

**Estimating the diversity of bird and mammal communities using camera traps in a
cloud forest environment, Costa Rica.**

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Abstract

With ongoing habitat change and deforestation, the need to monitor species diversity is more important than ever. Knowing what species are present in a habitat can influence conservation practices in order to provide the best measures for protection. Camera traps are used to sample species and communities in different environments without human interference. This study utilises camera traps to estimate the diversity of bird and mammal communities in the different successional stages of a cloud forest environment. Simpson's and Shannon's diversity indices were calculated to compare bird and mammal species diversity among different forest types. For the entire reserve a Shannon's index of 2.23 for birds and 1.91 for mammals, and a Simpson's index of 0.13 for birds and 0.2 for mammals were calculated. When comparing at the point of the lowest sample in a habitat, rarefaction analysis showed that mammals had the highest number of species in naturally regenerating forest <30 years, whereas birds had the largest number of species in old growth forest. The species accumulation curve showed birds had a higher number of species in the reserve, even though a higher number of individual mammals were recorded. This study shows that camera traps are a useful tool for investigating and providing an estimate of the diversity of ground dwelling bird and mammal communities in a cloud forest environment. Further suggestions have been given on how to sample and record the diversity of the communities as a whole, capturing data from the areas not covered by camera trapping.

Key words: Primary forest, Secondary forest, Rarefaction curves, Species Accumulation curves, Diversity indices.

1. Introduction

The tropics are an area of high ecological productivity that hold a wealth of diversity, where more than three quarters of the earth's total species reside (Barlow *et al.*, 2018). However, this huge number of species are at risk from a constellation of threats: habitat destruction and fragmentation, invasive species and climate change (Tilman *et al.*, 2017). Land use changes are thought to have had the worst impact on species diversity (Sala *et al.*, 2000), with this driven primarily by an increase in the intensification of agricultural practices. Between 1980 and 2000, 100 million hectares of forest were lost (UN, 2019), with many nations in the tropics justifying this agricultural intensification on the need to increase their economic development (National Research Council, 1993).

In spite of this, some countries in the tropics are managing to develop their economies without destroying their natural environments. Costa Rica and Guatemala, have managed the highest amount of extensification in comparison to other central American countries, helping to decrease pressure on the environment by minimising the use of artificial inputs and machinery (Carr *et al.*, 2006). Furthermore, Costa Rica has shown it is possible for countries to reverse the damaging effects of deforestation. In 1996 the Costa Rican government sanctioned a law protecting forests and the services they provide, where they incentivised farmers to protect forests, encouraged reforestation and made it illegal to harvest any forest without a management plan and approval by forestry authorities (FAO, 2001). The reforestation efforts are one reason why Costa Rica is now a hotspot for tourism. Between 2017 and 2019 nearly 70 % of visitors participated in ecotourism (Instituto Costarricense de Turismo, 2019), which in turn has funded conservation projects through donations at reserves and national parks. The success of the reforestation was aided by financial incentives, but the underlying respect Costa Rican's have for nature is a key aspect allowing the environment to flourish (Konyn, 2020).

Nowadays, Costa Rica is a country rich in a number of diverse ecosystems. At 51,000km² the country accounts for only 0.03 % of the earth's surface but contains 4 % of all species present on earth (Fauna & Flora International, 2021). Approximately 32 % of the area is protected within national parks, reserves and other protected areas (Sáenz-Bolaños *et al.*, 2020). The IUCN red list currently categorises 6545 species of plants and animals in Costa Rica, 335 of which are endemic and 262 of these are terrestrial (IUCN, 2021). The red list also describes

211 mammal species of these five are endemic, and 888 bird species of which eight are endemic (IUCN, 2021). High levels of diversity can be attributed to its geographical location. Being situated just north of the Equator within the tropics (9.7°N, 83.7°W), Costa Rica hosts a variety of ecosystems but is dominated by a matrix of different forests – most notably rainforest, cloud forest and tropical dry forest. Costa Rica's position between North and South America will also have influenced its diversity. Around three million years ago the creation of the Panamanian land bridge led to the Great American Interchange (Marshall *et al.*, 1982; Webb, 1991). The bridge meant that flora and terrestrial fauna species were able to mix between the now connected continents, and Costa Rica became a biological corridor.

Sampling terrestrial organisms in a rainforest environment can be complex, given the high level of species diversity (Hill & Hill, 2001), dense vegetation and unpredictable weather. Thus, different sampling methodologies offer varying capture success rates depending on the species being sampled and the location. For example, nocturnal transects can give an accurate representation of amphibian biodiversity (Whitworth *et al.*, 2017), whilst point counts have been proven successful for birds (Darras *et al.*, 2018). Another way of investigating terrestrial species is to track them, by following footprints or faeces (Bider, 1968; Martin, 2009). These types of surveys are efficient and low cost, however, they rely on suitable conditions in the field. For example, if the ground is too wet the tracks will be washed away. Line transects can also be used but are a more difficult method of surveying species. These species will generally have to be larger and diurnal to make identification easier (Silveira *et al.*, 2003). Although these methods of sampling do not require expensive equipment, it is the need for skilled researchers and the sustained systematic sampling which makes them labour intensive and time consuming.

Camera traps, used as a sampling method, allow for a different perspective compared to transect sampling and tracking. They were first developed in the 1890s by George Shiras, with the use of trip wires that triggered the cameras (Kucera and Barrett, 2011). These have been further developed into cameras that use infrared lasers, which are triggered when an animal passes in front of the camera and has a different body temperature to the background vegetation (Jacobs & Ausband, 2018). One major advantage of camera traps is that they are a continuous method of sampling an ecosystem as they can be left out in the field for a prolonged amount of time (Sollmann, 2018), without the presence of humans (Rovero & Zimmermann, 2016). Another advantage is being able to document a photo of the individuals

seen, creating a reference catalogue. Furthermore, they allow for the investigation of elusive, cryptic and nocturnal species, such as species of carnivore (Wu *et al.*, 2018). Despite their high initial cost, they are less labour intensive than other sampling methods and require little expertise (Silveira *et al.*, 2003).

