Bird Populations of Cerro Candelaria Reserve
A Comparative Study of Species Abundance and Diversity in Three Habitats

Andean Cock of the Rock (*Rupicola peruvianus*), photo from the Handbook of the Birds of the World Database: http://www.hbw.com/ibc/species/andean-cock-rock-rupicola-peruvianus

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Abstract:

This study analyzed the differences between three habitats in and around EcoMinga's Cerro Candelaria Reserve, which protects part of the Llanganates – Sangay Ecological Corridor in the eastern cloud forest of Ecuador. The EcoMinga Foundation began reforestation efforts in several abandoned pastures in the reserve in 2008, which have since been the focus of several forestry studies to determine the success of the reforestation effort. One aim of this study was to continue the analysis of the reforestation project through the use of avifaunal communities. Three 1,500 meter transects were set up along the main trails in each of the study sites. The point count method was used to observe and identify the birds seen both during morning and afternoon periods. The time spent observing at point counts totaled 27.3 hours, during which 506 individuals were observed, 306 were identified to the species level, and 51 species were identified in 25 different families. Chi-square tests confirmed that there was a statistically significant correlation between the study site and dietary guild, study site and migration pattern, and study site and foraging strata on the individual level, but not on the species level. Species richness, the Chao lower bound estimate of species richness, and the exponential Shannon entropy all found that the riparian site had the highest diversity, and the primary forest had the lowest diversity. Limitations on the observer's ability to identify surely skewed these results. Species abundance curves and sample coverage show that the avifaunal survey was not close to representative of the total avifaunal communities in the sites, so further study is recommended, especially focusing on the reforestation and primary forest sites, to determine the total population makeup and comparative diversities.

Key Words: birds, reforestation, diversity, Cerro Candelaria Reserve, cloud forest
Topic Codes: 608: Forestry and Wildlife, 624: Environmental Sciences, 614: Ecology

Resumen:

Este estudio analizó las diferencias entre tres hábitos en y cerca de la Reserva Cerro Candelaria de EcoMinga, que proteja parte del Corridor Ecológico de Llanganates – Sangay en el bosque nublado del este del Ecuador. La Fundación EcoMinga empezó esfuerzas de reforestación en unos pastos abandonados en la reserva en 2008, las cuales han sido el enfoque de unos estudios de la silvicultura para determinar el éxito de las esfuerzas de reforestación. Un objetivo de este estudio es continuar el análisis del proyecto de la reforestación con el uso de la comunidad de aves. Tres transectos de 1.500 metros estaban establecidos a lo largo de los senderos principales en cada de los sitios de estudio. El método de puntos de contado estaba usado para observar y identificar las aves durante la mañana y la tarde. En total, el tiempo pasado observando fue 27,3 horas, cuando 506 individuos fueron observados, 306 fueron identificados al nivel de la especie, y 51 especies fueron identificadas en 25 familias diferentes. Un examen de chi-squared confirmó que hay una correlación entre el sitio y el gremio de alimentación, el sitio y los patrones de migración, y el sitio y el estrato de forraje en el nivel de los individuos, pero no el nivel de las especies. La riqueza de las especies, la Chao estimación de límite bajo de la riqueza de las especies, y la entropía exponencial de Shannon mostraron que el sitio ribereño tenía la diversidad más alta, y el bosque primario tenía la diversidad más baja. Las limitaciones en la habilidad de la observadora para identificar sesgaron estos resultados. Las curvas de la abundancia de las especies y la cobertura de las muestras muestran que la encuesta de las aves no estaba representativa de la comunidad total de las aves en los sitios, entonces más estudio está

recomendado, especialmente enfocado en los sitios de la reforestación y el bosque primario, para determinar la población total y las diversidades comparativas.

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Introduction:

In this study, the avifaunal populations in three different habitats of the eastern Ecuadorian cloud forest – riparian, reforested pastureland, and primary forest – were compared to determine the differences in diversity and abundance between these three sites. The Ecuadorian cloud forest has a tenuous future because of the threat of climate change. The cloud forest is also critical habitat for many bird populations, making the study of avifaunal populations within various parts of the Ecuadorian cloud forest essential for conservation efforts. The Ecuadorian cloud forest exists on both sides of the two Andes mountain chains, with the western side formed from the rain shadow effect of the Pacific Ocean and the eastern side formed from the Amazonian rain shadow effect. This study in particular was focused on the eastern range of the Andes and the eastern Ecuadorian cloud forest. In general, cloud forest habitats range from 2,000 to 3,500 meters above sea level and are characterized by high relative humidity, epiphyte abundance, stunted trees, high endemism, high organic content in the soils, and high moisture and cloud coverage (Foster 2001).

The fragmented nature of cloud forests, while essential to the high endemism and diversity between different cloud forest locations, means that climate change will severely affect these ecosystems. As global climate change warms the planet, the altitudinal range of certain habitats will shift higher and higher. Therefore, habitats that were previously near the tops of mountain ranges will disappear and the general extent of cloud forest habitats will narrow as the altitude band for cloud formation narrows (Foster 2001). Tropical cloud forests are also particularly sensitive to climate change because of their slow regeneration rates, the low temperatures of the climate, and the fact that most tropical cloud forests exist in fragmented bands on separate mountain tops (Gomes, Oostra, Nijman, Cleel & Kappelle 2008). Some species may be able to survive the coming change in climate and habitat in the cloud forest by migrating, but for many species migration is an unviable option either due to geography or the ecological needs of the species. Some bird species, for example, have co-evolved symbiotic relationships with epiphytes. As epiphytes are fragile plants, they will be heavily hit by changing climate, therefore also heavily hitting the bird populations dependent on them (Foster 2001).

Understanding population dynamics of birds in various cloud forest habitats is critical to understand how to shape conservation practices in light of climate change. Birds can play a major role in regeneration of ecosystems, as many are seed dispersers. If a population of birds is shrinking or losing diversity, that means that the habitat's ability to regenerate will be diminished (Foster 2001). Studies have shown that frugivorous birds can easily regenerate moderately disturbed forest (Gomes et al 2008). These facts demonstrate how knowing the status of bird populations can aid in making decisions about what reforestation efforts are needed.

Bird populations can indicate the extent that an ecosystem has been influenced by human activities. Although the single species indicator system has flaws – the presence or absence of a single species masks the overall population trend of all birds in the area – studying the total avifaunal community presents a much more complete reflection of the total ecosystem (Canterburg, Martin, Petit, Petit & Bradford 2000). With the long history of clear cutting and deforestation not just in Ecuador but across the world, it is vital to understand how populations react to different successional stages of forest. Secondary growth and reforested areas can provide new habitat for species, and can increase connection between fragments of primary forest (Blake & Loiselle 2001). Monitoring bird populations can therefore indicate if a reforestation program has been successful.

The international community has created a standard to acknowledge when an area has an important population of avifauna – Important Bird Areas. Important Bird Areas, or IBAs, are identified based on internationally agreed upon criteria set by BirdLife International. Currently there are more than 12,000 IBAs identified throughout the world, though only 2,000 have full legal protection. IBAs have been in place since the 1970s. Each specific IBA is under the responsibility of the national BirdLife Partner in the country. These partners monitor, research, restore, educate, and promote sustainable economic activities within and around the IBA (BirdLife International 2016). In Ecaudor alone there are 107 identified IBAs, 97 of which are on continental Ecuador and 10 in the Galápagos Islands. In total, 1,583 bird species are registered within Ecuador, not counting migrant or wandering species or introduced species. When those populations are counted, Ecuador is home to 1,640 bird species and is the fourth richest country in bird biodiversity in the world (Ministerio del Ambiente 2015).

