Mammal diversity and species richness in old versus new cloud forest using camera traps in San Gerardo de Rivas, Costa Rica

Research report

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Abstract

Costa Rica holds 5% of the earth's mammal species discovered. In the past significant deforestation occurred, but recently there has been a big project to reforest the country and restore its biodiversity. This research will focus on the effects of deforestation and thus the difference between older and new forest at Cloudbridge Nature Reserve in Costa Rica. In both old forest (>30 years) and new forest (<50 years) five cameras were placed that recorded the whole duration of this study. All wild mammals were noted down and used during this research, with exceptions made for species that were too hard to identify. The Shannon Index was calculated for old (1,559) and new (1,781) as well as the Simpson Index for old (0,685) and new (0,759) forest. These diversity indexes were also calculated per camera. An independent t-test was done with the Shannon and Simpson Index as the dependent variable and forest type as the independent variable. The results for the Shannon Index were (t (7) = -0,211; p = 0,847) and the Simpson Index (t (7) = -0,418; p = 0,665). A higher diversity was seen in the younger forest which could be explained by a higher tree diversity. The recent presence of a jaguar could have resulted in different dynamics and competition. This research gives a good start in the insights of the dynamics and diversity within Cloudbridge Nature Reserve in general but, it also gives a potential example of what an apex species like the jaguar can do to the change in dynamics of the mammal population within the reserve.

Keywords: Deforestation, Shannon index, Simpson index, Cloudbridge Nature Reserve, Wildlife

Indices

Introduction

Nestled in the middle of Central America lies Costa Rica, one of the most biodiverse places on earth. Costa Rica makes up for only 0,03% of the earth's landmass while it holds over half a million species, which is estimated at around 5% of species known to earth (Embassy Costa Rica, n.d.). Costa Rica lies between the two continents North and South America. Around 20 million years ago these two continents were separated by a sea, resulting in different species evolution on both continents. Later when the two continents were connected, the different species were able to connect. To this day many of those species still live in Costa Rica, resulting the high biodiversity (Johnston, 2022).

Even though Costa Rica is a very small country, only 51.100 square kilometers, (which is the size of Denmark, for reference), it has 12 different ecosystems in the country: lowland tropical rainforest, the tropical dry forest, the highland mountain rainforest, páramo, semi-deciduous mid-elevation forest, mangrove forest, wetlands, coral reef, Caribbean coastline, pacific coastline, shallow seas and lastly the cloud forest (Parker, 2017). Cloud forests are typically found at altitudes between 1000 and 2500 meters, and a layer of clouds at the canopy level is common year-round. Cloud forests are sensitive to climatic conditions, elevation, and distance from the sea, which makes them quite rare (Petruzzelo, 2022). The coming climate changes appear very likely to upset the current dynamic equilibrium of the cloud forest. This will result in biodiversity loss, altitude shifts in species' ranges, subsequent community reshuffling, and possible forest death (Foster, 2001).

Other studies have been done on mammal diversity and species richness in cloud forests. In Mexico, cloud forests are listed as a priority of conservation due to their high levels of species richness and endemicity (Gual-Díaz and Rendón-Correa, 2014). They hold a high turnover of species and beta diversity (Villasenor, 2010). The loss of vegetation cover represents a main threat to change in land and thus loss of biodiversity in the cloud forest (CONABIO, 2010). Using camera trap records, distribution was verified and the species richness was analyzed (Romero-Calderón *et al*., 2021).

Over the years a lot has changed regarding Costa Rica's nature. During the first half of the 20th century half of the forest within the country was lost; however, from the early 1970s millions of hectares have been saved in 169 protected areas, ranging from different ecosystem types as listed above (Obano, 2011). Previous studies show that mammal diversity and species richness are lower in highly fragmented sites (Ahumada *et al.,* 2011 & Magioli, 2021). Globally about 900 species, plants and animals, are extinct due to deforestation and climate change. When natural forests shrink the native habitat is erased and animals ultimately become extinct (IUCN, 2021). In Monteverde (another cloud forest in the north of Costa Rica in the Guanacaste region), research was done on mammal diversity and the impact of deforestation. Results show that more mammals were photographed in areas with natural regeneration, as well as a higher abundance of mammals (Pruett, 2017).

