Analysing Camera Trap Results On Mammals At Different Locations Within Cloudbridge Nature Reserve.

Research Report

RESERVA CLOUDBRIDGE NATURE RESERVE

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Abstract

This study investigated species abundance and diversity of mammals at different locations in Cloudbridge Nature Reserve using camera trapping methods. The survey took place across a 6-month period in which 10 cameras and 2 different set-ups were used. The data collection was split into 2, 3-month periods in which the camera positioning differed. Each location was surveyed for a total of 92 camera trap (CT) nights and a total of 22 mammal species were caught and 2749 individuals. The capture rate, Simpson's Diversity Index (SDI) and species accumulation were analysed and compared across the different species, the CT locations, the hiking trails and the forest types found on the reserve. The results of this study found that set-up 2 captured 9 more species than set-up 1, with species such as the Collared Peccary dominating the whole study; set-up 2 experienced an increased capture rate as well as increases in felids/predators, specifically. R studio was used and discovered significantly higher diversities and significantly faster species accumulation rates in set-up 2. Additionally, the Don Victor trail in Cloudbridge collected the highest diversity out of all the hiking trails, while looking at abundance, this increased in nearly all the trails except the Gavilan and Montaña trail. Moreover, data from the last three months found that the old-growth forest captured the most mammals whereas planted forests found the least, also, young-growth forests gained the highest diversity while old-growth found the lowest. Overall, this study found that the movement of the CTs improved abundance and diversity, proving to be a more beneficial placement for monitoring mammals. However, due to mainly the short study period, bias and CT failures, the results from this study may not be representative, but, this survey has found a solid method and provided suggestions for improvement and future research.

Keywords: Camera Trap; Mammals; Wildlife; Cloudbridge Nature Reserve; Costa Rica; Shannon's Diversity Index.

Table Of Contents

Introduction

Camera trap surveys are used globally to monitor and record terrestrial mammal populations (Cusack *et al.*, 2015; Ahumada *et al.,* 2011; Rovero *et al.*, 2014) to aid in their conservation efforts. A camera trap is simply a camera placed in a location that automatically detects and captures images and/or videos without a photographer present. Camera traps are very important for studying nature, over the last decade they have grown to be one of the most powerful tools for wildlife research (Rovero *et al.*, 2013) since they are very easy to use, have low long-term costs, provide a plethora of information on a large range of species and provide data in real-time (Allan and James, 2011). Modern cameras and the cameras used in this research use a passive infrared sensor (PIR) that detects moving objects that have a different surface temperature to the environment in the background (Rovero *et al.*, 2013; Wearn and Glover-Kapfer, 2017).

Many studies have found camera traps to be more effective than other monitoring tools when investigating species richness, distributions, relative abundance and density (Silveira *et al*., 2003; Espartosa *et al.*, 2011; De Bondi *et al.*, 2010; Guthlin *et al.*, 2014; Anile *et al.*, 2014). This is mainly due to their ability to stay in the field for extended periods of time if needed, but also, they continuously register detections during the day and night with very small disturbance from humans, except for the emission of sound and light (Allan and James, 2011; Meek *et al.*, 2014).

Since camera traps are so important for wildlife research, it is crucial to think carefully about the location of where the camera is placed. Several studies found that placement impacted the rate that which animals were detected, the total number of species detected, and the detection probability across a suite of species (Kolowski and Forrester, 2017). Camera trap placement strategies can be broadly classified into random, using a random selection of locations, ignoring nearby features that may increase capture probability and non-random, which targets features such as game trails and water points to increase the probability of capturing species (Cusack *et al.*, 2015). Studies by Cusack *et al.* (2015), Wearn *et al.* (2013) and Kolowski *et al.* (2017) commended a random camera placement however a large sampling effort would be required to overcome low capture rates. On the other hand, studies such as Di Bittetti *et al.* (2014) and Blake and Mosquera (2014) found that a combination of both trail and off-trail cameras would provide comprehensive results on species composition and relative abundance. Tanwar *et al.* (2021) concluded that camera-trap surveys should be tailored to specific objectives.

Costa Rica is one of the most biodiverse places on earth, and even though it is a relatively small country, making up only 0.03% of the world's landmass, roughly half a million species can be found there, equating to around 5% of the total estimated species in the world (Johnston, 2022; Staff, 2018; Emanuelli, 2021). Before 1940, the forest covered 75% of the land, however, by 1987 it was estimated that around 50% of the forest had been destroyed, at this point the Costa Rican government stepped in and created laws on deforestation and enforcing ‘payments for ecological services’ providing Costa Ricans with financial support in return for helping restore the forest (Johnston, 2022). As a result, today the forest now covers roughly 60% of the country (Johnston, 2022). Costa Rica protects its terrestrial biodiversity through the creation of national parks, reserves and protected areas, today over 28% of the land is protected according to the World Bank (Trading Economics, n.d.). Furthermore, the IUCN reports that there are a total of 165,134 species in the world, with 7700 species found in Costa Rica alone, 238 of these are mammals, of which 109 are bats (IUCN, 2023). 341 species are now classified as vulnerable, 264 are endangered and 83 are critically endangered (IUCN, 2023), so research and conservation work on these animals and their habitats is crucial for their protection.

The objective of this study was, therefore, to evaluate how species abundance and diversity may differ at different locations across Cloudbridge Nature Reserve using camera traps, in order to better understand these species. I was specifically interested in creating an updated species inventory during this time while also exploring how I could improve the camera trap placement that was already in use within the reserve. A non-random placement was applied involving a mixture of trail and off-trail cameras in order to analyse capture rate, species richness and species accumulation across the locations, hiking trails and forest types.

Methodology

Study Site

This study was conducted in Cloudbridge Nature Reserve, Perez Zeledon, Costa Rica. Cloudbridge is a private nature reserve in the Talamanca mountains of Costa Rica, which stretches from 1550m to 2600m above sea level (Cloudbridge, n.d.). Since 2002, lots of pasture/cultivated land and some primary forest were bought by the reserve with the aim of reforesting and conserving the cloud forest, which was done through the planting of native trees and shrub species. Today the reserve covers around 700 hectares of land (Cloudbridge, n.d.), which consists of primary forest, old-growth forest, young-growth/naturally regenerated forest as well as areas of planted forest. Figure 1 below displays a map of the reserve including all the named hiking trails that can be found there.

Study Species

The species of interest for this particular study focussed on all mammals except humans, domesticated species (e.g., dogs), bats, mice and rats. Bats, mice and rats were not included since they are more difficult to detect and are very challenging to identify to a species level using camera traps, they all require different methodologies for example, Sherman traps for mice and rats and net trapping for bats.