Another method of recognizing the importance of biodiversity hot spots is through the creation of ecological corridors. An ecological (or biological) corridor is a large area of land that connects existing protected areas such as national parks and reserves to allow the free flow of species. This corridor allows for the maintenance of biodiversity as species are able to migrate long distances. Previously separated populations can intermingle with the connected habitat of an ecological corridor, allowing for the exchange of genes. Interchanging genes alleviates the problem of inbreeding and maintains genetic diversity, which is a species' frontline of defense against extinction, climate change, and introduced diseases (Jost 2015). The free flow of species is especially important in light of how climate change will shift the habitat range of many species; large connected areas of habitat are also critically important for large animals, such as the spectacled bear, which need vast reserves of space and resources (Mexican Biodiversity).

The study site of this avifaunal survey is located both next to an IBA and an ecological corridor: the Llanganates – Sangay Ecological Corridor (see Figure 1). The study site is the Cerro Candelaria Reserve, a private ecological reserve run by the EcoMinga Foundation. The reserve is located in the center of the Ecuadorian Andes, in Tungurahua Province, Cantón Baños, in the El Placer sector. The reserve contains part of the Río Pastaza watershed, including the main tributary Río Chinchín Grande, and is characterized by difficult topography, including many waterfalls and deep canyons. The altitudinal range of the reserve begins at 1,680 meters above sea level and continues up to 3,840 meters. The separation of different valleys within the reserves creates various conditions and therefore niches that have led to an explosion of genetic diversity in species (Robayo et al 2010). As an example, the reserve, which has an area of 2,600 hectares, contains 190 endemic plant species (Jost n.d. b). There are more than 200 bird species recorded in the Cerro Candelaria Reserve as well (Robayo et al 2010). The creation of this ecological reserve is located in an essential place for conservation purposes. The eastern corridor of the Andes Mountains is separated into a northern and southern range by the Río Pastaza valley. Therefore, if deforestation and rampant land use is allowed to continue in this area, the greater Andean ecosystem could be broken in two, thus ending the interchange of genes across the region and drastically damaging the ecosystem (Jost 2015).

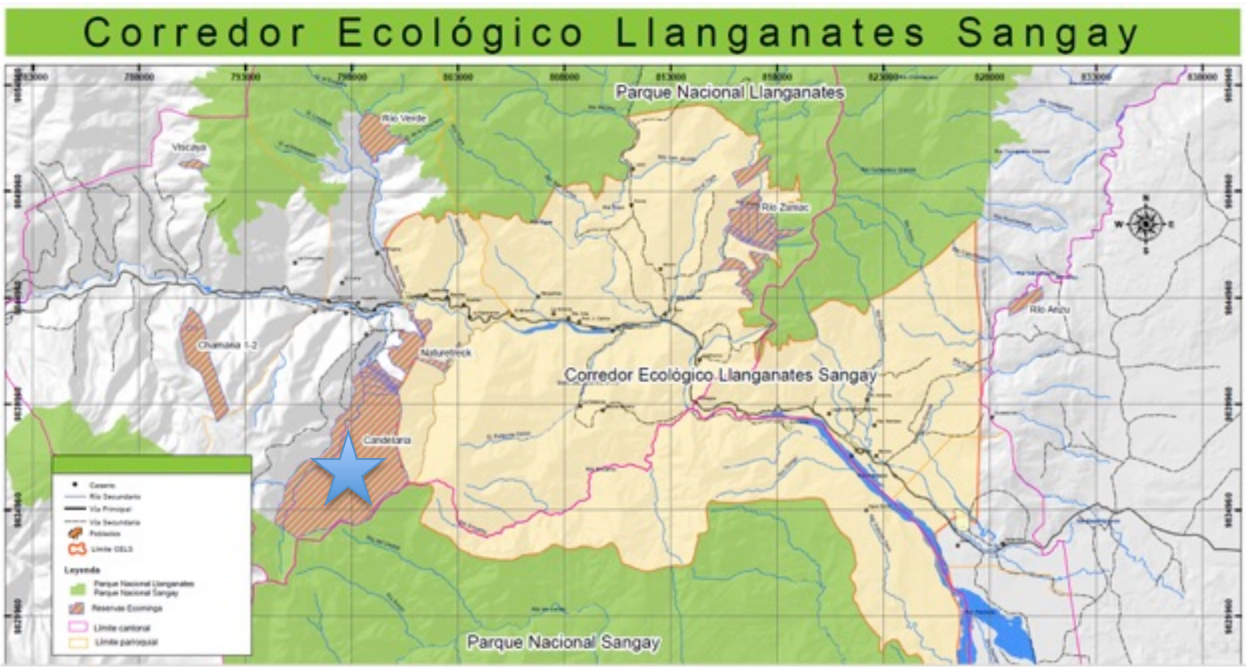


Figure 1: Map of the EcoMinga reserves connecting the Llanganates National Park with the Sangay National Park. The national parks are colored green, the official ecological corridor is yellow, and the various EcoMinga reserves are shaded in orange. The blue star indicates Cerro Candelaria Reserve. Image taken from: https://ecomingafoundation.files.wordpress.com/2015/10/wwf.jpg

The newly formed EcoMinga Foundation created the Cerro Candelaria Reserve in 2006. EcoMinga was founded by a group of concerned Ecuadorian and international scientists and conservationists with the goal of protecting the vulnerable and ecologically rich Upper Pastaza watershed (Jost n.d., b). Since 2006, the EcoMinga reserve system in the Río Pastaza watershed has grown to include seven reserves that total 5,000 hectares of protected land, with Cerro Candelaria being the largest reserve (Jost n.d., a). EcoMinga has sought to build positive relationships between the reserve and the local community, who use the surrounding land mainly for agriculture, by promoting sustainable agriculture and ecotourism. The variety of altitudinal ranges, soil types, and climate allows for the growth of products in one location that are traditionally grown either on the coast or in the sierra. The main agricultural products include naranjilla, tree tomato, mandarin, lemon, star fruit, guayaba, hierba luisa, cedrón, camote, and yucca (Robayo et al 2010).

One of the main reasons that the EcoMinga reserves in the Río Pastaza watershed is critically important for conservation is that it helps bridge the gap between the Llanganates National Park and the Sangay National Park, in an area known as the Llanganates – Sangay

Ecological Corridor (BirdLife International a). The World WildLife Fund recognized an area of 42,052 hectares as the official Llanganates – Sangay Corridor and as a Gift to the Earth – their highest designation for an area of conservation. This ecological corridor is essential to maintain as it connects a vulnerable area between the northern and southern branches of the Eastern Ecuadorian Andes. The ecological corridor contains 242 bird species, 30% of which are sensitive to habitat disruption, and 101 mammal species (World Wildlife Fund 2002). Besides being designated an Ecological Corridor in 2002, this area has also been designated an Important Bird Area: IBA EC057. The national partner of BirdLife International in Ecuador is the group Aves y Conservación, who work to manage, monitor, and protect the ecological corridor. The Llanganates Sangay Ecological Corridor is home to four globally threatened species: the Ecuadorian Piedtail, the Coppery Chested Jacamar, the Biocolored Antvireo, and the Cerulean Warbler. Two near threatened species are also present: the Napo Sabrewing and the Wattled Guan (BirdLife International a)

Threats to these endangered species and the ecological corridor as a whole include many human activities. The deforestation of land for pasture, agriculture, and logging is a major concern. Hydroelectric power plants, widening highways, and mining also destroy natural habitat and pollute the remaining ecosystem. Unregulated tourism has the potential to overburden and destroy land. The causes of these threats all stem from rapid population growth, poor land use planning, poor institutional support, and lack of local conservation legislation. These threats are particularly important to face and counter as although the Llanganates – Sangay Ecological Corridor is an official designation, it does not have any official legal protection. Private reserves, such as the Cerro Candelaria study site in this survey, provide additional protection and ensure that the land of the corridor is being properly conserved (BirdLife International a). In 2015, EcoMinga campaigned with their partner, World Land Trust, to buy a strip of land in the watershed that would finally connect the Llanganates – Sangay Ecological Corridor with fully protected land, not just land that was protected in name (Jost 2015).