Besides Monteverde in Costa Rica, lies Cloudbridge Nature Reserve, which is also located in a cloud forest. As of 2017, Cloudbridge has planted about 50.000 native trees to fight deforestation. At the same time, they are conserving the old-growth forest to prevent diversity loss. The old forest has not been harvested since the turn of the 20th century (Cloudbridge, 2023-a).

The following question will be answered in this research: How does the mammal diversity and species richness inside the Cloudbridge Nature Reserve differ between the old-growth forest and the new-growth forest?

With the aforementioned information it is expected to have a lower mammal diversity and species richness in the new forest than in the old forest.

Materials and Methods

Study site

Cloudbridge lies approximately 5 hours south from the capital San Jose. It is a private nature reserve at an elevation between 1550m and 2600m high in the Talamanca mountains of Costa Rica. It consists of 255 hectares of reforested land and 28 hectares of primary forest (Cloudbridge, 2023-c). Figure 1 gives an indication of where Cloudbridge is located, and figure 2 shows the nature reserve itself with an indication of the different forest types present. From mid-May to November it is the rainy season in Costa Rica, with September and October as the wettest months. Temperatures are much cooler in the mountain regions than on the coast, with the daytime temperature between 21-23 degrees Celsius and at night to 15-16 degrees Celsius (Mytanfeet, 2023).

Figure 1: Map of Costa Rica with Cloudbridge Nature Reserve pointed out (Google Maps, 2023).

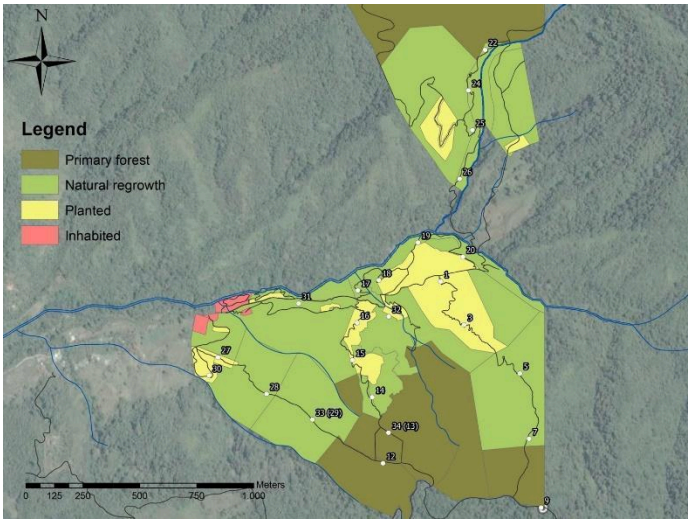

Figure 2: Map of Cloudbridge Nature Reserve with type of forest (Cloudbridge, n.d.).

Species

The species that were of interest in this study are wild mammals. Domestic animals, humans, bats, rats, mice and sloths were excluded from this research. Domestic animals and humans were excluded because this research focuses on wildlife. Bats, rats and mice were too difficult to identify through the footage of the trail cameras and were excluded because of this reason. Sloths were excluded because they haven't been seen in a very long time, with the belief they are no longer in the reserve. Table 1 shows all the mammals that were of interest for this research.

Table 1: List with species of interest of this study (Cloudbridge, 2023-b).

Number	Species	Scientific name	Number	Species	Scientific name
1	Red Brocket Deer	*Mazama americana*	19	Nine-banded Armadillo	*Dasypus novemcinctus*
2	Collared Peccary	*Pecari tajacu*	20	Central American Woolly Opossum	*Caluromys derbianus*
3	Coyote	*Canis latrans*	21	Common Opossum	*Didelphis marsupialus*
4	Jaguarundi	*Herpailurus yagouaroundi*	22	Mexican Mouse Opossum	*Mormosa Mexicana*
5	Ocelot	*Leopardus pardalis*	23	Grey Four-eyes Opossum	*Philander opossum*
6	Oncilla	*Leopardus tigrinus*	24	Dice's Cottontail	*Sylvilagus dicei*
7	Margay	*Leopardus wiedii*	25	Baird's Tapir	*Tapirus bairdii*
8	Jaguar	*Panthera onca*	26	Northern Tamandua	*Tamandua Mexicana*
9	Puma	*Puma concolor*	27	Central American Spider Monkey	*Ateles geoffroyi*
10	Striped Hog-Nosed Skunk	*Conepatus semistriatus*	28	Panamanian White-throated Capuchin	*Cebus imitator*
11	Tayra	*Eira Barbara*	29	Lowland Paca	*Cuniculus paca*
12	Greater Grison	*Galictis vittate*	30	Central American Agouti	*Dasyprocata punctata*
13	Neotropical Otter	*Lontra longicaudis*	31	Mexican Hairy Dwarf Porcupine	*Coendou mexicanus*
14	Long-tailed Weasel	*Mustela frenata*	32	Pocket Gopher	*Orthogeomys sp.*
15	Cacomistle	*Bassariscus sumichrasti*	33	Red-tailed Squirrel	*Sciurus granatensis*
16	White-nosed Coati	*Nasua narica*	34	Variegated Squirrel	*Sciurus variegatoides*
17	Kinkajou	*Potos flavus*	35	Blackish Small-eared Shrew	*Cryptotis nigrescens*

