty-capped Flycatcher	1	0,00438596	-5,4293456	-0,0238129
Southern Nightingale-Wren	4	0,01754386	-4,0430513	-0,0709307
Spot-crowned Woodcreeper	7	0,03070175	-3,4834355	-0,1069476
Spotted Wood-Quail	5	0,02192982	-3,8199077	-0,0837699
Spotted Woodcreeper	1	0,00438596	-5,4293456	-0,0238129
Streak-breasted Treehunter	1	0,00438596	-5,4293456	-0,0238129
Streak-headed Woodcreeper	1	0,00438596	-5,4293456	-0,0238129
Swainson's Thrush	5	0,02192982	-3,8199077	-0,0837699
Tennessee Warbler	1	0,00438596	-5,4293456	-0,0238129
Townsend's Warbler	2	0,00877193	-4,7361984	-0,0415456
Tropical Parula	4	0,01754386	-4,0430513	-0,0709307
Violet Sabrewing	1	0,00438596	-5,4293456	-0,0238129
Wedge-billed Woodcreeper	1	0,00438596	-5,4293456	-0,0238129
White-fronted Tyrannulet	3	0,01315789	-4,3307333	-0,0569833
White-winged Tanager	1	0,00438596	-5,4293456	-0,0238129
Wilson's Warbler	2	0,00877193	-4,7361984	-0,0415456
Yellow-bellied Flycatcher	2	0,00877193	-4,7361984	-0,0415456
Yellowish Flycatcher	9	0,03947368	-3,2321211	-0,1275837
Total	**228**			**3,6462275**

Primary forest

Species	# individuals	p*i*	lnp*i*	p*i**lnp*i*
Black Guan	8	0,03278689	-3,4177267	-0,1120566
Black-breasted Wood-Quail	2	0,00819672	-4,804021	-0,0393772
Black-cheeked Warbler	2	0,00819672	-4,804021	-0,0393772
Black-faced Solitaire	1	0,00409836	-5,4971682	-0,0225294
Blackburnian Warbler	3	0,01229508	-4,3985559	-0,0540806
Blue-throated Toucanet	12	0,04918033	-3,0122616	-0,148144
Brown-billed Scythebill	1	0,00409836	-5,4971682	-0,0225294
Brown-capped Vireo	5	0,0204918	-3,8877303	-0,0796666
Brown-hooded Parrot	7	0,02868852	-3,5512581	-0,1018804
Buff-fronted Foliage-Gleaner	3	0,01229508	-4,3985559	-0,0540806
Chestnut-capped Brushfinch	1	0,00409836	-5,4971682	-0,0225294
Common Bush Tanager	22	0,09016393	-2,4061258	-0,2169458
Eastern Wood Pewee	1	0,00409836	-5,4971682	-0,0225294
Elegant Euphonia	1	0,00409836	-5,4971682	-0,0225294
Eye-ringed Flatbill	2	0,00819672	-4,804021	-0,0393772
Flame-colored Tanager	1	0,00409836	-5,4971682	-0,0225294
Flame-throated Warbler	2	0,00819672	-4,804021	-0,0393772
Golden-bellied Flycatcher	1	0,00409836	-5,4971682	-0,0225294
Golden-browed Chlorophonia	1	0,00409836	-5,4971682	-0,0225294
Golden-crowned Warbler	5	0,0204918	-3,8877303	-0,0796666
Golden-olive Woodpecker	1	0,00409836	-5,4971682	-0,0225294
Grey-breasted Wood Wren	1	0,00409836	-5,4971682	-0,0225294
Grey-tailed Mountaingem	11	0,04508197	-3,099273	-0,1397213
Hairy Woodpecker	1	0,00409836	-5,4971682	-0,0225294
Lesser Greenlet	5	0,0204918	-3,8877303	-0,0796666