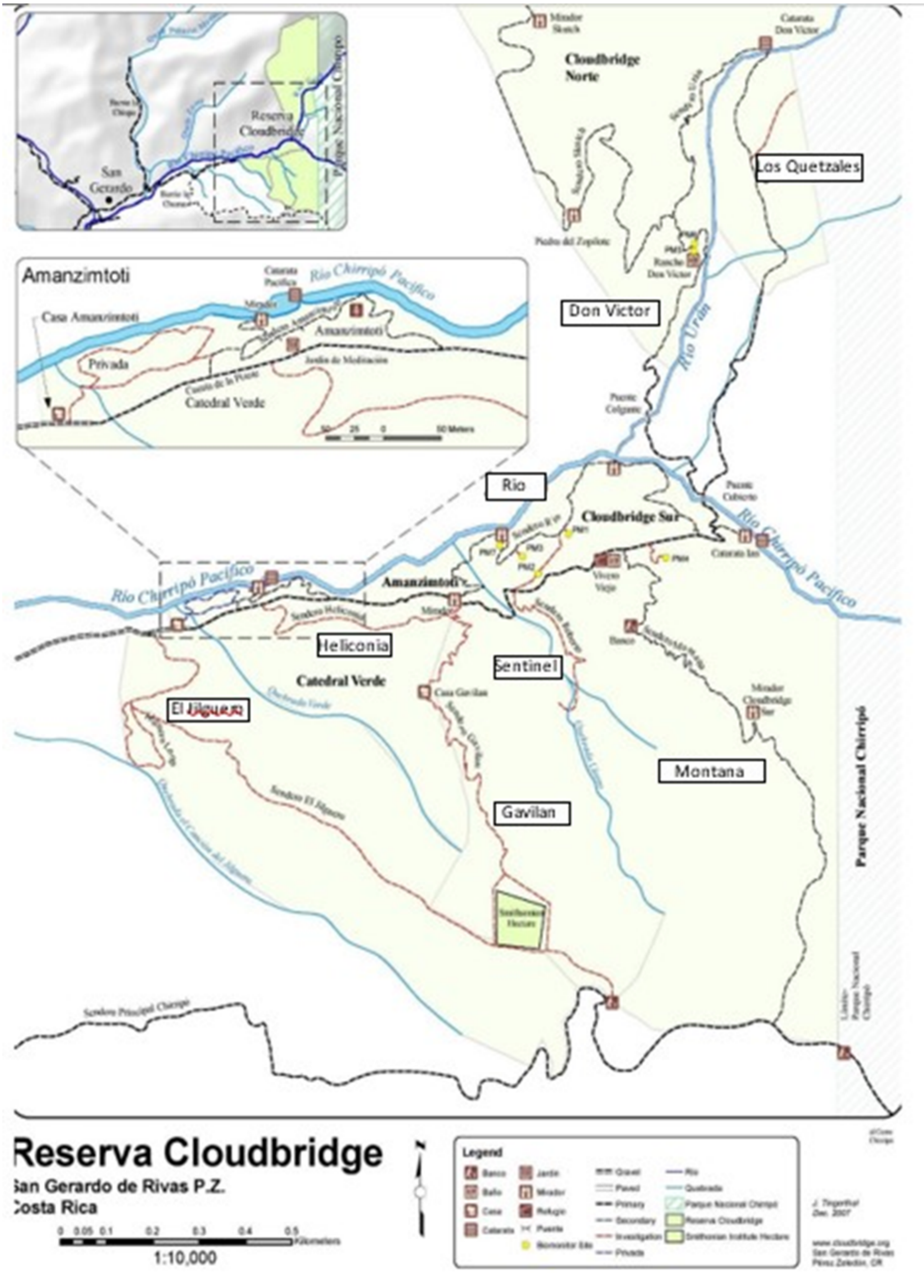

Fig. 1: Map of Cloudbridge Nature Reserve, including all the named hiking trails in the text boxes.

Data Sampling

The survey was split into 2 time periods, between the 15th of October 2022 to the 15th of January 2023 and between the 19th of January 2023 to the 19th of April 2023. From October to January the cameras remained in the original placement they were in before this survey was carried out, this is because camera trapping is an ongoing project on the reserve and so these cameras have been in place for over a year, as seen in Figure 2. The sites during this time period were selected using a grid and a random selection. Then, from January to April 2023 most of the cameras were moved into a new placement, seen in Figure 3, in which the camera sites were chosen non-randomly based on evidence of animal presence e.g., game trails. The camera traps were moved in order to collect data over a larger area within the reserve and to collect data on trails such as Los Quetzales and Don Victor (See Figure 1 and 3), which no data had previously been collected on, but also, to evaluate whether moving the cameras to new positions would increase the capture rate, abundance and/or species diversity within Cloudbridge.

The camera traps were set up to maximise the chances of capturing mammalian species and were deployed for a total of 92 days per camera trap set-up. One camera trap (E9), failed to work for the entire time period within the first 3 months, so was not included in the analysis, making the initial set-up decrease from 10 to 9 camera traps. The active camera trap nights of each trap for the first 3 months can be seen in Table 1 (see Appendix A).

The majority of the camera traps used were Bushnell trophy cam HD, however, two traps were of the Ceyomur brand and two Voopeak TC-11 traps were also used. The data settings were kept fairly consistent, with all the camera traps taking videos except for one (E11) which took photos. The video length was kept at ten seconds, the video quality was set to the highest option, and they all also had a three-second delay between the recordings. Furthermore, each camera trap had other settings such as sensor level, light-emitting diode (LED), and night vision (NV) shutter correctly set for the best possible quality of recordings for its specific location.