This study took place at Cloudbridge Nature Reserve, where the objective is conservation and reforestation of the cloud forest and the organisms that rely on it. Cloud forest environments are defined by the clouds and mist that exist in these tropical mountains (Bubb *et al.*, 2004). The forest around the reserve is made up of old growth primary forest, as well as secondary planted (for conservation purposes, not commercial use) and naturally regenerating forest, including areas which have been regenerating for more than and less than 30 years. Secondary forests have been impacted by human interference (Corlett, 1994), they have very closed canopies letting in less than 2 % of light (Kabakoff & Chazdon, 1996). As a result, young trees and plants cannot compete with larger trees for light, meaning the community is dominated by a few light demanding species and those that can grow rapidly after disturbance (Dent *et al.*, 2013). Old growth forests, with little or no human disturbance (Turubanova *et al.*, 2018), have more diverse and more unique species in the communities than secondary forests (Barlow *et al.*, 2007). They have more open canopies as a result of older trees dying and allowing light to reach the forest floor, making space for new species to grow. The objective of this study was to use camera traps to record and estimate the diversity of mammal and bird species communities that are present in the different forest types of the reserve. Analysis of this data, can help inform whether camera traps could be able to provide a good basis for assessing diversity of different groups of species in a cloud forest environment.

2. Methods

2.1 Study area

The study area is situated in Cloudbridge Nature Reserve, a heterogeneous cloud forest environment between 1500 – 2600 m above sea level in the Talamanca Mountain range in Southern Costa Rica. The reserve is 371 hectares in total and borders the Chirripó National Park. The camera trap locations were placed in a predefined area throughout 132 hectares of the reserve. Eight camera traps were rotated between 16 sites. These sites were in a grid

formation and were located in four different forest types. Five sites in naturally regenerating less than 30 years (< 30 years), three sites in naturally regenerating more than 30 years (> 30 years), four sites in old growth forest and four sites in planted forest (Figure 1). All camera trap sites were off the main trails apart from one (G4) which was situated on a research trail, meaning it was closed to anyone coming through the reserve other than those working at Cloudbridge or those staying in a cabin further up the trail. This meant, humans were detected on this camera location as well as animals. In the total study area, 52 mammal and 304 bird species have previously been recorded using a number of sampling methods (Cloudbridge Nature Reserve, 2018; Cloudbridge Nature Reserve, 2019). The data used in this study is from an ongoing camera trap research project at Cloudbridge Nature Reserve.

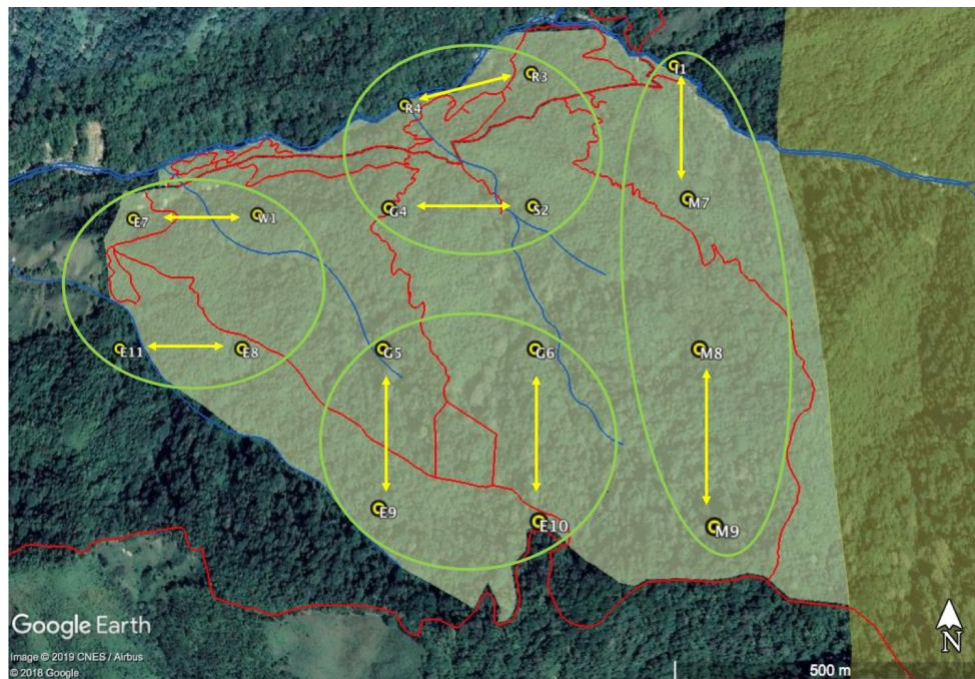


Figure 1: Camera trap localities in Cloudbridge Nature Reserve. Yellow lines indicate camera trap localities which cameras are moved between. Red lines show where the trails are, and gives context of how far some of the camera trap sites are from the main trails. The blue lines show rivers running through the reserve.

2.2 Camera deployment and collection

There were eight Bushnell Agressor HD No-glow camera traps used (Bushnell, 2021). Each camera was rotated between two locations every two weeks and would be placed approximately 0.5m from the ground, with a field of view of 38°. When the cameras changed

location the SD cards were removed and replaced with an empty one, batteries checked and changed if necessary. The cameras would run for 24 hours a day and when triggered would take three photos, each one second after the other. When an animal is in front of the cameras for a longer period of time, the cameras will carry on taking pictures for as long as they are there. Sampling was continuous and took place over 128 days from late January to the end of May 2020, encompassing both the end of the dry season and the start of the wet season.

2.3 Analysis

Photos were added to Cloudbridge's camera trap database and species in the photographs were identified. The number of individuals were recorded, and in some cases the sex of individuals was noted but this was not included in the analysis. To accurately identify species, two field guide books were used (Wainwright, 2007; Garrigues & Dean, 2007). It was difficult to reliably identify individuals caught on the cameras for most species, except for example, Jaguars (*Panthera onca*) which have distinct patterns. I decided that a record was considered unique if the same species was recorded again one hour apart. This allowed for an estimate of the number of individuals of a species and therefore species abundance could be quantified and compared.

Images of humans, unidentifiable species, or images with no animals (camera trap triggered by the movement of vegetation and the wind), as well as images of mice and rats were not included in the analysis. Mice and rats were not included as they are difficult to identify to species level from camera trap photos. Shannon's and Simpson's index of diversity was calculated to characterise species diversity within a community, these account for both evenness and richness (Solbrig *et al.*, 1991). A larger Shannon's index value will describe a more diverse community and a value of one will represent infinite diversity when using Simpson's index (Shannon & Weaver, 1949; Simpson, 1949). This allowed for comparison between the communities of mammals and birds in the different forest types.