18	Common Raccoon	*Procyon lotor*			

Data sampling

The data was collected between the 24th of August till the first of December. During this time most of the cameras held their original place. Two cameras were changed to a different trail. The camera on Heliconia trail was replaced on the 21st of September and the camera on Rio trail on was replaced the 29th of September. These two cameras were changed from Montaña to Heliconia and Rio. This was done because there was no capture rate on Montaña in the months prior to this study.

This study focuses on the difference in diversity within old and new forests. Old forest is considered over 50 years old and young forest under 30 years old. This is because reforestation started in the early 2000s and there is little to no data on the forest from before the deforestation, resulting in not knowing the exact age of the forest (King, personal communication, 2023).

Four different kinds of cameras were used. The Bushnell trophy cam HD, the Voopeak TC-11, the Ceyomur CY70, and an Apeman.

Even though there are four different models of cameras used, they all are programmed with the same settings. When motion is detected, the camera unit will be triggered once and automatically take a 10 second video. The camera is equipped with built-in infrared LEDs that function as flash. The camera can take black and white videos during the night, and clear videos in color under direct sunlight. The camera has auto PIR sensitivity monitors, in which ambient temperature conditions automatically adjust the sensor signal to be more sensitive to variations in temperatures (Bushnell, 2014).

When a camera is set up it is important to place them where capture rates are at their highest. This study focuses on all mammals present so it is best to place the cameras in a place with the highest possible capture rate. The camera should be placed so animals are detected as soon as possible to maximize the length of available footage. Wildlife cameras are very sensitive, so it is important to mount the traps not higher than 40 centimeters above the targets' shoulders. During rainy

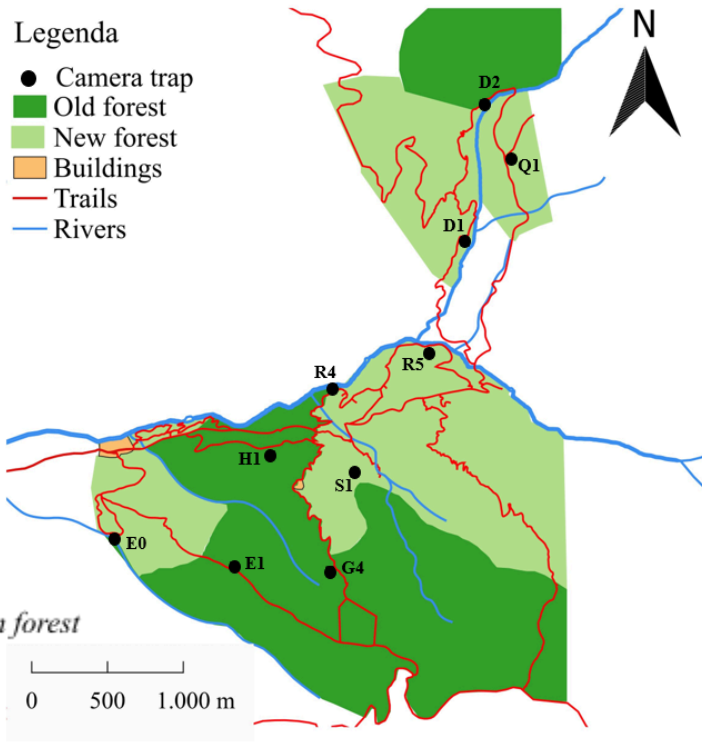

Figure 3: map with camera placement within Cloudbridge Nature Reserve with distinction in forest type.

seasons cameras that are placed too low to the ground can get splashed with dirt due to heavy rainfall. To reduce false triggers it is important to clear the view of vegetation that can be moved by the wind (Apps, 2018).