Although the Cerro Candelaria Reserve is now protected land, in the past deforestation took its toll on parts of the reserve. Plots of land were cleared to allow space for pastureland and agriculture. Since the establishment of the reserve, however, EcoMinga has worked to reforest these old pasturelands. In 2008, 6.7 hectares of land within the reserve were abandoned pasture. World Land Trust supported a successful pilot reforestation project that has since expanded to the other pastures (Jost 2008). Glyphosate was used in certain plots to counter the African grasses that dominated the abandoned pastures. Native plant species were introduced to reforest the plots, based on the species' growth rates and whether they would provide good habitat for wildlife (Gray 2016).

There have been several studies conducted in the Cerro Candelaria Reserve on the success of these reforestation efforts. Past SIT students have conducted forestry surveys in 2012, 2015, and 2016 to gauge the successional stage of the reforested areas and compare them to primary forest. The findings of these studies show that the reforestation efforts have been largely successful, as the diversity, density, and size of the trees in the plots continue to grow (Foster 2012; Keogh 2015). The final study, completed in spring of 2016, suggested that an avifaunal community survey would be beneficial as it would provide information on how species are responding to the new niches of the reforested plots (Gray 2016).

Purpose:

The main purpose of this study is to compare the diversity and abundance of bird populations in three different habitats in and around the Cerro Candelaria Reserve. Comparing these three habitats will lead to a better understanding of which bird species are using which habitats, thus providing important information for making conservation decisions. The comparison will also aid in evaluating the success of the reforestation project that began in 2008, as bird populations can function as indicators of the health of the ecosystem.

Methods and Materials:

Field Methods

This study was carried out over a three-week period in November of 2016 in and nearby the Cerro Candelaria Reserve, located next to the El Placer community in Tungurahua Province, Ecuador.

Data on the composition of the avifaunal communities was gathered using the point count method. In each of the three habitats, a 1,500 meter transect was laid out following the main footpaths. Point count stations were marked every 100 meters. The distance was measured by pacing. When data was being collected, the observer would arrive at a point count station, observe and identify all birds seen and heard in eight minutes, and then continue to the next station to repeat another eight minutes of data collection.

In the morning, all point count stations were visited for a total of 16 point counts, starting when the sun rose at 6:00 am and continuing to roughly 9:00 am. During afternoon data collection, the first 8 point counts (see figure 2) were visited between the hours of 4:00 pm and 6:00 pm, as the sun was setting. If a species that had not previously been identified was observed outside of the point count stations but within the boundaries of the transects, it was noted for inclusion in the species richness data, but was not counted in the abundance data during analysis.

Materials used to aid in bird identification included Swarovski 8 x 30 binoculars, the bird identification guide *Aves del Ecuador,* by Robert S Ridgely and Paul J Greenfield, and the iPhone app Voice Memos. Unknown birdcalls were selectively recorded and the website xeno-canto.org was used to compare and identify those birdcalls.

The point count method was chosen over other bird observation methods such as transects, sound recordings, and mist netting based on several reasons. Many sources have supported the use of point counts as a thorough, if not perfect, method of cataloging bird populations (Blake & Loiselle 2001, Whitman, Hagan & Brokaw 1997), and have shown the superiority of point counts in comparison to mist netting and sound recording identification (Haselmayer & Quinn 2000). These sources did recommend a combination of point counts and mist netting to gain a more complete population survey, but it was logistically impossible to use mist netting in this survey. The decision between using point counts and transects was made after a trial day of bird observation when it became clear that a more extended period of time observing in one area greatly aided the inexperienced observer in identifying individuals.

Sites

The three 1,500 meter point count transects were plotted on the map below (see Figure 2). The decision for where the three different transects would be located was made with the advice of the Cerro Candelaria park guards. The riparian transect was visited five times each in the morning and afternoon, for a total of 10 visits and roughly 25 total hours of observation. The reforestation and primary forest transects were visited three times each in the morning and afternoon. These transects had a total of 6 visits and roughly 15 hours of observation each. The discrepancy in time spent observing between the riverine and the reforestation and primary forest transects was purely based on logistics, as it was only possible to observe the reforestation and primary forest transects after staying over night at the cabaña.

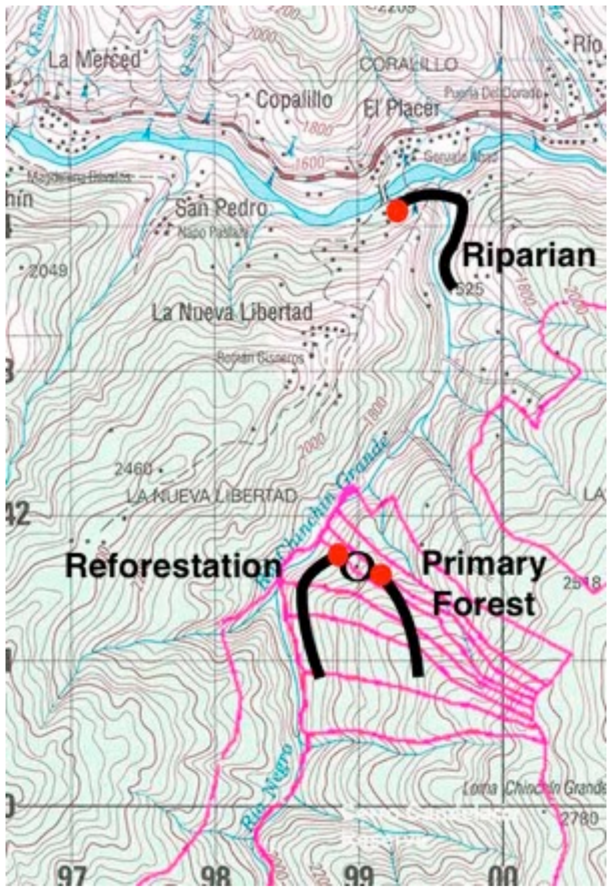


Figure 2: Map of three transects, transects are not to scale. The starting point of each transect is marked by a red dot. Each transect is 1500 meters long. The black circle between the Reforestation and Primary Forest transects marks the location of the Cabaña. The pink outlines are the various borders of the Cerro Candelaria Reserve. Map taken from https://ecomingafoundation.wordpress.com/about/

Riparian Transect

This transect begins immediately to the left after crossing the bridge across the Río Pastaza away from El Placer. The transect follows the main trail, crossing the second bridge over the Río Chinchín Grande, and continuing up along the Río Chinchín Grande. The afternoon transect ends after eight point counts, while the morning transect continues along the path, stopping 100 meters past the gate that ends the pasture.

The majority of this transect is land that is currently in use, either for agriculture (of mandarin, lemon, and naranjilla) or pastureland. The other parts of the transect pass through secondary forest, though it is frequently broken up by small fields and is heavily used by the people of El Placer. The last dominant feature of this transect is the near constant presence of the river.

Reforestation Transect

The reforestation transect begins very close to the cabaña. The trail for this transect begins about 5 meters to the west of the small EcoMinga storage hut, through a small patch of grasses. The first point count station begins after a roughly five minute walk on the trail, just past the abandoned pasture that looks very open. The afternoon transect ends after eight point counts, while the morning transect continues along the trail.

This transect alternates between sections of reforested pasture and sections of more mature forest. The trail leads slightly downhill as it travels away from la cabaña, but it maintains a more or less stable altitude above the Río Chinchín Grande, which flows roughly 200 meters below it.