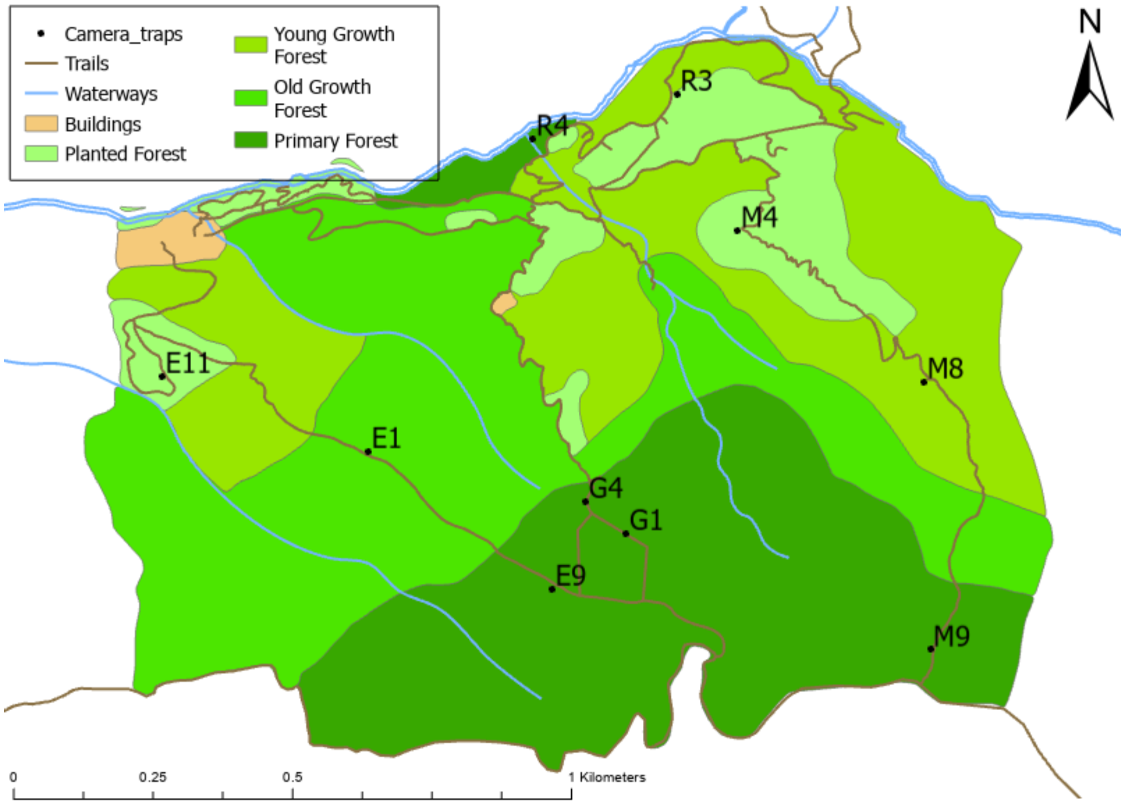

Fig. 2: The camera trap locations within Cloudbridge Nature Reserve from the 15th of October to the 15th of January 2023

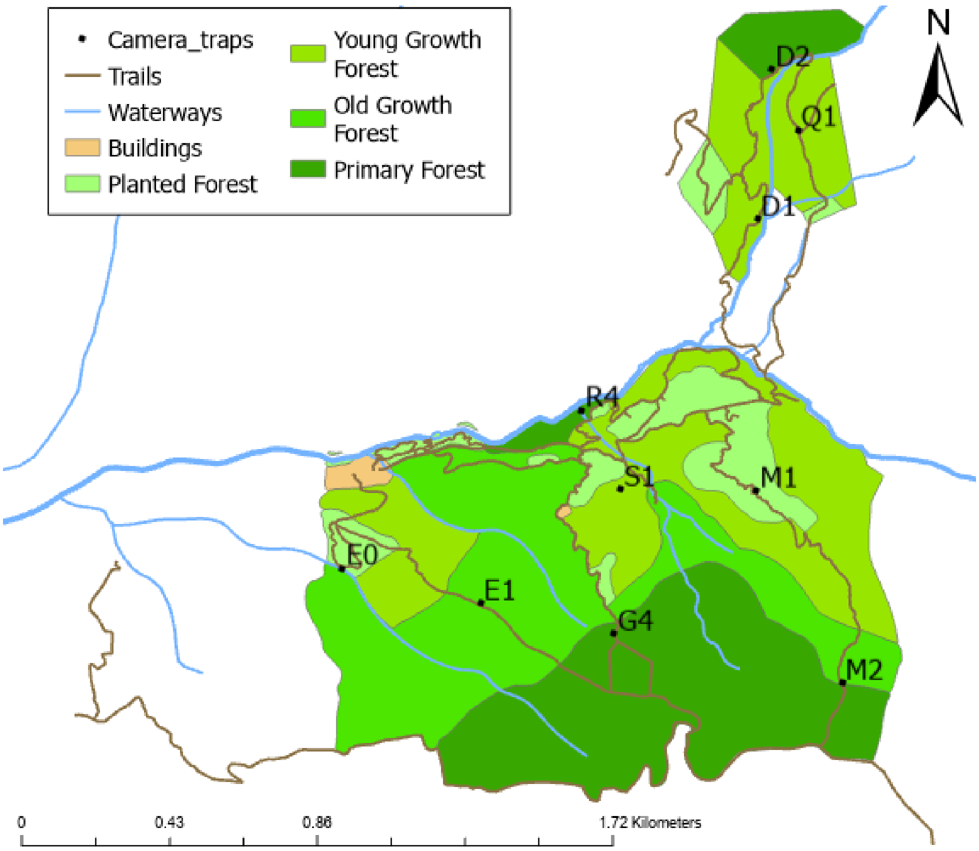

Fig. 3: The camera trap locations within Cloudbridge Nature Reserve from the 19th of January to the 19th of April 2023

Data Collection

Data was collected between the 15th of October 2022 to the 19th of April 2023, where every Tuesday and Thursday, one set of cameras on certain trails would be checked and this would alternate each week (e.g., El Jilguero and Montaña one week then Rio-Sentinel and Don Victor-Los Quetzales the following week) to ensure that each of the cameras were checked and had secure digital (SD) cards and rechargeable batteries replaced (if needed) every two weeks to minimise disturbance.

Data Analysis

All mammals except for humans, domesticated species (e.g., dogs), bats, mice and rats were used in the analysis. Additionally, unidentifiable species and images with nothing (false triggers) were not included. All the accepted mammalian species that were caught on the cameras were recorded in the Cloudbridge database. The photo/video number was recorded into an Excel spreadsheet along with the location, the common and scientific name, the date and time of the recording, the number of individuals and if the individual was an adult or juvenile. All the species were accurately identified using field guides, Google and experienced Cloudbridge staff knowledge; however, it was difficult to reliably identify specific individuals of a species, so it was decided that a record was considered unique if the same species was recorded again at least an hour apart, to prevent double counting the same individuals.

Capture Rate

Firstly, the capture rate for each set-up was calculated to show the frequency each species was caught per 100 active camera trap (CT) nights. To do this all the cameras for each set-up (n=10) were used and the species capture rates were calculated as the number of independent events of each species, divided by the total sampling effort of all the cameras multiplied by 100 (Palmer *et al.*, 2018). The location capture rates were calculated as the total number of independent observations of all species at a certain location divided by the sampling effort of that location, multiplied by 100. The sampling effort was the sum of the number of days each camera was operational throughout the study period.

Shannon's Diversity Index

The Shannon's Diversity Index was used in this analysis. This is a measure of species diversity in a community that considers both the richness of species and their relative abundance (evenness) in a habitat (Rain *et al.*, 2023). This was chosen instead of the Simpson's diversity index because it does not get significantly affected by the sample size whereas Simpson's is more of a dominance index, giving an equal weight for the species with only a few individuals and the species with many individuals (Kiernan, 2021). The formula for the Shannon's Diversity Index can be seen in Figure 4 below (Zach, 2021).

$$H = (\Sigma(p_i * ln(p_i)))-1$$

Fig. 4: Shannon-Wiener Index where:
Σ = A Greek symbol indicating "sum of"
Ln = Natural log
*P*i = The proportion of the community made up of the species

Species Accumulation

Accumulation curves were generated through Excel by looking at the number of species found across the sampling effort (92 days) to find the time taken to find new species. This can be used to check if data collection lasted a sufficient number of days to capture the total number of species (Rovero *et al.*, 2014).

Results

Within the first 92 days (October 2022 – January 2023), 1032 individuals were caught, including 13 different species of mammals (see Appendix A1). Within the mammal community certain species were found to be more abundant than others, for example, Collared Peccaries were the most common species with 469 individuals recorded, making up 45% of the total mammal individuals recorded. This was followed by Red-tailed Squirrels making up 28% of total recordings. On the other hand, the more elusive Striped Hog-nosed Skunk was only recorded once. Within the second 92 days (January 2023 – April 2023), 1717 total individuals were caught which involved 22 different species (See Appendix A2). As a result, the last 3 months caught 9 more species and nearly 700 more individuals than the first 3 months. Similarly, Collared Peccaries dominated again, making up 55% of the total results, followed by Red-tailed Squirrel and Dice's Cottontail which both made 10% of the total recordings.