Lineated Foliage-gleaner	8	0,03278689	-3,4177267	-0,1120566
Masked Tityra	1	0,00409836	-5,4971682	-0,0225294
Mistletoe Tyrannulet	1	0,00409836	-5,4971682	-0,0225294
Northern Tufted Flycatcher	4	0,01639344	-4,1108739	-0,0673914
Ochraceous Wren	10	0,04098361	-3,1945831	-0,1309255
Olive-striped Flycatcher	3	0,01229508	-4,3985559	-0,0540806
Red-crowned Woodpecker	2	0,00819672	-4,804021	-0,0393772
Red-headed Barbet	3	0,01229508	-4,3985559	-0,0540806
Resplendent Quetzal	2	0,00819672	-4,804021	-0,0393772
Ruddy Pigeon	2	0,00819672	-4,804021	-0,0393772
Ruddy-capped Nightingale-Thrush	2	0,00819672	-4,804021	-0,0393772
Rufous-breasted Wren	3	0,01229508	-4,3985559	-0,0540806
Rufous-browed Peppershrike	1	0,00409836	-5,4971682	-0,0225294
Rufous-tailed Hummingbird	2	0,00819672	-4,804021	-0,0393772
Scale-crested Pygmy Tyrant	3	0,01229508	-4,3985559	-0,0540806
Scaly-throated Foliage-gleaner	4	0,01639344	-4,1108739	-0,0673914
Silver-throated Tanager	9	0,03688525	-3,2999436	-0,1217192
Slate-throated Whitestart	18	0,07377049	-2,6067965	-0,1923047
Slaty Antwren	1	0,00409836	-5,4971682	-0,0225294
Spangle-cheeked Tanager	4	0,01639344	-4,1108739	-0,0673914
Spot-crowned Woodcreeper	6	0,02459016	-3,7054088	-0,0911166
Spotted Wood-Quail	2	0,00819672	-4,804021	-0,0393772
Spotted Woodcreeper	3	0,01229508	-4,3985559	-0,0540806
Streak-breasted Treehunter	1	0,00409836	-5,4971682	-0,0225294
Streak-headed Woodcreeper	9	0,03688525	-3,2999436	-0,1217192
Stripe-tailed Hummingbird	1	0,00409836	-5,4971682	-0,0225294
Swainson's Thrush	14	0,05737705	-2,8581109	-0,16399
Tropical Parula	1	0,00409836	-5,4971682	-0,0225294
Wedge-billed Woodcreeper	1	0,00409836	-5,4971682	-0,0225294
Wilson's Warbler	2	0,00819672	-4,804021	-0,0393772
Yellow-bellied Flycatcher	4	0,01639344	-4,1108739	-0,0673914
Yellow-winged Vireo	5	0,0204918	-3,8877303	-0,0796666
Yellowish Flycatcher	12	0,04918033	-3,0122616	-0,148144
Total	**244**			**3,6287277**

Appendix 10: Results chi-square test

Observed

	CBT	STW	SWT	BCV	ELE	YFC	STT
Planted	56	18	13	15	14	3	3
Younger secondary	39	28	15	14	12	9	9
Older secondary	17	21	5	7	7	9	9
Primary	22	18	14	5	1	12	12
Total (N)	**134**	**85**	**47**	**41**	**34**	**33**	**33**

Expected

	CBT	STW	SWT	BCV	ELE	YFC	STT
Planted	34	21	12	10	9	8	8
Younger secondary	34	21	12	10	9	8	8
Older secondary	34	21	12	10	9	8	8
Primary	34	21	12	10	9	8	8
Total (N)	**136**	**84**	**48**	**40**	**36**	**32**	**32**

Results chi-square test

	CBT	STW	SWT	BCV	ELE	YFC	STT
Planted	14,23529412	0,42857143	0,08333333	2,50000000	2,77777778	3,12500000	3,12500000
Younger secondary	0,73529412	2,33333333	0,75000000	1,60000000	1,00000000	0,12500000	0,12500000
Older secondary	8,50000000	0,00000000	4,08333333	0,90000000	0,44444444	0,12500000	0,12500000
Primary	4,23529412	0,42857143	0,33333333	2,50000000	7,11111111	2,00000000	2,00000000
Total	**27,70588235**	**3,19047619**	**5,25000000**	**7,50000000**	**11,33333333**	**5,37500000**	**5,37500000**
P-value	**4,1867E-06**	**0,3632**	**0,1544**	**0,05756**	**0,0101**	**0,1463**	**0,1463**