Primary Forest Transect

The primary Forest transect begins after a five minutes walk up the trail leading south behind la cabaña. The trail is a series of switchbacks that reach up the hill behind the cabaña, passing through mature primary forest and eventually leading east behind the tree with the platform. Like the other two transects, the afternoon transect ends after eight point counts, while the morning transect continues along the trail and ends about 100 meters east of the platform tree.

The dominant feature of this transect is the slope that the trail leads up, which is quite steep. The trail passes mainly through mature forest, though there is a segment around point counts 12-14 where the forest is more open and dominated by bamboo.

Analysis

Several statistical methods were used to analyze the bird population data gathered in this study. Species accumulation curves and species abundance curves were created for each of the three sites studied. Calculations were also performed for sample coverage and community similarity between each of the three sites and also between the riparian transect and the combined reforested area and primary forest together.

$$C = 1 - \frac{f_1}{n} \qquad\qquad CC = \frac{2C}{S_1 + S_2}$$

f_1 = number of singleton species
n = total number of species

C = number of species that the communities share
S_1 = number of species in community 1
S_2 = number of species in community 2

Equations 1 and 2: Sample Coverage (C) and Community Similarity (CC)

For all species identified, their migration patterns, dietary guild, and foraging strata were noted. The information for these categories was taken from the Cornell Lab of Ornithology Neotropical Birds database and the Handbook of the Birds of the World database (Cornell Lab of Ornithology n.d., Lynx Editions n.d.). To analyze if there was any relationship between where the species were seen and these criteria, a chi-squared test was performed. The chi-square test was run both with data entered on the number of species seen at each site and the number of individuals seen at each site. This test was applied to all species besides the Black Headed Hemispingus (*Hemispingus verticalis*), Ash Colored Tapaculo (*Myornis senilis*), and Inca Jay (*Cyanocoraz yncas yncas*), as very little information about their preferred habitats, diets, and foraging strata is published (Cornell Lab of Ornithology).

$$\Sigma \frac{(Observed - Expected)^2}{Expected}$$

Equation 3: Chi Squared Test

The species richness for each community was also noted, and the Chao Lower Bound Estimate for Species Richness was calculated based on the number of singletons and doubletons in the communities. This calculation takes into account the likelihood of elusive species being uncounted in the survey, based on the number of singleton and doubleton species identified in the study (Jost, 2016).

$$Chao = S + \frac{f_1^2}{f_2^2}$$

S = number of species observed, f_1 = singleton species,
f_2 = doubleton species

Equation 4: Chao Lower Bound Estimate of Species Richness

Finally, the diversity of the three sites studied was calculated using the exponential of the Shannon Entropy. The exponential form of this diversity index was chosen, as it is a true diversity index, and therefore can be used to make easy linear comparisons between communities (Lou, 2006).

$$e^H, \qquad H = -\Sigma p_i \ln p_i$$

H = Shannon Entropy, p_i = proportion of individuals of one species over total population

Equation 5: Exponential of Shannon Entropy

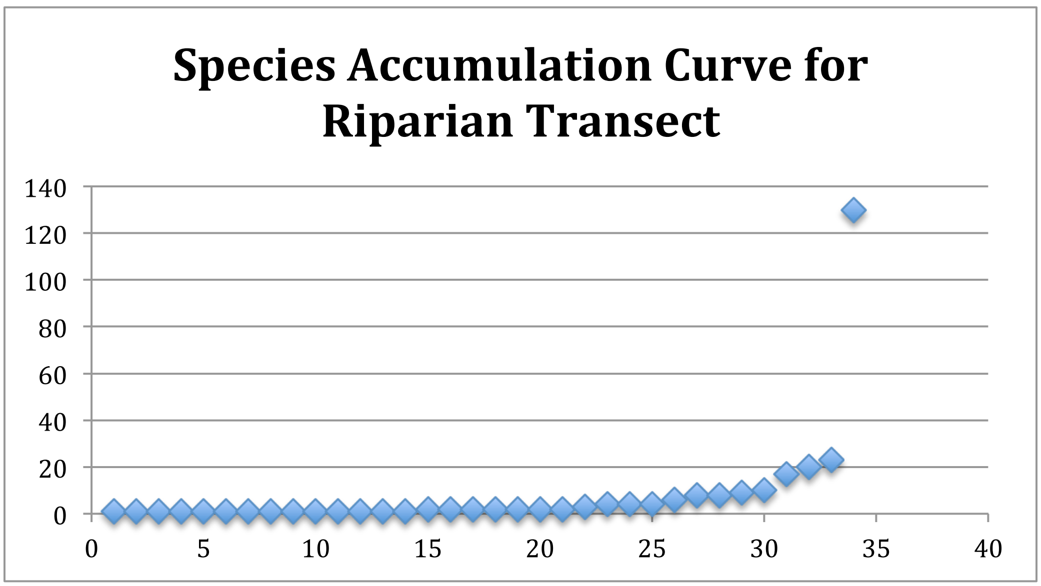
The only individuals included in data analysis were those that were identified down to the species level. Out of 503 individual birds seen and recorded, 306 were identified down to the species level. The majority of unidentified birds were identified to family level – 119 individuals out of 197 – based on either a quick sighting or identification of song (see appendix for charts of species and families seen). Additionally, some species were identified only outside of the data collecting time during point counts but still within the limits of the various transects. The Sickle Winged Guan (*Chamaepetes goudotii tschudii*), Torrent Duck (*Merganetta armata*), White Capped Dipper (*Cinclus leucocephalus*), and Zimmer's Flatbill (*Tolmomyias assimilis*) were all identified and included in species richness for the respective sites they were seen at, but they were not included in any other data analysis.

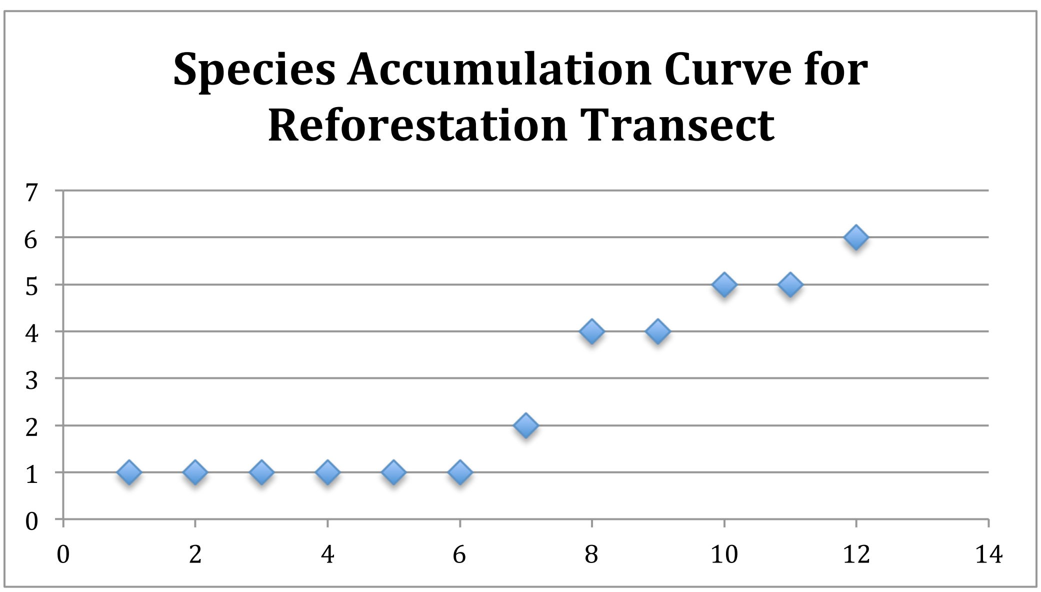
Results:

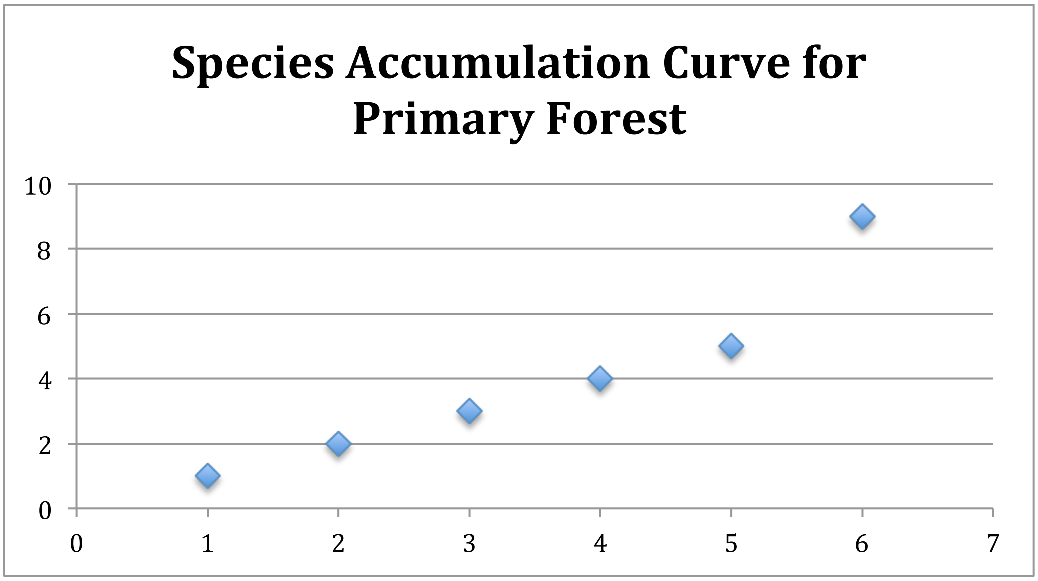
Table 1: *General Results*

	Riparian	Reforestation	Primary Forest
Number of Species	34	13	6
Unique Species	30	9	2
Individuals Identified	274	40	24
Unknown Individuals	69	69	59

Figures 3-5: *Species Accumulation Curves*

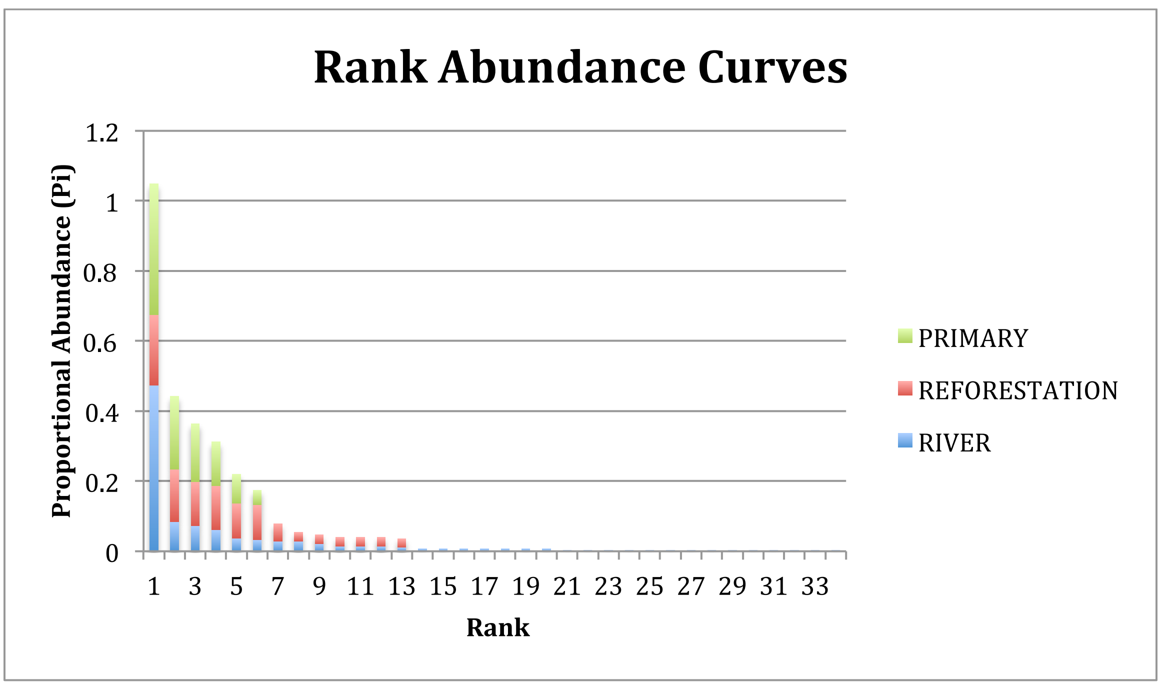






Figures 3 through 5 show the species accumulation curves for each of the three study sites in this survey. The exponential shape of these three graphs indicates that the bird surveys did not record the total population of the sites. If the species accumulation curves ended approaching an asymptotic plateau, then they would represent much more complete surveys of the populations.

Figure 6: *Species Abundance Curve*



The rank abundance curves of Figure 6 compare the evenness of the three study sites. The steep slope of the primary forest curve indicates that this site was dominated by one main species (White Capped Parrot) and thus was a very uneven population. The reforestation curve and the riparian curve also have one particularly dominant species (Slate Throated Whitestart and Blue and White Swallow respectively) that contributes to the steep slope, indicating unevenness. However, ignoring the first dominant species in each site, the riparian site has a much more even slope than either the reforestation or primary forest curve, indicating that the riparian site had, in general, a more even community of birds.

Table 2: *Sample Coverage*

Riparian Transect	Reforestation Transect	Primary Forest Transect
0.588235294	0.538461538	0.833333333

Sample coverage is represented on a 0 to 1 scale, with a value closer to 1 indicating more coverage of the population being studied. Generally, a coverage greater than 0.8 is considered sufficient coverage to have a good sample of the population studied (Jost 2016). The primary forest site is the only site that surpasses this standard.

Table 3: *Community Similarity*

Riparian and Reforestation	0.085106383
Riparian and Primary Forest	0.1
Reforestation and Primary Forest	0.210526316
Riparian and Reforestation/Primary Forest	0.150943396

The value for community similarity ranges from 0 to 1. As the value approaches 1, the similarity of the two communities compared increases. The two communities with the highest similarity are the reforestation and the primary forest, which correlates with visual observation of the sites. Both are entirely covered forest, only varying in the age of the community (mature in the primary forest and 9 year old secondary growth in the reforestation).

Table 4: *Chi-Squared Tests*

	Degrees of Freedom	Species Level	P-Values	Individual Level	P-Values
Dietary Guild	6	7.817958604	> 0.10	25.77284378	< 0.005
Migration	4	6.936557315	> 0.10	79.63961431	< 0.005
Foraging Strata	10	17.09778124	> 0.10	113.980963	< 0.005

The chi-squared test was used to see if there was a statistically significant correlation between the three study sites and the dietary guild, migration patterns, or foraging strata of the species found. The chi-square test does not indicate what the relationship of the correlation between these characteristics and the sites is, it only indicates whether there is a relationship or not. A p-value of less than 0.05 indicates statistical significance; thus there is no statistically significant relationship between any of the characteristics on the species level related to site, but there is a statistically significant relationship between the characteristics when analyzed on an individual level in relation to site. The regular chi-squared test was used with the individual level data. The species level data did not have enough information to work with a regular chi-squared test, so the Yate's correction for continuity was used to account for the small dataset (Yates, 1934).