All graphs were developed in the R statistical environment (R Core Team, 2016), using the "Vegan" and "dplyr" packages (Oksanen *et al.*, 2019; Wickham *et al.*, 2021). Sample-based rarefaction curves were developed to analyse species richness patterns between forest types for both birds and mammals. Unlike sample-based rarefaction curves, species accumulation curves take into account sampling effort, which in this case is the number of cameras placed

in a forest type, and show how species have accumulated over this time (Gotelli & Colwell, 2001). This has been used for bird and mammal communities without differentiation of forest type. This was also utilised for birds and mammals in old growth and planted forest alone, as these had the same number of camera traps placed, eliminating the difference in sampling effort allowing for comparison. Data compiled from the cameras was then compared with the total species list of the reserve to determine whether camera traps can provide a reliable estimate of the species richness and abundance of a cloud forest nature reserve in Costa Rica.

3. Results

Over the total of 128 active camera trap days, 1049 individuals were recorded comprising 41 species – 19 species of mammals and 22 species of birds. A total of 646 mammals and 403 birds were recorded (see appendix Table 1). The abundance of mammal and bird communities are dominated by a few species with a high number of individuals. Although the overall species richness is high, the species composition is relatively low. For mammals, Collared peccaries (*Pecari tajacu*) were the most common with over 200 individuals caught on the camera traps during this study, making up 30 % of mammal individuals and 19 % of total individuals. The most common bird species recorded was the Chestnut-capped brush finch (*Arremon brunneinucha*), with a total of 90 individuals recorded, 22% of all bird individuals and 8% of total individuals. Contrastingly, Jaguar and Ruddy quail dove (*Geotrygon montana*) were only seen once. This is the first record of a ruddy quail dove in Cloudbridge Nature Reserve.

3.1 Diversity indices

The diversity of birds and mammals differed in each site. Shannon's index showed mammals had the highest diversity in the naturally regenerating forest < 30 years in comparison with birds which are highest in the old growth forest. However, this is contrasted by Simpson's index which shows mammals are most diverse in planted forest and birds are most in the naturally regenerating forest < 30 years. Overall, mammals had a higher diversity value using Simpson's index, whilst Shannon's index calculated a higher value for birds (Table 1).

Table 1: The Shannon and Simpson's diversity indices for the bird and mammal communities in different parts of the forest.

BIRDS	Shannon's index	Simpson's index
Natural regeneration < 30 years forest	1.71	0.24
Natural regeneration > 30 years forest	1.79	0.19
Old Growth forest	2.05	0.15
Planted forest	1.82	0.17
Whole reserve	2.23	0.13
MAMMALS		
Natural regeneration < 30 years forest	2.01	0.16
Natural regeneration > 30 years forest	1.60	0.25
Old Growth forest	1.77	0.22
Planted forest	1.44	0.35
Whole reserve	1.91	0.20

3.2 Rarefaction curves

The rarefaction curve for mammals reaches a plateau for three sites (Natural regenerating forest < 30 years, Old growth forest and, planted forest) - suggesting the sample size was adequate to describe the species richness of these sites. Furthermore, the curve for the naturally regenerating forest > 30 years, fails to reach an asymptote, suggesting more sampling is required to fully characterise the inventory of species in this forest type. The highest number of species were recorded in natural regenerating forests < 30 years, whilst the lowest was in old growth areas of forest (figure 2).

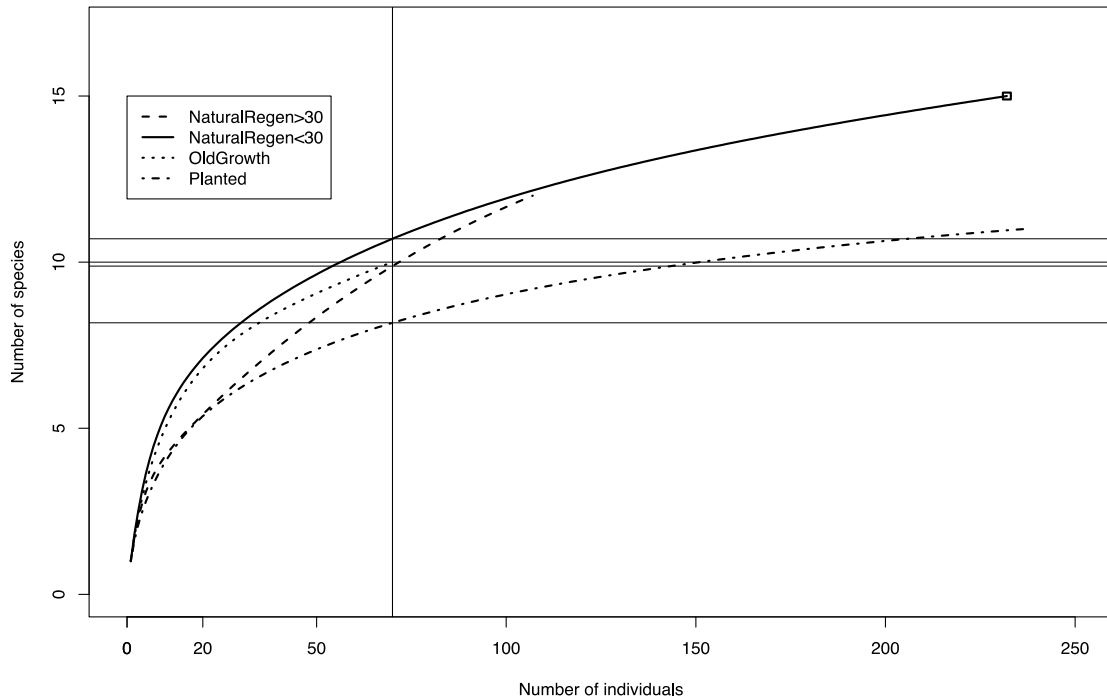


Figure 2: Rarefaction curve for mammal communities in the different forest types. Vertical line indicates the lowest sample of individuals. Horizontal lines indicate rarefied species richness.

The rarefaction curve for birds shows both naturally regenerating forest types have reached an asymptote, showing the species richness at these sites has been described well by the sampling carried out. Contrastingly, old growth and planted forest have not yet come to an asymptote, indicating that more sampling is necessary to document the species present in these forest types. Both naturally regenerating < 30 years and old growth forest had 12 species recorded, and both naturally regenerating > 30 years and planted forest had nine species recorded (Figure 3).