Data collection

Between the 24th of August and the 1st of December, the cameras were constantly working and thus capturing species. Table 2 shows per camera the exact capturing days. Every two weeks the SD card and batteries of the cameras on a set of trails were changed. The sets of trails were divided in a way that they were close enough to each other to walk in one morning. The trails were divided as follows: Heliconia (H1) was together with Gavilan (G4), Jilguero (E1) and Jilguero Loop (E0); Don Victor (D1 & D2) and Los Quetzales (Q1) were combined; and Sentinel (S1) and Rio (R4 & R5) were paired together. These cameras are shown in figure 3.

Table 2: Capturing days per camera.

Camera	Start date	End date	Capturing days
E0	24th of August 2023	16th of November 2023	84
E1	24th of August 2023	16th of November 2023	84
G4	24th of August 2023	16th of November 2023	84
H1	21st of September 2023	30th of November 2023	70
Q1	29th of August 2023	1st of December 2023	94
D1	29th of August 2023	9th of November 2023	72
D2	19th of September 2023	1st of December 2023	73
R4	14th of September 2023	1st of December 2023	78
R5	29th of September 2023	1st of December 2023	63
S1	15th of September 2023	30th of November 2023	76

All the wild mammals were recorded in an Excel sheet. The retriggers were deleted as well as the data with unidentified species. The date, time of capture, temperature, number of individuals, species and their scientific name, forest type, trail, trail type, and file name were all noted in the Excel sheet.

The altitude was measured with the app My Altitude. Retriggers were removed afterward, with a retrigger referring to the same animal seen within an hour. For species like the Ocelot or the Jaguar rosettes were noted to indicate if it was the same individual as they are unique to each individual. For other species it was too hard to identify the individuals. Too keep the same type of data collection for

all species types, if was seen that a jaguar or ocelot was the same individual as seen previously, this was noted down but not deleted. For all species only retriggers were deleted, this results in having events rather than individuals.

Data preparation

Before the data can be analyzed it first needs to be prepared. This will be done by calculating the Shannon and Simpson index. With the Shannon index, the diversity of species in a community can be measured (Statology, 2021). The Simpson index is used to calculate the relative abundance of the species.

Data analysis

To analyze the data collected during this research an independent T-Test test will be completed with the program SPSS, edition 28. The Shannon and Simpson index (dependent variable) will be tested against forest type (independent variable).

Results

Capture rate

Figure 4 shows the capture rate in both new (light green) and old forest (dark green) along each other. The highest capture rates (>60) are cut off in the graph to give the species with a lower capture rate a bigger appearance. Figure 5 shows the same results but only the species with an capture rate below eight, to give a clearer view of these species with a lower capture rate. For both new and old forest the Collared Peccaries have a higher rate of capture than the figure shows. For new forest this is 76 and for old forest this would be 412. The Red-tailed Squirrel has a rate of 127 in old forest and the White-nosed coati has a capture rate of 107 in old forest. The Agouti, Coyote, Jaguar, Jaguarundi, Kinkajou, Margay, Mexican Mouse Opossum, Northern Tamandua, and Variegated Squirrel were only captured either once or twice in total.