Table 5: *Species Richness*

Riparian Transect	Reforestation Transect	Primary Forest Transect
37	14	6

The species richness for each site was made including species that were seen outside of specific point count times, but on the transect path (as in, when traveling between point counts or when walking back from the end of the point count times).

Table 6: *Chao Lower Bound Estimate for Species Richness*

Riparian Transect	Reforestation Transect	Primary Forest Transect
278	76	25

The Chao lower bound estimate for species richness is an estimate of how large the total population in an area is, based on the assumption that the sample population includes many elusive species. The riparian site has a high Chao lower bound due to the many singleton and doubleton species identified, while the primary forest has a low Chao lower bound due to the few species identified.

Table 7: *Exponential Shannon Entropy*

Riparian Transect	Reforestation Transect	Primary Forest Transect
9.216881196	9.874458917	4.916796436

Table 8: Ratio Comparisons for Exponential Shannon Entropy:

Riparian – Reforestation	0.933406202
Riparian – Primary	1.874570427
Reforestation – Primary	2.008311519

The exponential Shannon entropy is a true diversity that can be compared linearly; as the number of species in a population of equally common species is doubled, the exponential Shannon entropy is also doubled. Therefore, when looking at the values of this diversity index for the three study sites, the diversity of riparian and reforestation sites is roughly double that of the primary forest site. The ratios of the three sites are summarized in Table 8, and confirm that the reforestation and riparian sites have very similar diversity that is roughly twice that of the primary forest site.

Discussion:

Species Accumulation Curve

The species accumulation curves for the three different sites do not approach an asymptote, which indicates that the different sites were not fully surveyed. The highest number of species observed was in the riparian site, but as many (41%) of the species were singletons, having only one observed individual, the species accumulation curve barely begins to approach the asymptotic plateau that would indicate completeness of the sampling effort. The reforestation and primary forest sites also do not approach the asymptotic plateau, but these graphs have the more important characteristic of very few data points, meaning that many fewer species were identified in each transect than in the riparian site.

Species Abundance Curve

The evenness and the species richness can be compared across the three study sites on this graph. As noted in the Results section, when the dominance of one species is ignored for each of the three sites, the riparian site had the highest evenness, while the reforestation and primary forest had less even avifaunal communities. The evenness of the riparian site can be explained as many more species were identified, with the majority (65%) of those species having fewer than five individuals recorded. In contrast, the number of species observed at the reforestation and primary forest sites was much lower, so therefore the proportional abundance of the different species recorded varied greater than in the riparian site.

Sample Coverage

Sample coverage results indicate that only the primary forest site had sufficient coverage to meet the generally accepted 0.8 cutoff (Jost 2016). Sample coverage is calculated based on the number of singleton species as compared to the total number of species observed, so the high sample coverage in the primary forest site is due to the fact that only six species were identified, with one singleton. When considering the high number of unidentified species in the primary forest site – 59 individuals in three known families and possibly many more unidentified families – the sample coverage is likely much lower than the calculated 0.833 value, as surely many of the unidentified individuals would end up being singleton species. The riparian and reforestation site sample coverage values were very similar, 0.588 and 0.538 respectively, and are also likely overestimates of the coverage as both sites had 69 unidentified individuals in at least three different families. As all three sample coverage calculations are therefore overestimations and likely do not meet the standard for sufficient coverage, the results of this avifaunal survey can only be considered preliminary observations on the populations. Future study is needed to fully survey the avifaunal populations.

Community Similarity

One method of comparing the three study sites was using community similarity to analyze and quantify the difference in species makeup between study sites. All of the community similarity values calculated were quite low, which indicates that the three study sites had different avifaunal communities. The two study sites that were closest in community composition were the reforestation and primary forest sites, with a community similarity value of 0.21, which is twice that of the community similarity between the riparian and primary forest sites: 0.10. Interestingly, the riparian site and the primary forest site had more in common (0.10) than the riparian site and the reforestation site (0.08), which is unusual as the reforestation site represents the halfway point in succession between the riparian site and the primary forest. The small values of the community similarity results, however, indicate that the difference between the two values is likely not significant.

Chi-Squared Tests

The most interesting feature of the results of the chi-squared tests is that for all three characteristics analyzed, the species level chi-squared tests had no statistically significant correlation, while they had a large statistically significant (p-value of <0.005) correlation on the individual level. This pattern of significance depending on species and individual level analysis also mimics the results of the Marie Lilly's chi-squared dietary guild analysis in her 2016 comparative study of bird populations in the Amazon (Lilly, 2016). One potential explanation for this pattern is the greater quantity of data in the individual level analysis as compared to the species level analysis makes the chi-squared test more reliable. The Yate's correction for continuity was used to correct for the influence of the small data set in the species level analysis, which did lower the p-value of the results.

The p-value of the foraging strata species level analysis almost reached the p-value of 0.05 and of the three species level categories analyzed, was the closest to reaching statistical significance. This result makes sense when considering the characteristics of the different sites – species that forage in the riparian or terrestrial strata are much more likely to be concentrated in the riparian site, as there is far more open space and access to the river. The species that forage in the canopy, midstory, or understory are more likely to be found in either the reforestation site or the primary forest site, where they are close to their source of food, while they have less reason to be found in the riparian site, where they do not forage. There are fewer obvious reasons for species to be so starkly divided based on migration pattern or dietary guild.

On the individual level analysis, it makes sense that there would be more of a correlation between these three characteristics and study site. The species level analysis does not take into account how often the species was seen in each study site – if one individual of a species was seen in the primary forest while twenty individuals were seen in the riparian transect, they were still weighted evenly. The individual level analysis does take into account the number of individuals seen, thus accounting for the correlation between study site and dietary guild, migration pattern, and foraging strata.

Species Richness and Chao Lower Bound Estimate of Species Richness

Both the species richness and the Chao lower bound estimate of species richness follow the same pattern: the riparian transect has the greatest species richness, followed by the reforestation transect, with the primary forest transect having the lowest species richness. Interestingly, the land that is heavily in use, including pastureland, agricultural land, and unused land, supposedly has the highest number of species, while the untouched primary forest has the fewest. The scale of the difference between the riparian transect and the primary forest is most likely exaggerated by methodological errors; it was far easier to see and identify species in the open area of the riparian transect while in the primary forest transect an individual could be 5 meters away and unidentifiable due to the dense undergrowth. However, the finding that the riparian transect in general has more individuals and species identified corresponds to anecdotal evidence of the park guards that there are also more birds closer to where people are working (Recalde 2016).

One likely explanation for this pattern is that currently used areas have a much more dependable supply of food, especially in areas of agriculture. Anecdotal evidence from the observer agrees with this pattern – point count stations that were immediately next to or in the naranjilla or mandarin fields consistently had more bird activity, while point counts simply along the path of the riparian transect had less bird activity. The reforested site and primary forest site both had a great diversity of plant life, but did not have the concentrated sources of food that the riparian site had.

Just because the riparian site has a high species richness and Chao lower bound estimate of species richness does not necessarily mean that all of those species found in the site necessarily live in the site or would be able to be sustained solely by the site. Some of the species found in the riparian site could be "sink species" that may have individuals living in the riparian, heavily used area but rely on a greater population in nearby secondary forest (Gomes et al 2008).

Exponential Shannon Entropy

The exponential Shannon entropy shows that the primary forest has an avifaunal community that is half as diverse as either the riparian transect or the reforestation transect. The low species richness of the primary forest transect contributes greatly to the low exponential Shannon entropy. This low species richness does not accurately reflect the true population of the primary forest site, as supported by the 59 unidentified individuals seen in the site from at least three different families. Therefore, the exponential Shannon entropy and any other analyses based on species richness are bound to underestimate the diversity of the primary forest.