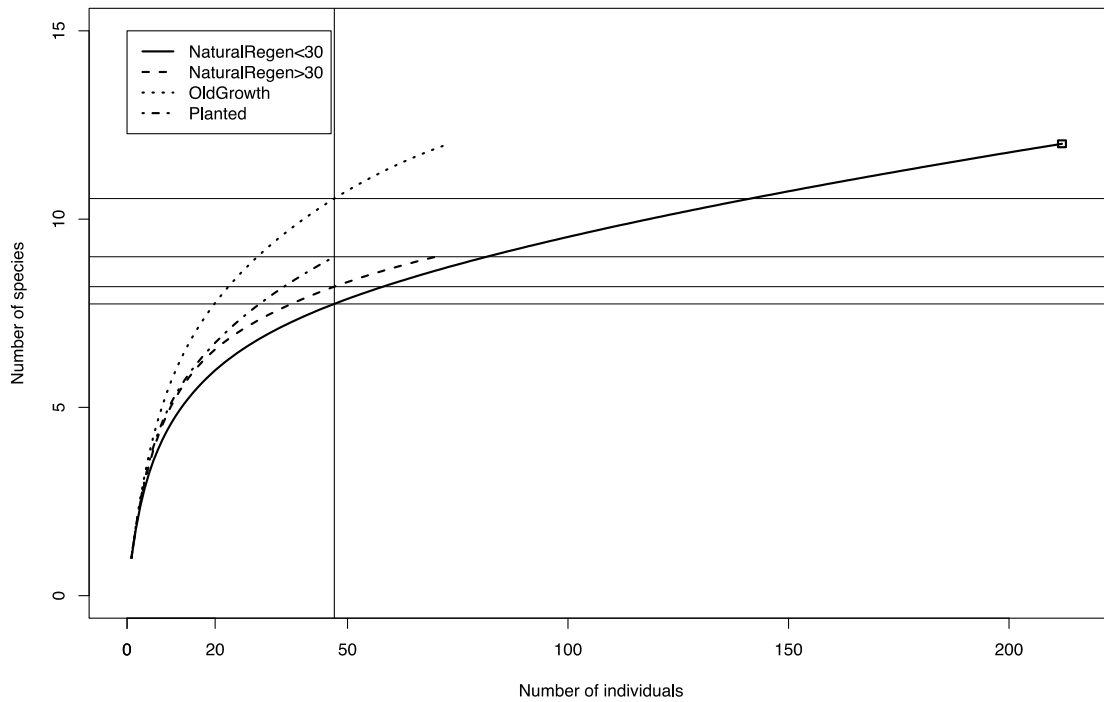


Figure 3: Rarefaction curve for bird communities in the different forest types. Vertical line indicates the lowest sample of individuals. Horizontal lines indicate rarefied species richness.

3.3 Species accumulation curves

As shown by the species accumulation curve (Figure 4), birds overall have a higher number of species than mammals. The gradient for birds is still increasing and so more sampling should be done in order to reliably conclude that the whole community of birds has been recorded by the camera traps. The accumulation curve for mammals is approaching an asymptote suggesting the inventory is likely complete. The curve for all species has a rapid accumulation up until around 50 days, after which it reaches an asymptote. For both groups of species, the initial accumulation was rapid but after around 20 days this began to level off. Despite the rapid accumulation of species early on, it took significantly longer to obtain a more complete inventory, with 95 % of both bird and mammal species detected by day 100 (Figure 4). The species recorded after the first 100 days were rare and only seen once throughout the sampling time, these were Jaguar and Yellow-thighed brushfinch (*Pselliophorus tibialis*).

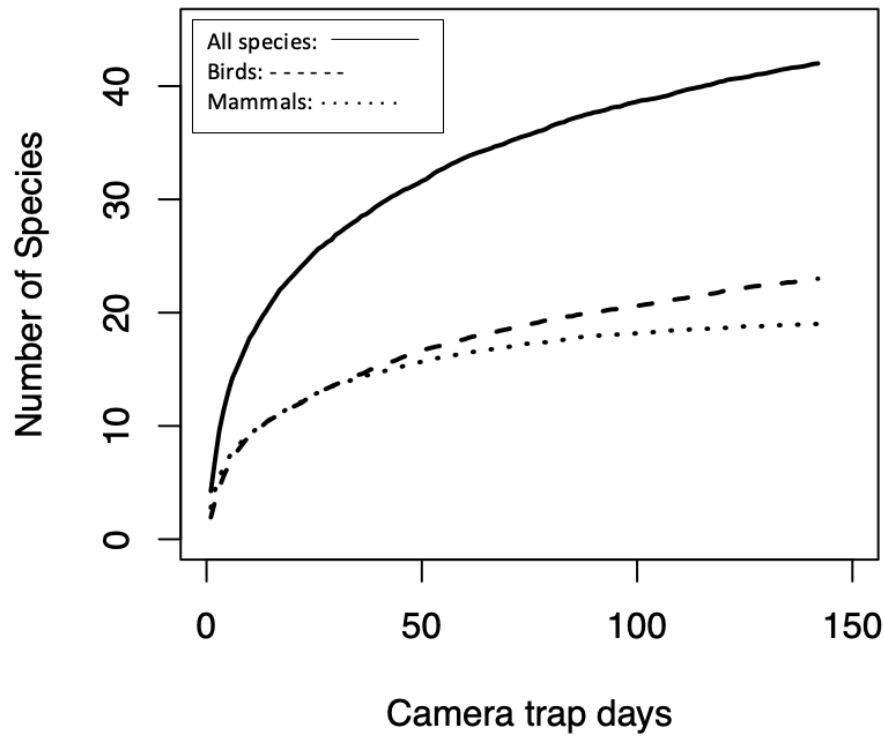


Figure 4: Species accumulation curve of birds and mammals throughout the whole reserve.

The species accumulation curve for mammals shows a higher number of species documented in the planted areas of forest over the sampling time (Figure 5a). The bird species accumulation shows the opposite trend (Figure 5b), with a higher number of species in the old growth forest. Overall, for birds this is a much lower number than the total number of species found throughout the forest. For both birds and mammals in old growth and planted forest, it can be concluded that more sampling should be done as neither group in each forest has reached a plateau yet, and therefore not all species have been documented.