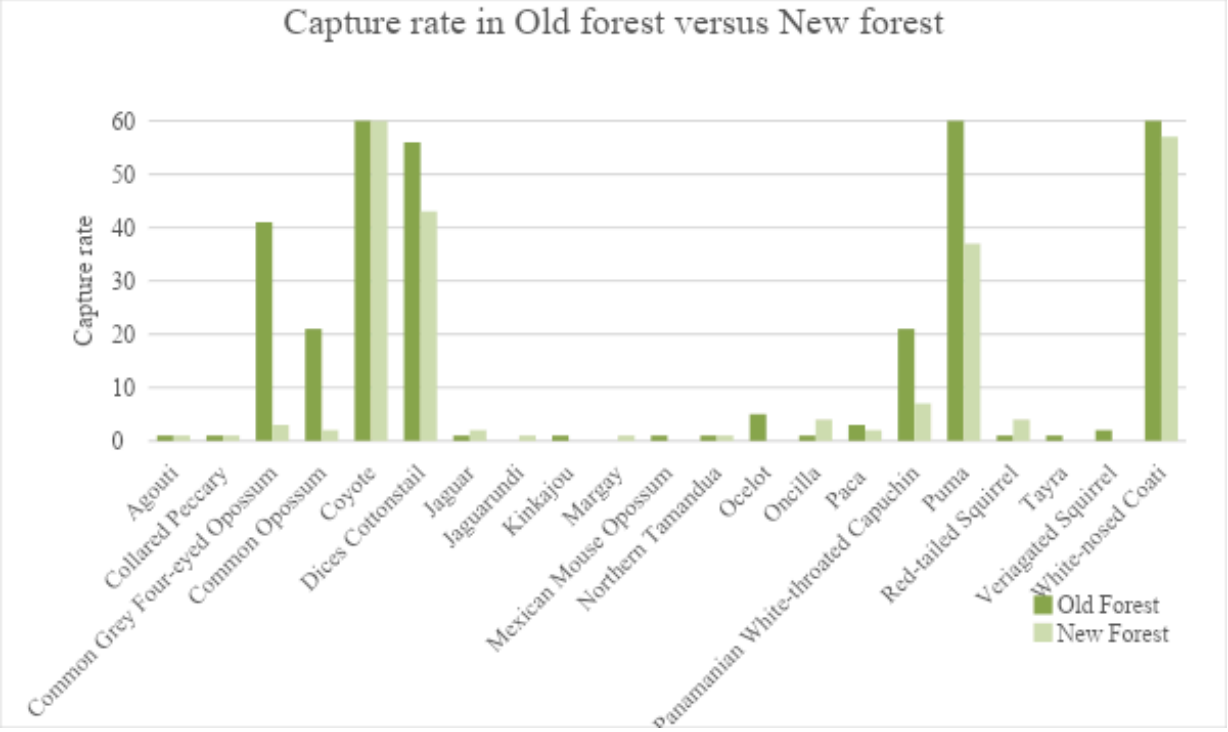

Figure 4: Capture rate at the end of the research period in new forest (light green) versus old forest (dark green) along each other.