Across the whole study, 22 species were confirmed and 2749 individuals were captured. See Appendix A3 for the completed species inventory during this study.

Capture Rate

The capture rate was calculated for each species across all the camera trap locations. Looking at Figure 5 below you can see that Collared Peccaries were caught the most frequently in both set-ups, but 44% more frequently in set-up 2 than in set-up 1. The next most abundant species were Red-tailed Squirrels, which decreased by 56% from set-up 1 to set-up 2, and then White-nosed Coati, which also decreased by 39% in set-up 2. All the other species had relatively low capture rates which can be seen more clearly in Figure 6. Pumas were caught 260% more frequently in set-up 2 with around 3 being caught every 100 active CT nights. Furthermore, you can also see that 9 species were only found in set-up 2, whereas there were no species only found in set-up 1. This means that every species found in set-up 1 was also found in set-up 2.

The capture rate per 100 days was also calculated for each location. Looking at Figure 7 you can see there was high variation, but G4 caught species the most frequently (320) in set-up 1, while E1 captured the most in set-up 2 (555). The capture rate at G4 remained very similar across both the set-ups while E1 increased massively in set-up 2. Since E1 remained in the same location across the whole survey, this may be due to the different times of year, with wet and dry seasons causing some species to be more abundant in set-up 2. E11 had the poorest results with only 22 individuals every 100 active CT nights, 93% lower than G4 in set-up 1.

The capture rate for set-up 1 as a whole was found to be around 161 species per 100 active CT nights, while in set-up 2 it was 193 per 100 active CT nights. As a result, overall set-up 2 captured mammals more frequently.

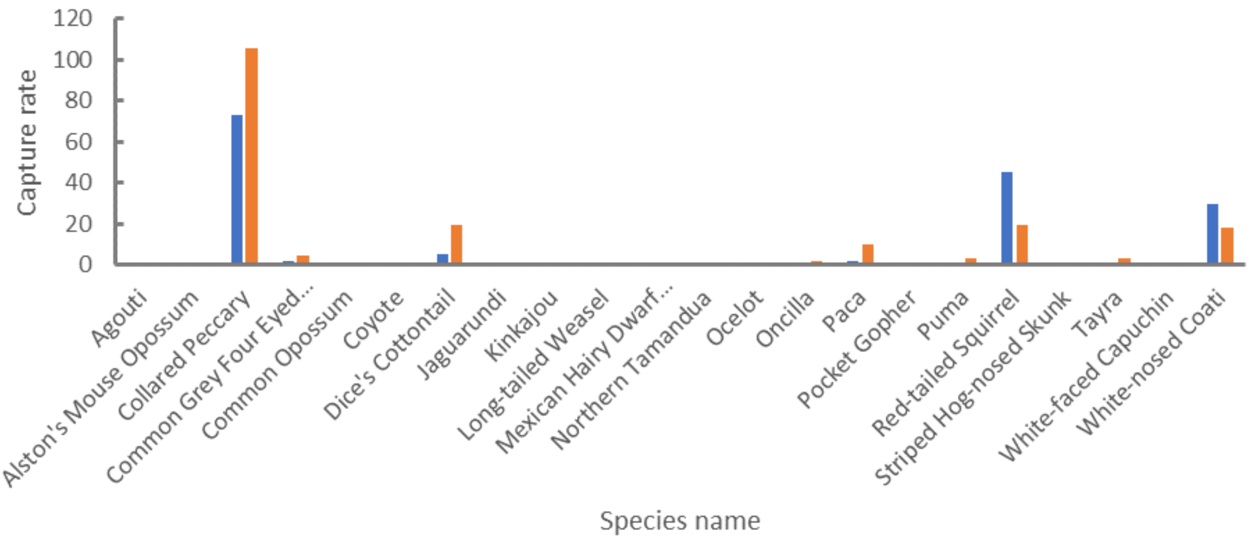

Fig. 5: The capture rate per 100 camera trap nights across all 22 species in set-up 1 (Blue) and set-up 2 (Orange).

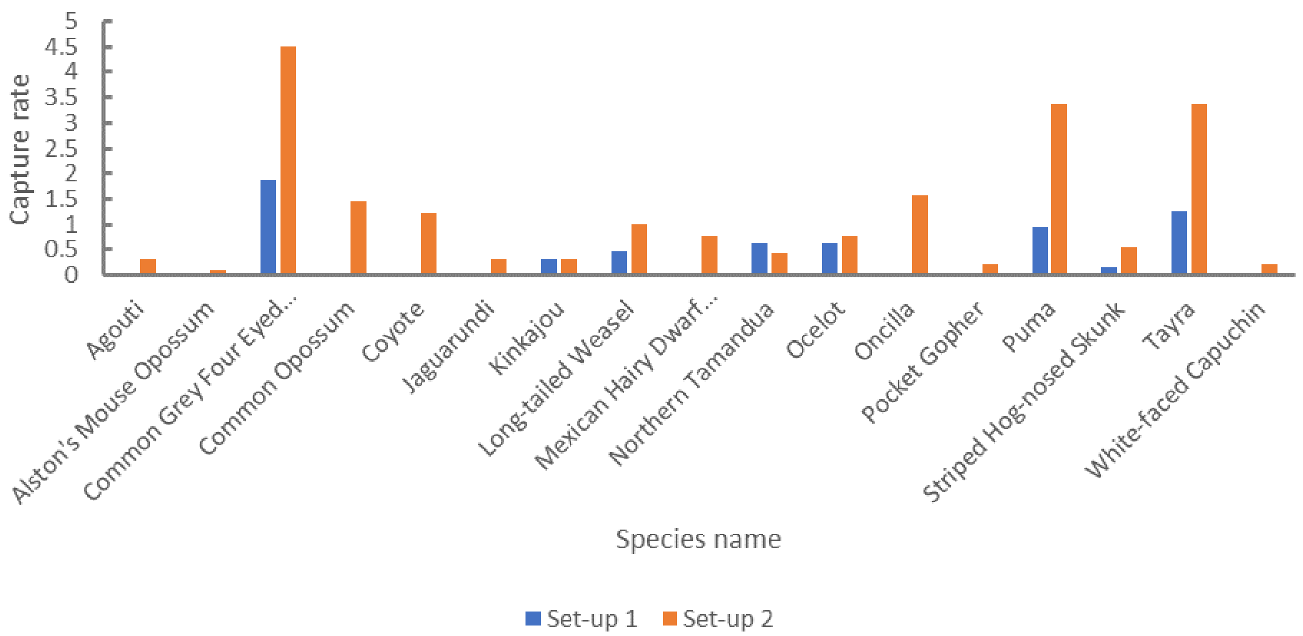

Fig. 6: The capture rate per 100 camera trap nights across all 22 species in set-up 1 (Blue) and set-up 2 (Orange), excluding the 5 most abundant species: Collared peccaries, Red-tailed squirrel, White-nosed Coati, Dice's cottontail and Paca.