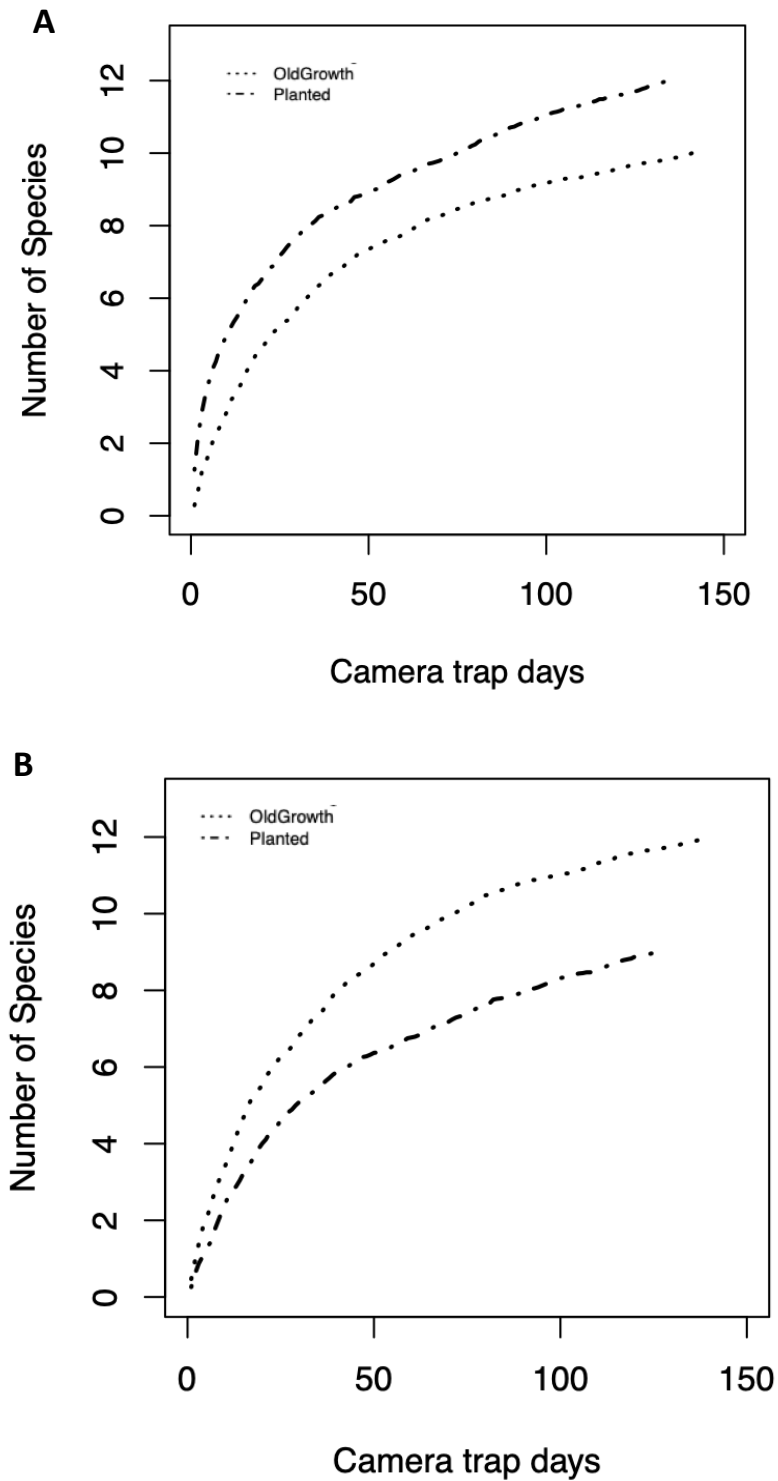


Figure 5: Species accumulation curve for mammals (A) and birds (B) in old growth and planted forests.

4. Discussion

This study recorded a total of 22 bird species and 19 mammal species using camera traps in a cloud forest environment. The graphs generated and diversity indices calculated, show mammals generally had a higher diversity in naturally regenerating forest < 30 years, and

birds were higher in old growth forest. The total species recorded by the camera traps is much lower than the number seen using other sampling methods, however this can be explained by the characteristics of camera trap sampling and the behaviour of the different species.

In total 52 mammal species have previously been recorded in the reserve (Cloudbridge Nature Reserve, 2018), using multiple sampling methods. Mammal species are commonly sampled using camera traps (Wearn & Glover-Kapfer, 2019). This study further demonstrates this, as over a third of the mammal species previously seen were recorded over a relatively short period of time. Of the mammal species not detected by the camera traps, 12 are different species of bat (*Chiroptera*). Species from the family *Phyllostomidae* are nocturnal and during the day some species roost inside plant leaves, for example Pygmy fruit-eating bat (*Dermanura phaeotis*) (Burns *et al.*, 2014; López-González, 2020). These characteristics make them difficult to sample using camera traps, however, recent studies have shown that camera traps can be used for sampling and documenting new feeding behaviours of bat species (Pereira *et al.*, 2018; da Rocha *et al.*, 2017). The results of da Rocha *et al.* (2017) have been achieved through placing camera traps within the roost of a colony. There have previously been 16 carnivore species seen on the reserve, eight of which were recorded on the camera traps during the study time. Camera traps are well tailored to sampling elusive and nocturnal carnivores (Wu *et al.*, 2018), especially from the cat (*Felidae*) family (Oliveira-Santos *et al.*, 2012; Herrera *et al.*, 2018). Without the use of camera traps many carnivores would not be recorded at Cloudbridge. In order to detect the remaining eight carnivore species previously seen in Cloudbridge, a longer sampling time would be beneficial. Tobler *et al.* (2008) discussed how survey effort is the most important factor when recording species and even with a total of 4815 camera trap days detecting rare species is difficult with some only being recorded once.