While the primary forest site has an artificially low calculated diversity, it is important to note that the problem of unidentified individuals is present across all transects, therefore likely lowering the diversity measures across all transects.

Results as Evaluation of Reforestation Efforts

One of the purposes of this study was to follow up previous SIT student research on quantifying the success of reforestation efforts in the Cerro Candelaria Reserve by providing avifaunal population data on the reforested area in comparison to primary forest. It is difficult to provide a definitive evaluation of the reforestation efforts solely based on the avifaunal diversity surveyed in this study, as several limitations may have resulted in an inaccurate assessment of the diversity in the study sites (see Limitations section below). However, the results of the community similarity, Chao lower bound estimate for species richness, and the exponential Shannon entropy all point to the reforestation site having a diverse avifaunal population comparable to the riparian site and surpassing the primary forest site. In addition, 69% (9 out of 13) of the species found in the reforestation site were unique species not found in either the riparian site or the primary forest site, indicating that the reforestation site is providing new niches, an important characteristic of successful secondary forest (Blake & Loiselle 2001).

Although the finding that the reforestation site is twice as diverse as the primary forest site is dubious, the avifaunal community observed appears to be healthy and diverse. When this fact is taken in tandem with the findings of previous SIT students that the forest makeup was healthy and growing, it points to a successful reforestation effort (Foster 2012, Gray 2016, Keogh 2015). Further study of both the forestry and avifaunal communities of the reforested plots is still recommended to better understand both the impact of the reforestation efforts and the avifaunal communities in the reforestation sites and primary forest.

Limitations

As mentioned previous, limitations and error in the data collection process have reduced the reliability of the results presented in this paper. The major problem faced was the lack of confidence in the accuracy of the avifaunal survey – this highly likely inaccuracy in the survey caused the diversity indices calculated to be skewed, thus making it difficult to make any conclusive comparisons among the study sites.

One main limitation was that the survey did not count enough individuals and species to reflect the true species richness of the communities, so it is difficult to reach conclusive results. Weather was one challenge while surveying bird populations – early morning rain storms would reduce the time available in the morning for data collection, which was especially significant when only certain days could be spent at the cabaña and several of those days had bad weather. Another major challenge was identifying birds, as the observer had little previous experience with identification by sight or sound of the birds present in the reserve. This lack of experience coupled with the difficulty of identifying birds in dense undergrowth in the primary forest and reforestation sites contributed greatly to the large discrepancy between the number of identified species in these two sites and the number of identified species in the wide open riparian site. Future studies on the avifaunal communities of the Cerro Candelaria Reserve would benefit from focusing solely on the difference between the reforestation and primary forest sites, as those two sites need greater study time than the riparian site to identify a greater number of species.

There were also many recorded unidentified individuals in each site, but certainly there were many more individuals that went unidentified, particularly elusive and quiet species. The point count method, while chosen because it reliably detects a large percentage of species, still is not a perfect method for identification of the total avifaunal community as it naturally favors the loud and mobile species that are easily observed and located close to ground level, where the observer is stationed. The use of recordings to detect unseen species hopefully countered some of the limitations of observing with the point count methods, but further familiarity with birdcalls is recommended for future studies. The presence of the river next to the majority of the riparian transect also reduced the observer's ability to identify birds based on calls as the sound of the river drowned out many calls.

Conclusions:

This study compared the avifaunal communities of three different habitats within and around the Cerro Candelaria Reserve in the eastern cloud forest of Ecuador. The riparian site was found to have the highest species richness, while the reforestation site had the highest exponential Shannon entropy diversity. The primary forest site had the lowest species richness and exponential Shannon entropy diversity. When analyzed on an individual level, the dietary guild, migration pattern, and foraging strata all had a significant correlation to the study site the individuals were found in, though the nature of this correlation is yet unknown. These results all indicate that the three study sites contain avifaunal communities that differ to some extent, likely reflecting the different resources and niches within the different sites. However, limitations in the study also made the avifaunal survey incomplete and likely skewed the data to make the primary forest and reforestation sites seem less diverse than they really are. Future study is suggested to focus exclusively on the populations and differences between the avifaunal communities in the reforestation sites and the primary forest, to determine both the total diversity of these areas and also to add to the literature on the success of the 2008 EcoMinga reforestation project in the Cerro Candelaria Reserve.

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Appendix:

Chart of all species identified during the survey, contains all species seen in all three study sites:

Family	Scientific Name	Spanish Common Name	English Common Name
Anatidae	*Merganetta armata*	Pato Torentero	Torrent Duck
Bucconidae	*Nystalus striolatus*	Buco Estriolado	Striated Puffbird
Cardinalidae	*Chlorothraupis stolzmanni*	Tangara Pechiocrácea	Ochre Breasted Tanager
Cathartidae	*Coragypus atratus*	Gallinazo Negro	Black Vulture
	Cathartes aura ruficollis	Gallinazo Cabecirrojo	Turkey Vulture
Cinclidae	*Cinclus leucocephalus*	Cinclo Gorriblanco	White Capped Dipper
Columbidae	*Patagioenas fasciata*	Paloma Collareja	Band Tailed Pigeon
Corvidae	*Cyanocoraz yncas yncas*	Urraca Inca	Inca Jay
Cotingidae	*Rupicola peruvianus*	Gallo de la Peña Andina	Andean Cock of the Rock
Cracidae	*Chamaepetes goudotii tschudii*	Pava Ala de Hoz	Sickle Winged Guan
Emberizidae	*Zonotrichia capensis*	Chingolo	Rufous Collared Sparrow
	Chlorospingus flavigularis	Clorospingo Goliamarillo	Yellow Throated Bush Ranager
Falconidae	*Falco sparverius*	Cernícalo Americano	American Kestrel
Fringillidae	*Euphonia xanthogaster*	Eufonia Ventrinaranja	Orange Bellied Euphonia
Furnariidae	*Synallaxis azarae*	Colaespina de Azara	Azara's Spinetail
Hirundinidae	*Notiochelidon cyanoleuca*	Golondrina Azuliblanca	Blue and White Swallow
Icteridae	*Psarocolius decumanus*	Oropéndola Crestada	Crested Oropendula
	Cacicus haemorrhous	Cacique Lomirrojo	Red Rumped Cacique
	Cacicus uropygialis	Cacique Subtropical	Subtropical Cacique
Momotidae	*Momotus aequatorialis*	Momoto Montañero	Highland Motmot
Parulidae	*Setophaga fusca*	Reinita Pechinaranja	Blackburnian Warbler
	Cardellina canadensis	Reinita Collareja	Canada Warbler
	Myioborus miniatus	Candelita Goliplomiza	Slate Throated Whitestart
	Basileuterus tristriatus	Reinita Cabecilistada	Three Striped Warbler
Psittacidae	*Pionus seniloides*	Loro Gorriblanco	White Capped Parrot
Rhinocryptidae	*Myornis senilis*	Tapaculo Cenizo	Ash Colored Tapaculo
Scolopacidae	*Calidris minutilla*	Playero Menudo	Least Sandpiper
Thraupidae	*Sporophila luctuosa*	Espiguero Negriblanco	Black and White Seedeater
	Hemispingus verticalis	Hemispingo Cabecinegro	Black Headed Hemispingus
	Thraupis episcopus	Tangara Azuleja	Blue and Gray Tanager
	Tangara cyanicollis	Tangara Capuchiazul	Blue Necked Tanager
	Tangara arthus	Tangara Dorada	Golden Tanager
	Tangara schrankii	Tangara Verdidorada	Green and Gold Tanagers