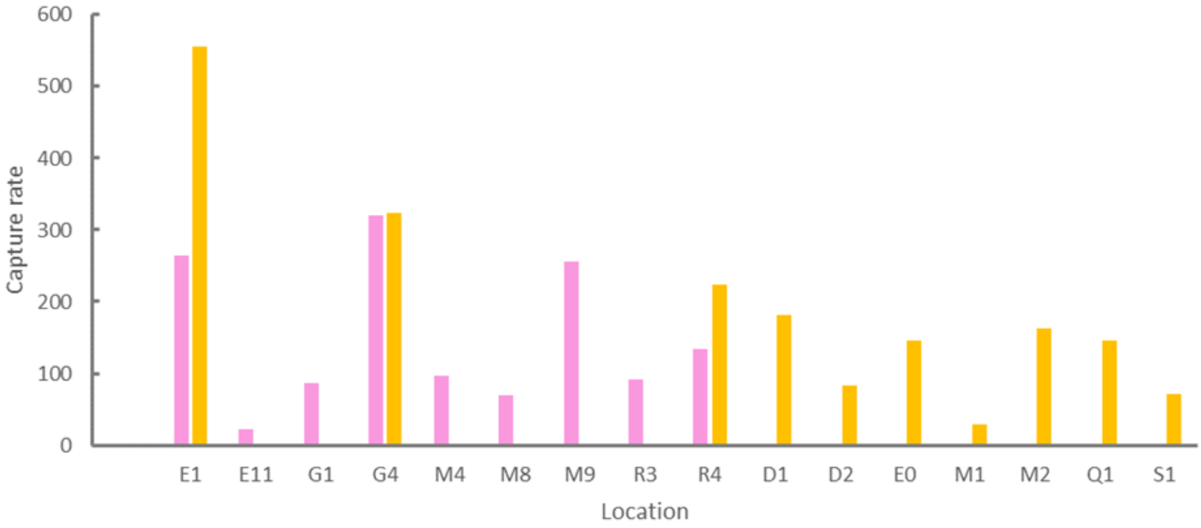

Fig. 7: The capture rate per 100 camera trap nights across all the locations in set-up 1 (Pink) and set-up 2 (Orange).

Shannon's Diversity Index

Figure 8 below displays the Shannon's Diversity Index (SDI) across all the locations in both set-ups, which presents high variation. It shows that in set-up 1, R4 recorded the highest diversity out of the 9 locations (1.177), E1 and R3 were similar with SDIs of 1.099 and 1.098 respectively. M9 had the lowest diversity with an SDI of 0.281, this was 76% less diverse than R4. In set-up 2, D2 was the most diverse location with an SDI of 1.946, followed by R4 (1.683) and M1 (1.637). The least diverse location in set-up 2 was E1 with an SDI of 0.608 which was 69% lower than D2. Overall, set-up 1 had a diversity index of 1.387 while set-up 2 was nearly 20% higher with an index of 1.662.

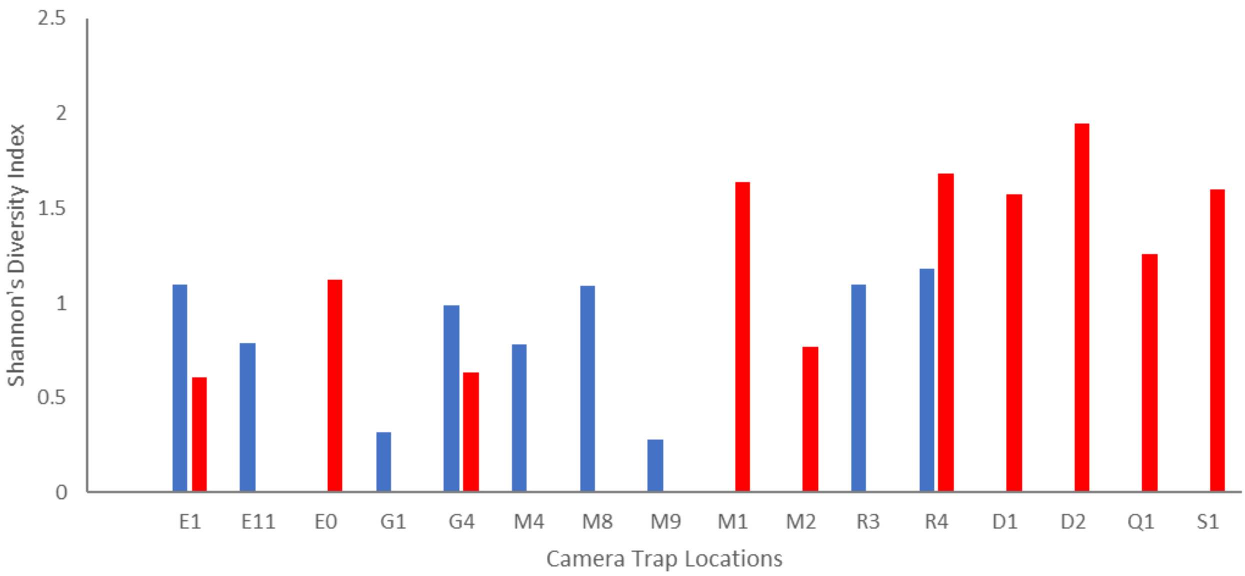

Fig. 8: The Shannon's Diversity Index across all the different camera trap locations within set-up 1 (Blue) and set-up 2 (Red).

Data analysis was carried out using R studio to compare set-up 1 and set-up 2. Firstly, an F test was calculated, verifying the assumption that the 2 samples came from normally distributed populations with equal and unknown variances ($p > 0.05$). Next, a two-sample t-test found that the difference in Shannon's Diversity Index between set-up 1 ($M = 0.847$, $SD = 0.340$) and set-up 2 ($M = 1.282$, $SD = 0.481$) was significant ($t\,(17) = -2.254$; $p = 0.01885$).

This diversity index was calculated excluding Collared Peccaries (the most dominant mammal species), since the abundance of this species was so much higher than all the others, and it could be giving extreme values. This can also be seen in Appendix A4. In set-up 1, R4 remained the most diverse (1.177), E1 and R3 decreased in diversity giving it an index of 0.777 and 0.735 respectively and M9 decreased and remained as the least diverse location (0.199). In set-up 2, D2 decreased but still kept the position of the most diverse with an index of 1.668, this was followed by R4 (1.658) and D1 (1.341) and E1 remained the least diverse (0.461). A two-sample t-test found that the difference in Shannon's Diversity Index excluding Collared Peccaries between set-up 1 ($M = 0.651$, $SD = 0.302$) and set-up 2 ($M = 1.086$, $SD = 0.452$) was significant ($t\,(17) = -2.437$; $p = 0.01305$).

See Appendix A5 for a box plot for a clear comparison of this information.