304 bird species have previously been recorded within the reserve using a number of sampling methods (Cloudbridge Nature Reserve, 2019). The camera traps in this study recorded only 22 species. Not all species on the total list are expected to be seen on the camera traps as a large number are canopy dwellers, for example *Piciformes*. The Northern-emerald toucanet (*Aulacorhynchus prasinus*) is from the *Piciformes* family and because it spends most of its life in the upper canopy and nests within tree cavities (Clinton-Eitnien, 1982) it was not expected to be seen, however, one was recorded. 11 *Columbidae* species have previously been seen around the reserve, and are likely to be recorded by the camera

traps as they are adapted to manoeuvring through dense understory forests (Ocampo *et al.*, 2019). However, only three species from this family were recorded, the Chiriqui quail-dove (*Zentrygon chiriquensis*), Buff fronted quail-dove (*Zentrygon costaricensis*) and Ruddy quail dove (*Geotrygon montana*). It would be expected that other species from this family, such as the Plain breasted ground dove (*Columbina minuta*), Ruddy ground dove (*Columbina talpacoti*) and Gray-headed dove (*Leptotila plumbeiceps*), would be recorded by the camera traps given a longer sampling duration. The remaining species from this family were less likely to be recorded on the camera traps due to their behaviour, as they spend more time higher in the canopy and flying further distances for foraging (Ocampo *et al.*, 2019; The Cornell Lab, 2021). Camera traps do not currently support high speed recording (Rico-Guevara & Mickley, 2017), which excludes the large family of Hummingbirds (*Trochilidae*) that are seen in the reserve. Not only this, hummingbirds also build nests in trees high off the ground, for example, the Calliope Hummingbird (*Selasphorus calliope*) has been found nesting 50 to 120 feet high (Weydemeyer, 1927). Therefore, it is unlikely they would come into the field of view of the camera traps.

It has proved difficult to find studies using Shannon's and Simpson's index to estimate the diversity of birds and larger mammal species in cloud forest environments. However, some studies have allowed for comparison including Hulton (2008) and Ahumada *et al.* (2011). Hulton (2008) investigated bird species in Bajo del Tigre, a forest fragment connected to Monteverde Reserve, Costa Rica. A Shannon's index of 2.78 was obtained for Bajo del Tigre, in comparison to the value for the whole reserve at Cloudbridge which is 2.23. The higher result is not entirely unexpected as the birds in Hulton's (2008) study were sampled using point counts rather than camera traps, therefore decreasing bias to ground dwelling species.

A study using camera trap data from a number of countries, including Costa Rica, sampled terrestrial rainforest mammals and calculated Shannon's index of diversity (Ahumada *et al.*, 2011). For the Costa Rican site (Volcán Barva), Ahumada *et al.* (2011) recorded a Shannon's index of 2.5. This is a higher result than the Shannon's index recorded for the mammal communities in the whole reserve at Cloudbridge (1.91). Ahumada *et al.* (2011) acknowledged the species sampled are ground dwelling mammals, which allowed for a meaningful comparison with the Cloudbridge mammal communities. However, the disparity

between the results is likely a consequence of a larger amount of sampling effort and area (12000 hectares) used by Ahumada *et al.* (2011).

An interesting result from the diversity indices is that they contradict the results of each other (see table 1). This can be explained by the impact of different factors in the calculations. Shannon's is more influenced by species richness, whereas Simpson's takes evenness into account (Nagendra, 2002). However, this is an area for potential bias. Utilising both of these indices can reveal characteristics about the community that might otherwise have gone unnoticed. If a study only uses one of these indices, it could draw an incorrect conclusion of the community diversity. By using both indices it can reveal whether the community is composed of many species but few individuals within these, or whether there are a few highly abundant species. Results from a study by Ahumada *et al.* (2011) used five different measures of diversity, including Shannon's index, and showed where the communities differ in richness and evenness. The outcome that richness and evenness values contradict is present in the study by Ahumada *et al.* (2011). Not only this, there is more bias in Shannon's index of diversity, as when there is a smaller sample size (e.g. less than 50) the true diversity of a community is drastically underestimated (Smith & Grassle, 1977). Of the bird and mammal communities at Cloudbridge, birds in the planted forest (47 individuals) were the only sample with less than 50 individuals. This eliminated the chance of most communities diversity being underestimated due to the large sample sizes.

The naturally regenerating forest < 30 years had the highest species richness and largest total number of individuals when looking at mammal communities (Figure 2). This forest type was dominated by four common species, Collared peccary (*Pecari tajacu*), Paca (*Cuniculus paca*), Red tailed squirrel (*Sciurus granatensis*) and white nosed coati (*Nasua narica*). The other 11 species were composed of fewer individuals showing the community was not an even distribution. This result is contradictory to previous literature which states that mammal diversity increases with successional stage (Rueda-Hernandez *et al.*, 2015; Mukul & Saha, 2017; Derhé *et al.*, 2017). A study by Parry *et al.* (2007) also found that mammal species richness was higher in old growth, but experienced a more frequent encounter rate in secondary forest, likely due to the difference in species composition. The higher encounter rate correlates with this study as all areas of secondary forest recorded more individuals than the old growth forest.

In contrast, the highest species richness for birds was found in the old growth forest and when comparing the number of individuals at the point of the lowest sample, this is also highest in old growth (Figure 3). It has been found that large frugivorous and understory insectivores are susceptible to decline as a result of tropical forest disturbance (Rueda-Hernandez *et al.*, 2015). This could explain why more bird species were recorded in old growth forest at Cloudbridge. Two frugivorous species were recorded in the reserve, the black guan (*Chamaepetes unicolor*) was found in all forest types and the buff-fronted quail-dove (*Geotrygon costaricensis*) only found in old growth forest and naturally regenerating forest > 30 years. As the buff-fronted quail-dove is only found in these two forest types and are both late successional stages, it shows they are highly sensitive to disturbance (Price, 2006). Although black guan are also considered highly sensitive to disturbance (Price, 2006) their presence in secondary forest could be due to the proximity of old growth forest in the reserve which may have acted as a source population (Acevedo-Charry & Aide, 2019).

This study showed that mammals accumulated species faster and to a higher amount in planted forest than in old growth forest (Figure 5A). However, all species recorded were common and also found in at least one other area of forest in the reserve. Cacomistle (*Bassariscus sumichrasti*) was a rare species to be recorded in this study as it was only found in old growth. This could be due to the previous damage done to these areas of forest leading to a higher presence of species with lower forest specificity (Zimbres *et al.*, 2017). However, the presence of other species including ocelot (*Leopardus pardalis*) and margay (*Leopardus wiedii*) show that secondary forest could be used as corridors into old growth areas.