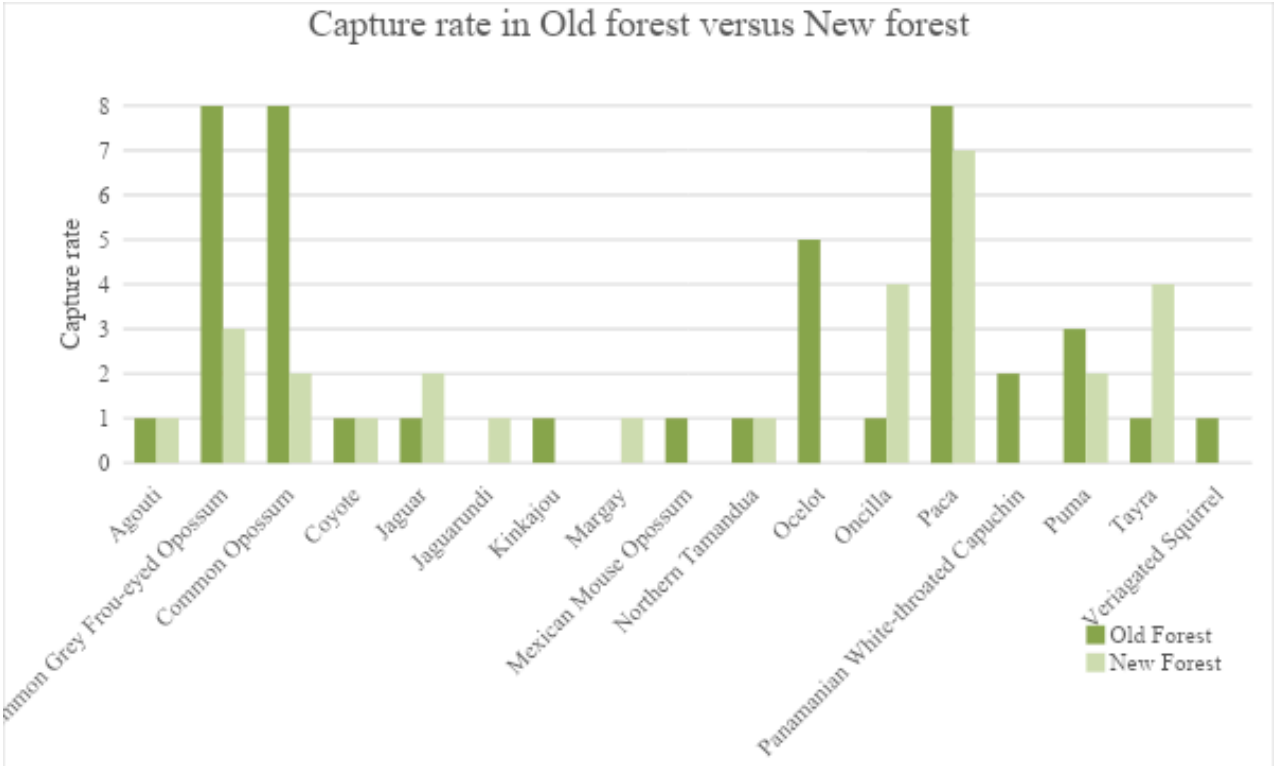

Figure 5: Capture rate of the species lower than 8 at the end of the research period in new forest (light green) versus old forest (dark green) along each othe.

Diversity indexes

Figure 6 shows the results of the Shannon and the Simpson index per camera. Camera H1 has neither a Shannon nor Simpson index, R5 has a Simpson index of 1. Furthermore Camera D1 has the highest Shannon index, while Camera D2 has the highest Simpson index. Both camera's S1 and E1 have a Shannon index below 1.

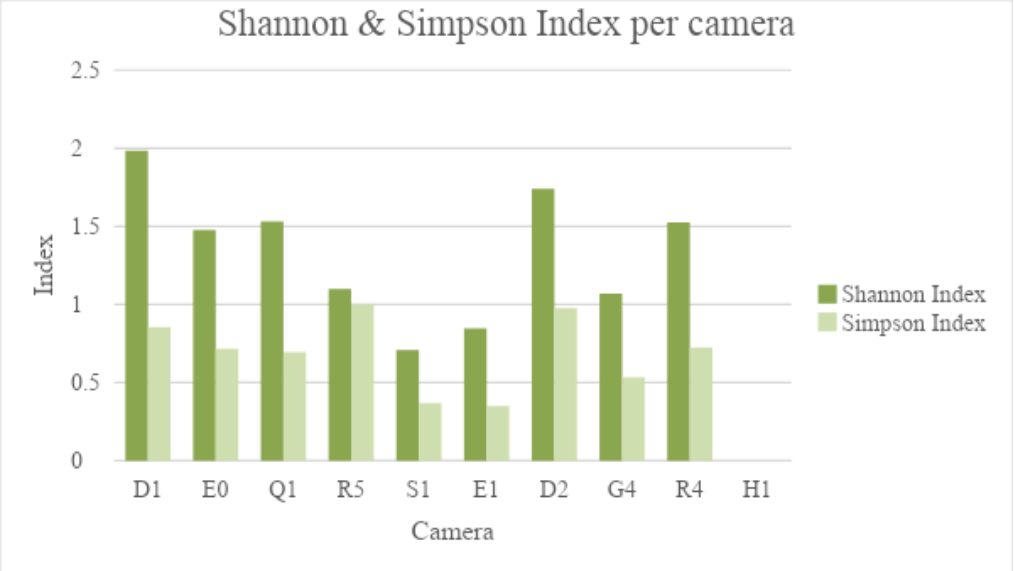

Figure 6: Shannon (dark green) and Simpson index (light green) per camera.

Table 3 shows the Shannon and Simpson index per forest type. New forest has a higher score in both indexes than old forest.

Table 3: Shannon and Simpson index per forest type.

	New forest	**Old forest**
Shannon index	1,781	1,559
Simpson index	0,759	0,685

An independent T-test shows neither a significant difference for the Shannon Index (t (7) = -0,211; p = 0,847) nor for the Simpson Index (t (7) = -0,418; p = 0,665) between old and new forest.

Discussion

If looked at the results above, although not statistically significant, an interesting trend that can be seen is that younger forest has a higher Shannon and Simpson Index than older forest. Meaning that the diversity is higher in younger forest. Appendix A, table A1, shows the capture rate per camera with exact numbers in species caught. If looked at the table it is shown that even though young forest only has 243 events in total, there were 16 different species seen. In older forest there were 804 events and 19 different species seen. Although young forest has fewer events than old forest, the amount of different species seen is almost even. The old forest did have one camera (H1) with a capture rate of zero, and thus no species were caught over the entire period this research took place, and hereby lacking a lot of potential data and potential species caught. Even though the old forest did lack data from one camera, this does not explain the small difference in species types caught.