Trails

Next, comparisons were made between the different trails found on the reserve. Firstly, a graph was plotted with the Shannon's Diversity Index across all the different trails for both set-ups (Figure 9). All the trails increased in species diversity in set-up 2 except for El Jilguero and Gavilan. Additionally, the Don Victor trail was found to have the highest diversity, followed by the Rio trail.

Moreover, a graph was created comparing abundance across all the trails, as seen in Figure 10. El Jilguero had the highest abundance across all the trails, however, this was made up of 80% Collared Peccaries. Furthermore, the abundance decreased for the Montaña and Gavilan trails. However, the camera traps on the Gavilan trail remained in the same location for both set-ups so this decrease may have resulted from other variables, such as time of year.

Similarly, this data was also calculated excluding Collared Peccaries. The results have been displayed in Appendix A6 and A7.

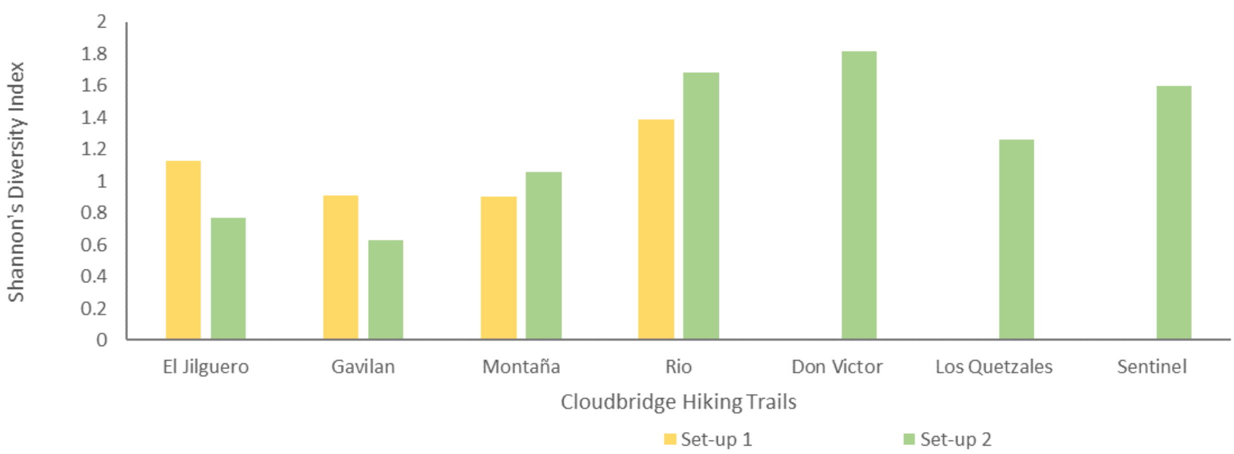

Fig. 9: The comparison of Shannon's Diversity Index across the different hiking trails found on Cloudbridge Nature Reserve.

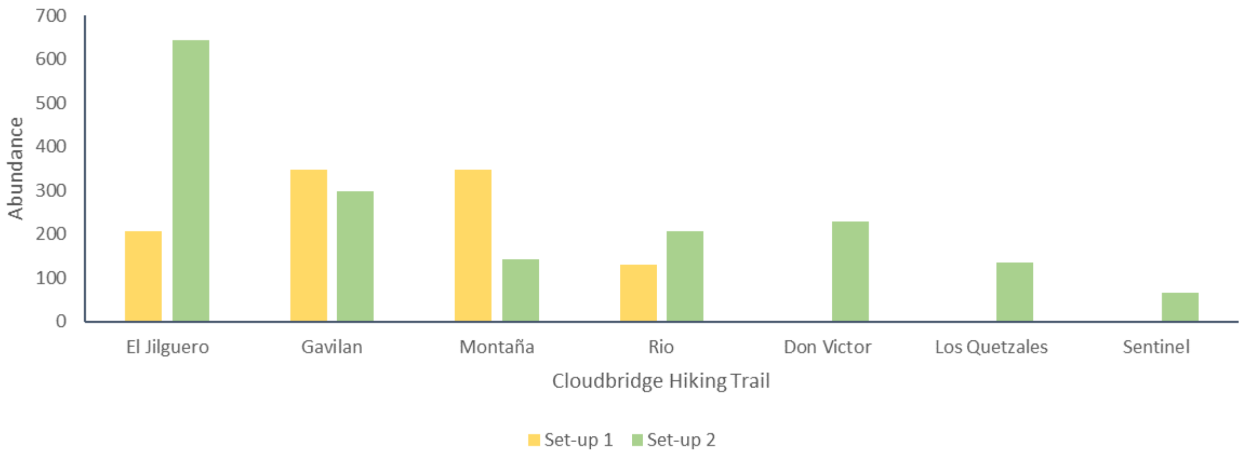

Fig. 10: How species abundance differed across the different trails found on the reserve between set-up 1 (Orange) and set-up 2 (Green).

Forest Type

The last 3 months of data were used to compare the different habitat types.

Figure 11 displays how the abundance of species differed between the habitats. The old-growth forests captured the most mammals (627), providing the highest abundance. This was followed by primary forest which captured just 7% fewer mammals with 580 individuals, young growth/natural regeneration made up 20% while planted captured the least, with only 160 individuals.

In contrast, the Shannon's Diversity Index was calculated for each forest type, as seen in Figure 12 below, the old-growth forest was found to have the lowest diversity with a score of 0.685. Whereas, the young-growth forest had the highest diversity with a score nearly three times higher than that of the old-growth forest (1.850).

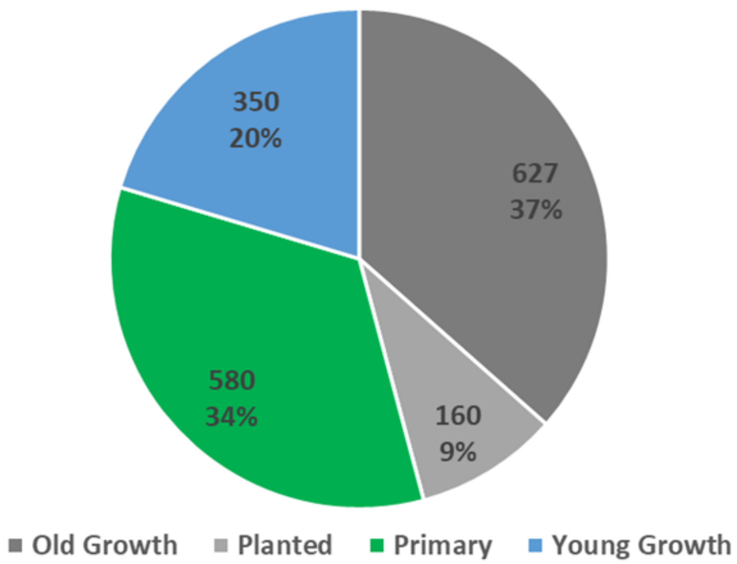

Fig. 11: Comparison of abundance across the different forest types found on the reserve.