A camera trap study in Ecuador by Vanderhoff *et al.* (2011) focused on recording Margays, it was discussed how the sporadic recordings of individuals within the sanctuary is likely due to them using the area as a corridor into the national park. This result supports the idea that Margays could be using secondary forest as a corridor into old growth forest, explaining why Margay were recorded in the planted forest areas in this study. The purpose of the planted forest at Cloudbridge is conservation, leading to fewer detrimental impacts on the mammal communities than commercial plantations. For example, palm oil plantations in Colombia saw a significantly reduced terrestrial mammal species composition and richness in comparison to the nearby riparian forest (Pardo *et al.*, 2018).

The higher number of bird species recorded in old growth forests may be as a result of a larger amount of niche availability, leading to the presence of rare species in those areas

(Blake & Loiselle, 2001). For example, the old growth forest recorded four species that were not seen in any of the other forest types, including Black breasted wood quail (*Odontophorus leucolaemus*), Highland tinamou (*Nothocercus bonapartei*), Ruddy quail dove (*Geotrygon montana*) and Yellow thighed finch (*Pselliophorus tibialis*). However, Blake & Loiselle (2001) found that although there is no preference in forest type from bird species, their presence in secondary forest is often due to the proximity of the old growth forest. This is due to old growth forest areas being the primary and source habitat for a number of bird species (Blake & Loiselle, 2001). The different forest types at Cloudbridge Nature Reserve neighbour each other, meaning species can move freely between the preferred old growth forest to secondary forests. Nevertheless, the planted areas of forest recorded the lowest amount of bird species suggesting that the diminished variety of flora may have an impact on the presence of certain species. The planted areas of forest at Cloudbridge are used for conservation, rather than commercial use, this has been found to have fewer negative impacts on bird species communities, especially when connected to areas of primary forest (Castaño-Villa *et al.*, 2019).

The level of diversity recorded at Cloudbridge could be attributed to its location in the Talamanca mountain range and the fact it borders Chirripó National Park. Large ranging species can move through the national park and into Cloudbridge. A variety of these species were recorded by the camera traps which indicates the environment is healthy. For example, Jaguars are important predators in the environment and by recording their presence shows that prey species will be maintained and the food chain is balanced (Cardoso *et al.*, 2020). The presence of other important species such as Tapirs (*Tapirus bairdii*) and Paca suggest that Cloudbridge is a healthy cloud forest ecosystem (Sáenz-Bolaños *et al.*, 2020). Tapir eat over 98 species of plant and play a major role as seed dispersers (Naranjo, 2009). Paca eat fruits that have fallen onto the forest floor, and disperse seeds through their faeces making them another important species for healthy forest maintenance and development (Beck-King *et al.*, 1999).

Camera traps are a continuous method of sampling and allow for insight you would not get from more traditional sampling methods. Data can be carried out in many different locations including remote areas, and captures species that can be elusive, rare and nocturnal. For example, a number of the cat species including Jaguar, ocelot and margay, recorded in this study are difficult to sample due to these qualities (O'Connell *et al.*, 2010). Jaguars are

especially demanding to follow for long periods of time due to their large ranges. A study done by Schaller and Cranshaw (1980) found that female Jaguars in the Pantanal region in Brazil ranged over at least 25 – 38 sq km, and males covered twice as much terrain. It has been found in other studies that camera traps can provide more information on a number of carnivores than traditional studies. For example, in Tanzania, De Luca & Mpunga (2005) recorded 15 species using camera traps, compared to only nine using other methods. The use of camera traps can help to discover new information about species and their behaviours, for example the burrowing behaviour of northern hopping mice (*Notomys aquilo*) (Diete *et al.*, 2014). Without the use of camera traps at Cloudbridge Nature Reserve it would have been very unlikely to see some of the species recorded, such as the Jaguar and Baird's tapir.

There were, however, limitations to the use of the camera traps in this study, one being that cameras were only placed at ground level. This overlooks a whole community of species that live further up in the canopy and creates an obvious bias for individuals at ground level. Camera traps are not restricted to placement on the ground and despite the difficulties of positioning cameras higher up in the canopy, it is possible. Gregory *et al.* (2014) carried out a study using camera traps to investigate arboreal species. Different climbing techniques were utilised in order to get the cameras into position. The results gave reliable information on 20 species of mammal and 23 species of bird. These results suggest that using camera traps at a number of different levels throughout the canopy, from the forest floor to the canopy, will give a well-rounded documentation of the ecosystem as a whole. If implemented at Cloudbridge this could record, for example, arboreal species such as the White-faced capuchin (*Cebus capucinus*) and Central American spider monkey (*Ateles geoffroyi*), previously not seen on camera traps but known to be in the forest.

The majority of the 304 bird species previously recorded at Cloudbridge Nature Reserve do not spend much time, if any, on the ground, meaning they are unlikely to be caught on ground level camera traps. A mitigating strategy to limit bias could be to employ the use of other sampling techniques in conjunction with camera traps. Bird point counts offer a standardised and unbiased way of collecting data throughout different habitats (Ralph *et al.*, 1995), and are already used at Cloudbridge for other research projects. Fontúrbel *et al.* (2020) shows how bird point counts can be supplemented with the use of camera traps to record more elusive and inconspicuous species. Therefore, further study could utilise both camera

trap and point count data to give a broader understanding of the diversity of bird communities at Cloudbridge.

Throughout the study there were missed photographs due to the way the camera is triggered and the field of view. An infrared sensor is used, which triggers the camera when something moves in front of it that has a different temperature to the background vegetation (Jacobs & Ausband, 2018). Plants which have a different temperature to the rest of the background can trigger the camera, leading to a blank photo, resulting in many images having to be discarded. As the cameras have a limited field of view (38°), it is down to luck whether the individuals pass through the area. This can be mitigated by placing multiple cameras at a site to increase the number of detections. One study found that a site with four camera traps in one location detected 1.25 more species than a site with only one camera trap (Pease *et al.*, 2016). However, although this allows for a higher detection rate, the addition of multiple cameras at a site will increase the cost of the study.

In comparison to other camera trap studies the sampling time of this investigation was relatively short. For example, Sáenz-Bolaños *et al.* (2020) conducted 10,120 days of camera trapping in the Talamanca mountain range, compared with 128 days sampled in this study. Extending the duration of sampling time has been found to increase the number of species recorded (Tobler *et al.*, 2008), especially rarer species, as well as increase the reliability and reproducibility of the results from studies.