A possibility could be that the difference in age between old and new forest was not as big as first thought. There is no data on the actual age of the forest, only what has been planted since the opening of Cloudbridge Nature Reserve, but for the forest that already existed the age was assumed based on visible structure (King, *personal communication, 2023)*. But again, there is no existing data on the actual years of the trees, therefore calling it a primary forest is a big risk. There is no tree width measured, which could help indicate the age of the forest.

Another reason why younger forest has a higher mammal diversity could be because of the tree diversity. An area with a higher tree diversity results in higher mammal diversity (Camargo *et al.,* 2018). From 2010 Cloudbridge Nature Reserve focused on planting a variety of tree species with enough space between the trees for natural regrowth. These newly planted areas consist of tropical oaks (*Quercus Mexicana)*, Mexican Elm *(Ulmus Mexicana)*, Cedro Dulce *(Cedrela tonduzii),* and lastly wild avocado (*Persea americana)* (King, personal communication, December 7th 2023). The younger forest consists of these newly planted areas.

If looked at the cameras separately (figure 6) it shows that camera D1 has the highest Shannon Index, but not the highest Simpson Index, which would be camera R5. But it is important to keep in mind that camera R5 has only caught 3 events in total (Appendix A: table A1), all different species. Both cameras R4, Q1 and E0 have a Shannon Index that is very close to one another. Camera D1 (new forest) has caught 10 different species but only caught 33 events in total, which results in a high Shannon index. This camera is also placed off trail (Appendix A: table A2) in comparison to other cameras that are placed on trail. Camera S1 captured 55 events but only 5 different species, and this camera was placed on trail. On trail means that there is a higher disturbance from visitors entering the reserve compared to off-trail where no people walk. A higher disturbance often leads to fewer species seen (Dornelas, 2010). This is also the case for this study since the top five cameras with the highest capture rate are D1, R4, E1, G4, and E0 in which D1, R4, and E0 are cameras that were placed off

trail. If looked at the number of species seen both Q1 and R4 caught eleven different species and D1 and E1 ten. From these four camera's only Q1 was placed on trail (Appendix A: table 4).

From the total of 21 species seen 5 species are near threatened or vulnerable according to the classification of Catalogue of life (2023). The species that are near threatened are the Jaguar and the Margay, while the the Dice's Cottontail, Panamanian White-throated Capuchin and the Oncilla are vulnerable. These were all seen in low quantities except the Dice's Cottontail, which was seen 99 times in total.

A previous study of mammal diversity within Cloudbridge Nature Reserve was done by Louise Ilott-Baudon in the beginning of 2023. Ilott-Baudon caught 22 species types and in total, this research caught 20 species types. Her research took place in the dry season while this one took place during the wet season which could result in a difference. One interesting thing is that the Puma was caught 10 times less in this research compared to Illot-Baudon's research. Illot-Baudon's research did however also find a higher diversity in the young growth forest, just like this research did (Illot-Baudon, 2023). The upcoming presence of the jaguar is most likely the cause of capturing fewer pumas and possibly also the cause of the catching of fewer species in general. The puma and the jaguar are both top predators and eat the same type of food and thus compete with each other (Gutiérrez-González and López-González, 2017). It is possible for the puma and the jaguar to coexist, factors that allow this to happen are their activity pattern and their diet (Ávila-Nájera *et al.*, 2020). With overlap in diet, the jaguar tends to go for larger mammals and the puma tends to have a more diverse diet (Scognamillo *et al.*, 2003). The sudden presence of the jaguar could disrupt the food chain within the reserve.

Conclusion

To conclude, during this research 20 different mammal species were caught which includes all 6 Felid species. Ten cameras were placed, five in young forest (<30 years) and five in old forest (>50 years). The young forest has a higher Shannon and Simpson index compared to the old forest which could be explained by a higher tree diversity. Research from Camargo *et al.* (2018) shows that older forests should have a higher mammal diversity but tree diversity could change this. This research gives a good start in the insights of the dynamics and diversity within Cloudbridge Nature Reserve in general but, it also gives a good start of the changes within the dynamics now that the Jaguar is back and seen regularly.