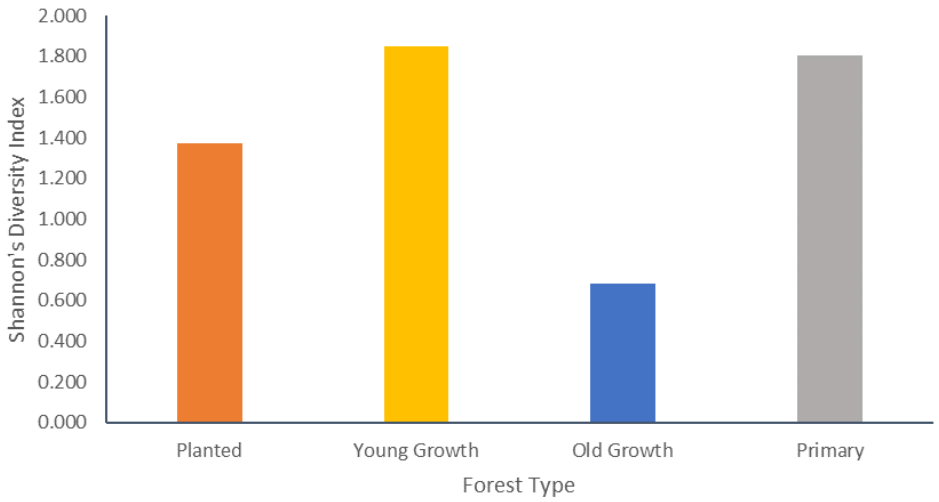

Fig. 12: Comparison of Shannon's Diversity Index across the different forest types found on the reserve.

Species Accumulation

The time taken for species to accumulate in both set-ups was plotted (Figure 13). As shown, both set-ups experienced a rapid initial increase in accumulation which over time slowed down to a more gradual increase. For example, in set-up 1 within the first 23 days, 10 species were caught, but after this, it took 43 more days to gain another 3 species. On the other hand, in set-up 2 it only took 5 days to capture 10 species which was nearly 5 times faster than in set-up 1, but also after this point, new species were found faster than in the initial set-up with 22 found by the 66th day (compared to 13 in set-up 1). Additionally, both of the graphs do not plateau which suggests that the 3-month length of these studies was not a sufficient amount of time to catch all the species in the area.

Furthermore, using R studio, a paired t-test was then used and found that the difference in species accumulation between set-up 1 and set-up 2 was significant (t (91) = -30.713; p = 2.2e^{-16}).

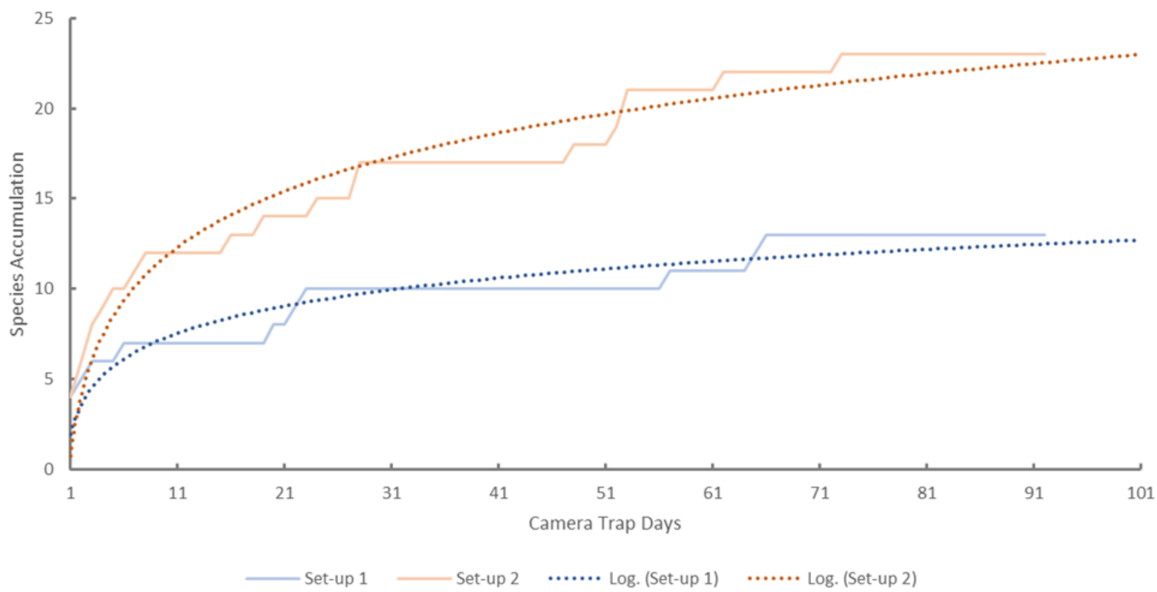

Fig. 13: The species accumulation throughout set-up 1 (Blue) and set-up 2 (Orange).

Discussion

This study aimed to compare species abundance and diversity across the reserve to better understand the species distribution and to explore how the camera trap placement in Cloudbridge could be improved. The initial camera trap placement (set-up 1) was in place before this study occurred and was chosen using a grid and a random selection to pick the sites. Whereas this study moved them and used a non-random method of selecting the sites based on evidence of animal presence e.g., game trails. See Appendix B1 and B2 for examples of some of the camera trap sites used.

The results of this study found the presence of 22 species on the reserve, of this, certain species such as the Collared Peccary dominated the community as they were captured the most frequently across the whole study period. Additionally, the movement of the cameras to their new positioning increased the capture frequency of 19 species, especially the 4 (out of 6) cat species that were found. Also, the new position found 9 new species not found in the initial set-up, recorded significantly higher diversity values and accumulated species nearly 2x faster. This may be because the previous camera placement was chosen by a more random selection, whereas the new positionings were located and picked due to having signs of animal use e.g., tracks and game trails, proving a much higher probability of capturing the species. For example, Cusack *et al.* (2015) found that if sampling periods were short and/or the number of cameras available to use were limited, then a more non-random trail-based placement would facilitate the detection of more species, more rapidly, however, he also suggested that surveys with a large sampling effort of more than 1,400 active camera trap nights would yield a greater species inventory with a random camera placement. Since this study surveyed over a total of 1,523 active camera trap nights, this might suggest that a more random placement may have been preferred.

Moreover, looking at the different locations, traps such as E1, R4 and G4 remained in the same locations over the whole study period, however, R4 and E1 specifically, experienced big increases in capture frequency, while G4 remained practically the same. This is thought to be due to the different times of year since the first 3 months were surveyed at the end of the wet season while the new positioning of the cameras was surveyed during the dry season, suggesting that some species may be more abundant in the dry season. On the other hand, G4 remained the same signifying that the increases in E1 and R4 may have just been coincidental. Nevertheless, the increases in these 'control' cameras could imply that any of the new locations that were found to have a higher capture rate compared to the previous locations may also just be by chance.