This study has demonstrated the usefulness of camera traps for estimating the diversity of bird and mammal communities in a cloud forest environment. The diversity was highest for birds in old growth, and naturally regenerating forest < 30 years for mammals. Using previous studies to understand the results further, shows the importance of old growth forests as source populations for bird species (Blake & Loiselle, 2001), as well as the ongoing protection of primary and secondary forest types to allow for the continuous movement and conservation of species in different areas (Vanderhoff *et al.*, 2011; Parry *et al.*, 2007). For future camera trap investigations at Cloudbridge Nature Reserve, there are a number of recommendations regarding the enhancement of data collection in order to record a higher number of species and obtain a more reliable estimate of the diversity present. For example, having a longer sampling time, placing camera traps at different heights, as well as using

more than one sampling method to ensure all communities within the reserve are being sampled. When analysing the data, it is important to understand that not all species previously seen on the reserve will be recorded by the cameras due to the placement of the camera and behaviours of species present. Overall, it can be concluded that the camera traps used in this study have sampled a representative percentage of the ground dwelling bird and mammal communities in Cloudbridge Nature Reserve. Sampling the whole community at Cloudbridge would be challenging, however, if the recommendations made in this paper were implemented, more of the community could be recorded adding even more depth and insight alongside the results of this study.

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Appendix



Figure 1: Jaguar (*Panthera onca*) 01/05/2020



Figure 2: White nosed coati (*Nasua narica*) 24/02/2020



Figure 3: Baird's tapir (*Tapirus bairdii*) 16/02/2020



Bushnell

M S2

78°F 25°C

03-21-2020 13:07:18



Bushnell

M S2

78°F 25°C

03-21-2020 13:07:20

Figure 4: Collared peccary & baby (*Pecari tajacu*) 21/3/2020



Figure 5: Northern Emerald Toucanet (*Aulacorhynchus prasinus*) 10/2/2020

Table 1: Bird and mammal individuals and what location they were recorded at.

BIRDS	Common name	Latin name	CT Location & Forest type		M9	E11	I1	R4	S2	W1	E7	G4	M7	R3	E8	G5	M8	Grand Total		
			E10	E9																
Common name	black guan	<i>Chamaepetes unicolor</i>	2					2	20	1		1				2	1	29		
	Black-breasted wood-quail	<i>Odontophorus leucolaemus</i>		2												1		2		
	Buff-fronted Quail-Dove	<i>Zenaidura macroura</i>	3	1	1	2										1		7		
	chiriqui quail-dove	<i>Catharus fasciater</i>		3		8	1		16	3	2	1		1		5	2	53		
	Costa Rican Warbler	<i>Basileuterus melanotis</i>						1										1		
	Chestnut-capped Brush-finch	<i>Arremon brunneinucha</i>	4	2	6	2	40		2	13	1	12		1		2	2	90		
	Golden-crowned warbler	<i>Basileuterus culicivorus</i>									1					2		3		
	great tinamou	<i>Tinamus major</i>							1									2		
	Hairy Woodpecker	<i>Picoides villosus</i>																1		
	highland tinamou	<i>Nothocercus bonapartei</i>																1		
	Lessson's Motmot	<i>Momotus lessonae</i>																10		
	Mountain Thrush	<i>Turdus plebejus</i>						1				1				2		4		
	Northern Emerald-toucanet	<i>Aulacorhynchus prasinus</i>												1				1		
	Orange-billed Nightingale-Thrush	<i>Catharus aurantiirostris</i>							1									1		
	ovenbird	<i>Scieur auropigalla</i>																1		
	ruddy quail-dove	<i>Gecorygon montana</i>	1															4		
	Ruddy-capped Nightingale-Thrush	<i>Catharus frontalis</i>	1			3												4		
	Slate-throated redstart	<i>Myioborus miniatus</i>																3		
Slaty-backed Nightingale-Thrush	<i>Catharus fasciater</i>							80					3				80			
Spotted Wood-Quail	<i>Odontophorus guttatus</i>	3	4	3		7		1			9			1		6	5	41		
swainson's thrush	<i>Catharus ustulatus</i>		1			2	1	10					5			17	8	44		
Yellow-thighed Finch	<i>Pselliophorus tibialis</i>	1																1		
Total:			18	19	19	15	54	4	131	18	4	23	10	13	1	35	10	25	403	
MAMMALS	Common name	Latin name	CT Location & Forest type		M9	E11	I1	R4	S2	W1	E7	G4	M7	R3	E8	G5	M8	Grand Total		
E10	E9																			
Common name	baird's tapir	<i>Tapirus bairdi</i>																1	2	
	Central American Agouti	<i>Bassariscus sumichrasti</i>																5	1	
	collared peccary	<i>Dasyprocta punctata</i>	2	2	3	1	1	1	1	19	13	5	12	5	112	26	5	1	208	
	Common Opossum	<i>Didelphis marsupialis</i>					3											3	3	
	Dice's Cottontail	<i>Sylvilagus discolor</i>					5					1	3	2	1	2		14	14	
	Jaguar	<i>Panthera onca</i>																1	1	
	Kinkajou	<i>Potos flavus</i>							12									12	12	
	long-tailed weasel	<i>Mustela penata</i>							3									3	3	
	leopard	<i>Leopardus wiedii</i>		1								1	1					3	3	
	mexican hairy porcupine	<i>Spilogurus mexicanus</i>																2	2	
	mexican mouse opossum	<i>Marmosa mexicana</i>							2										11	11
	Nine-banded Armadillo	<i>Dasypus novemcinctus</i>	4	1	1	1	1					2					3	1	5	5
	opossum	<i>Leopardus pardalis</i>																1	4	4
	red-tailed squirrel	<i>Didelphidae sp.</i>						2	10	1	2	1	4				1		24	24
	Sciurus paca	<i>Citellus paca</i>	4	3	4		9	1	41	1	6	4			7				82	82
	Squirrel	<i>Sciurus granatensis</i>	10	7	7	6	7	1	44	5	1	20	7	2	3	13	19		158	158
	Tayra	<i>Eira barbara</i>	1					4	4					4	1	1			12	12
	white-nosed coati	<i>Nasua narica</i>	1	2	1	2	5	1	23	5	2	13	8	2	8		12	8	96	96
Grand Total			21	17	17	15	34	5	140	34	19	49	39	15	134	57	37	13	646	