	Tangara xanthocephala	Tangara Coroniazafrán	Saffron Crowned Tanager
Trochilidae	*Phaethornis atrimentalis*	Ermitaño Golinegro	Black Throated Hermit
	Coeligena lutetiae	Frentiestrella Alianteada	Buff Winged Starfrontlet
	Coeligena torquata	Inca Collarejo	Collared Inca
	Taphrospilus hypostictus	Colibrí Multipunteado	Many Spotted hummingbird
	Campylopterus villaviscensio	Alasable del Napo	Napo Sabrewing
	Colibri coruscans	Orejivioleta Ventriazul	Sparkling Violetear
	Adelomyia melanogenys	Colibrí Jaspeado	Speckled Hummingbird
	Phaethornis syrmatophorus	Ermitaño Ventrileonado	Tawny Bellied Hermit
	Chaetocercus mulsant	Estrellita Ventriblanca	White Bellied Woodstar
Troglodytidae	*Pheugopedius euophrys*	Soterrey Colillano	Plain Tailed Wren
	Cinnycerthia unirufa	Soterrey Rufo	Roufus Wren
Turdidae	*Myadestes ralloides*	Solitario Andino	Andean Solitaire
	Catharus ustulatus	Zorzal de Swainson	Swainsons Thrush
Tyrannidae	*Sayornis nigricans*	Febe Guardarríos	Black Phoebe
	Serpophaga cinerea	Tiranolete Guardarríos	Torrent Tyrannulet
	Ornithion inerme	Tiranolete Alipunteado	White-lored Tyrannulet
	Tolmomyias assimilis	Picoancho de Zimmer	Zimmer's Flatbill

Additional information about species identified (Species with NA in Number of Individuals were not seen during point counts themselves, so were not included in most data analysis):

English Common Name	**Number of Individuals**	**River**	**Reforestation**	**Primary Forest**
Torrent Duck	NA	Yes	No	No
Striated Puffbird	1	No	Yes	No
Ochre Breasted Tanager	6	Yes	No	No
Black Vulture	23	Yes	No	No
Turkey Vulture	8	Yes	No	No
White Capped Dipper	NA	Yes	No	No
Band Tailed Pigeon	5	No	Yes	Yes
Inca Jay	1	No	Yes	No
Andean Cock of the Rock	6	No	Yes	No
Sickle Winged Guan	NA	No	Yes	No
Rufous Collared Sparrow	1	Yes	No	No
Yellow Throated Bush Tanager	4	Yes	No	No
American Kestrel	1	Yes	No	No
Orange Bellied Euphonia	1	No	No	Yes

Azara's Spinetail	1	Yes	No	No
Blue and White Swallow	130	Yes	No	No
Crested Oropendula	17	Yes	No	No
Red Rumped Cacique	1	No	Yes	No
Subtropical Cacique	4	Yes	Yes	No
Highland Motmot	5	No	Yes	No
Blackburnian Warbler	1	Yes	No	No
Canada Warbler	2	Yes	No	No
Slate Throated Whitestart	8	Yes	Yes	No
Three Striped Warbler	2	No	Yes	No
White Capped Parrot	9	Yes	No	Yes
Ash colored Tapaculo	1	No	Yes	No
Least Sandpiper	1	Yes	No	No
Black and White Seedeater	20	Yes	No	No
Black Headed Hemispingus	1	Yes	No	No
Blue and Gray Tanager	1	Yes	No	No
Blue Necked Tanager	10	Yes	No	No
Golden Tanager	2	Yes	No	No
Green and Gold Tanagers	3	No	No	Yes
Saffron Crowned Tanager	3	Yes	No	No
Black Throated Hermit	1	Yes	No	No
Buff Winged Starfrontlet	2	Yes	No	No
Collared Inca	1	Yes	No	No
Many Spotted hummingbird	1	Yes	No	No
Napo Sabrewing	1	Yes	No	No
Sparkling Violetear	2	Yes	No	No
Speckled Hummingbird	1	Yes	No	No
Tawny Bellied Hermit	1	No	Yes	No
White Bellied Woodstar	2	Yes	No	No
Plain Tailed Wren	2	Yes	No	Yes
Roufus Wren	1	No	Yes	No
Andean Solitaire	4	No	Yes	Yes
Swainsons Thrush	1	Yes	No	No
Black Phoebe	4	Yes	No	No
Torrent Tyrannulet	2	Yes	No	No
White-lored Tyrannulet	1	Yes	No	No
Zimmer's Flatbill	NA	Yes	No	No

Chart of the migratory, dietary, and foraging characteristics of species. This information was used in the Chi-Squared Test to determine if any of these characteristics were statistically related to the site the species were found in.

English Common Name	**Migration**	**Dietary Guild**	**Foraging Strata**
Torrent Duck	Resident	Carnivore	Riparian
Striated Puffbird	Resident	Insectivore	Understory/Midstory
Ochre Breasted Tanager	Resident	Omnivore	Understory
Black Vulture	North-South	Carnivore	Terrestrial
Turkey Vulture	South	Carnivore	Terrestrial
White Capped Dipper	Resident	Carnivore	Terrestrial/Riparian
Band Tailed Pigeon	North-South	Frugivore	Canopy
Inca Jay	Resident	Omnivore	Various
Andean Cock of the Rock	Resident	Carnivore	Understory
Sickle Winged Guan	Resident	Omnivore	Midstory
Rufous Collared Sparrow	Resident	Omnivore	Terrestrial
Yellow Throated Bush Tanager	Resident	Omnivore	Understory
American Kestrel	North-South	Carnivore	Terrestrial
Orange Bellied Euphonia	Resident	Omnivore	Understory
Azara's Spinetail	Resident	Omnivore	Understory
Blue and White Swallow	South	Carnivore	Aerial
Crested Oropendula	Resident	Omnivore	Canopy
Red Rumped Cacique	Resident	Omnivore	Midstory/Canopy
Subtropical Cacique	Resident	Omnivore	Canopy
Highland Motmot	Resident	Omnivore	Understory/Midstory
Blackburnian Warbler	North-South	Insectivore	Canopy
Canada Warbler	North-South	Insectivore	Understory
Slate throated Whitestart	Resident	Carnivore	Midstory
Three Striped Warbler	Resident	Omnivore	Terrestrial
White Capped Parrot	Resident	Omnivore	Canopy
Ash Colored Tapaculo	Resident	Unknown	Understory/Midstory
Least Sandpiper	North-South	Carnivore	Terrestrial/Riparian
Black and White Seedeater	South	Frugivore	Terrestrial
Black Headed Hemispingus	Resident	Unknown	Unknown
Blue and Gray Tanager	Resident	Omnivore	Canopy

Blue Necked Tanager	Resident	Omnivore	Canopy
Golden Tanager	Resident	Omnivore	Canopy
Green and Gold Tanagers	Resident	Omnivore	Midstory
Saffron Crowned Tanager	Resident	Omnivore	Canopy
Black Throated Hermit	Resident	Frugivore	Understory
Buff Winged Starfrontlet	Resident	Frugivore	Understory
Collared Inca	Resident	Frugivore	Understory
Many Spotted Hummingbird	Resident	Omnivore	Terrestrial
Napo Sabrewing	Resident	Omnivore	Understory
Sparkling Violetear	South	Frugivore	Understory/Terrestrial
Speckled Hummingbird	Resident	Frugivore	Understory
Tawny Bellied Hermit	Resident	Omnivore	Understory
White Bellied Woodstar	Resident	Omnivore	Understory/Midstory/Canopy
Plain Tailed Wren	Resident	Omnivore	Understory
Roufus Wren	Resident	Omnivore	Understory
Andean Solitaire	Resident	Omnivore	Understory
Swainsons Thrush	North-South	Insectivore	Aerial
Black Phoebe	South	Insectivore	Terrestrial
Torrent Tyrannulet	Resident	Carnivore	Aerial
White-lored Tyrannulet	Resident	Carnivore	Canopy
Zimmer's Flatbill	Resident	Omnivore	Midstory