Limitations

The biggest limitation during this research was the placement of the camera traps. Considering this was the first time I worked with camera traps there was some trial and error. I placed two cameras myself which were less effective in capturing mammals than the other cameras that were already placed within Cloudbridge Nature Reserve. The SD cards caused some limitations as well. These cameras had to be formatted periodically, but there were times when I was too late in doing so. This would result in the loss of two weeks' worth of data for that particular camera.

The actual capturing of the mammals was also a limitation. The cameras were set up to catch as many mammals as possible and thus not biased on particular mammals. This made it sometimes hard to see which species was caught on camera. Big mammals like the puma for example would be very close to the camera and only a stomach would be seen, while with smaller mammals like the paca or the red-tailed Squirrel, you would only catch a little glimpse of the animal. This made it especially difficult in the beginning to identify the species when my knowledge of the mammals was not as high as it was later on.

The setups from the cameras could lead to unclear videos. With some cameras, the set-up screen would not work and thus changing the set-ups was not possible. A general set-up is that it takes three seconds for the camera to start recording. Especially with the smaller mammals this made it very difficult to catch them fully on video since they move quickly. Another issue was overexposure. Some videos were too overexposed to see anything, leading to a completely white video. On the other end, it also occurred that there was not enough light added, resulting in completely black videos.

Future research

For future research, I would suggest moving cameras R5 and H1 due to capturing little to no data. I would recommend keeping the other cameras in this position until at least the 19th of January, then they have been capturing in these positions for a year. If moving the cameras I would suggest keeping

one on the path of Los Quetzales to see any activity from the jaguar considering it was seen here twice.

Recommendations I would give in case a similar study wants to be held would be the measurements of tree width. In this way clearer conclusions can be formed on the difference between old and new forest. If there is a possibility to use more camera traps, I would recommend placing more traps on all possible locations. Right now the camera traps are not biased for particular species, just to catch as many species as possible. If one camera could be biased for smaller species, while the other one is biased for the bigger mammals, clearer videos could be caught.

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Appendix A: Discussion

Table A1: Capture rate per camera and forest type.

	New Forest					Total New	Old Forest				Total Old
	D1	**E0**	**Q1**	**R5**	**S1**		**D2**	**E1**	**G4**	**R4**	
Agouti	1					**1**		1			**1**
Coyote			1			**1**		1			**1**
Common Grey Four-eyed Opossum	1	2				**3**	5	6	1	29	**1**
Common Opossum		1	1			**2**	1			20	**218**
Collared Peccary	8	22	2	1	43	**76**	6	268	138		**412**
Dice's Cottontail	9	6	28			**43**	23	21	12		**56**
Jaguar			2			**2**			1		**1**
Jaguarundi	1					**1**					
Kinkajou										1	**1**
Margay				1		**1**					
Mexican Mouse Opossum							1				**1**
Northern Tamandua					11	**1**				1	**1**
Ocelot								3	1	1	**5**
Oncilla	2		2			**4**				1	**1**
Puma		1	1			**2**		1	1	1	**3**
Paca	3	3		1		**7**	13	5		3	**21**
Panamanian White-throated Capuchin									2		**2**
Red-tailed Squirrel	3	16	17		1	**37**	20	14	19	74	**127**
Tayra	1		2		1	**4**				1	**1**
Variegated Squirrel										1	**1**
White-nosed Coati	4	41	3		9	**57**	4	14	39	50	**107**
End Total	**33**	**92**	**60**	**3**	**55**	**243**	**74**	**334**	**212**	**182**	**804**

Table A2: Camera placing details such as trail, forest type, trail type, elevation and placed on or off trail.

Camera	Trail	Forest type	Trail type	Elevation in meters	on/off trail
E0	Jilguero Loop	New	Private	1616,45	off
E1	Jilguero	Old	Private	1818,39	on
H1	Heliconia	Old	Private	1676,04	on
G4	Gavilan	Old	Private	1869,1	on
D1	Don Victor	New	Public	1746,05	off
D2	Don Victor	Old	Public	1808,09	off
Q1	Los Quetzales	New	Public	1825,79	on
R4	Rio	Old	Public	1680,1	off
R5	Rio	New	Public	1671,96	on
S1	Sentinel	New	Public	1740,32	on