Additionally, the results of this study found that in Cloudbridge Nature Reserve, the Don Victor hiking trail was the most diverse, while the Sentinel trail seemed to be the least diverse. The reasons why this might be are uncertain, however explanations could include that Sentinel only had one camera trap and was a much smaller trail, whereas Don Victor had two traps placed on it and was around three or four times longer in length. This means that Don Victor has double the amount of chance to capture mammal species. The trails were also at slightly different elevations, with Don Victor being around 100m higher, however, this study couldn't find any correlation between diversity/abundance with elevation gain. Moreover, the abundance of species saw an increase in nearly all the trails, except the Gavilan and Montaña trails. Both of these trails did experience a decrease in camera traps placed on them, going from three in set-up 1 to two in set-up 2, decreasing their chances and the area covered to capture species. The Gavilan trail also had one trap that was not moved during the study which may be another reason why the abundance would not have increased. However, especially for the Montaña trail this suggests that the placement on this particular trail may need to be changed.

Furthermore, only the last 3 months of data were able to be used to analyse the forest types. This found that old-growth forests captured the most mammals whereas planted forests recorded the least amount. On the other hand, old-growth forest was discovered to be the least diverse out of all four forest types, while young-growth had the highest diversity. This was interesting because initially it was predicted that primary forest would have the highest abundance and diversity, however, this was not the case. Reasons behind these results may be that as forests get older, trees produce significantly more shade, reducing the number of other plants that can survive causing animals to have fewer places to eat and causing predators and prey to decrease (Actforlibraries, n.d.). Also, each site was unique and perhaps the young-growth forest camera sites were placed in more suitable spots for a wider range of species, such as nearer water sources etc.

In total, fifty-four mammalian species have been previously recorded in the reserve (Cloudbridge Nature Reserve, 2018), however, this included twelve bat species. This study confirmed the presence of twenty-one of these mammal species, while also recording a new species, the Alston's Mouse Opossum (*Marmosa alstoni*), which was not included within the Cloudbridge species list. Additionally, the last published research using camera trapping methods within Cloudbridge Nature Reserve dates back to two years ago in 2021 by Georgia Smith. Smith's study caught a total of nineteen species, six of which this study failed to find, including Baird's Tapir, Cacomistle, Jaguar, Margay, Mexican Mouse Opossum and the Nine-banded Armadillo (Smith, 2021). On the other hand, this survey caught ten species not found in Smith's research, which consisted of the Oncilla, White-faced Capuchin, Northern Tamandua, Puma, Pocket Gopher, Gray Four-eyed Opossum, Coyote, Jaguarundi, Alston's Mouse Opossum and the Striped-hog Nosed Skunk. Furthermore, Smith obtained an overall Shannon's Diversity Index score of 1.91 (0.3 higher than this study) for the whole reserve and also discovered young-growth forests to be the most diverse of the forest types.

Limitations

Several limitations were found while carrying out this study. Firstly, the camera traps were very time-intensive and high maintenance. This is because surveying would consist of a lot of hiking up different trails weekly to check the cameras, but also there were many hours' worth of videos that needed to be watched closely, which was time-consuming. Then, occasionally, the camera would break or be faulty, with only three working for the whole 92 days in the first 3 months of the study. This massively impacted the data that was collected in the first 3 months of this study, since the longer a camera was left out, the more likely it would catch something, especially the more elusive species. This minimised the amount of time some of the locations had to collect data, which may be the reason why set-up 2 had significantly better results since it experienced much less camera failure. Additionally, some of the cameras could still record, however, the screen or settings were broken, meaning the date and time were incorrect. Similarly, cameras can have bad image quality, making it very challenging to identify the species being recorded or even see anything at all.

Furthermore, as the cameras use batteries and SD cards, when the batteries ran out or the SD card filled up, the camera would stop collecting data, sometimes causing several days' worth of data to be lost, greatly limiting the study. To minimise this happening, the cameras would be checked every 2 weeks, however, it would still occur, especially when placed in a busy location, like on a main trail where many people pass through. Additionally, the cameras had a very limited field of view so it was only luck as to whether a species walked into that specific area, and the traps were not very effective at capturing small mammals such as mouse opossums due to their small size. Moreover, the length of my study was only 92 days per set-up which isn't much time at all. The more time, the more species that should be caught.

Lastly, a big limitation that was observed was biases, since the cameras were positioned in a non-random placement. This was in order to maximise the chances of catching mammals, however, it did mean that this study violated a central principle of sampling theory: the random selection of sampling units (Wearn *et al.*, 2013; Cusack *et al.*, 2015). This is because, even though this survey aimed to study all mammals, some of the camera placements used were biased toward large carnivores such as cats. This is because, in set-up 2, six of the cameras were placed on trails while 4 were placed off trails. Kolowski and Forrester (2017) found that this bias placement affects the detection probability of other species. But also, advice was utilised from previous Cloudbridge researchers on where they caught certain species, and so, this study involves bias in catching those particular species, especially the cats. Additionally, all the cameras were set at ground level, creating bias to only ground-level mammals, meaning all the mammals in the canopy, such as the monkeys, were less likely to be caught.

Future Research

If this research were to be continued or repeated then the cameras should be left out for a longer period of time in order to collect more reliable and reproducible data. It would also be beneficial to use a larger number of cameras (if possible) as this would allow the researcher to gain a more equal spread across the different forest types and different hiking trails. Also, their placement on and off the trails would give the researcher the ability to efficiently compare all the different aspects. Additionally, a study period of at least 365 days would eliminate any limitations or uncertainty in the results due to the time of year or seasons.

Moreover, since technology is constantly improving and new methods are arising, even though camera traps are currently one of the most effective tools for studying wildlife, there have been many studies that have suggested environmental DNA (eDNA) to be a more effective method. As mammals move through an environment they leave pieces of skin, fur, faeces and/or saliva which all contain DNA, as a result, soil or water samples can be analysed to detect which species has passed through that environment (Cat, 2019; Minh, 2022). This provides similar data to camera traps, however, non-invasively. A study by Leempoel, Hebert and Hadly (2020) found that all species recorded by camera traps were also detected with eDNA, but also the eDNA was able to detect many small mammals which are more difficult and unreliable to study using camera trapping methods. Similarly, Lyet *et al.* (2021) revealed that in their study, eDNA detected 25% more terrestrial mammal species compared to camera trapping methods, and for half the cost. It is also thought that eDNA can provide insight into the impacts climate change may be having on the environment as well as identify viruses and bacteria, but most importantly, it holds the ability to assess the overall health of an ecosystem (Minh, 2022). In contrast, this method is still understudied and so research is still required as there is uncertainty in how frequently an animal must pass to be detectable in an eDNA sample or how recent the passage must be. Also, eDNA cannot provide the same level of detail on individuals and populations, camera traps can identify individuals through images, they can be used to estimate population size and density, but also they can be used to observe behavioural patterns and histories (Lyet *et al.*, 2021).

Conclusion

To conclude, this study confirmed the presence of 21 mammal species within Cloudbridge Nature Reserve, including four out of six of the wild felid species, but also it found a new species to add to the reserve's list: the Alston's Mouse Opossum. The results of this study saw that the movement of the camera traps into the new placements did improve the results obtained from the reserve's previous site selection. This suggests that a more non-random placement for the camera trap studies may be beneficial for capturing and studying mammalian species since this report found that it increased the capture rate, diversity and accumulation rates. However, several literature were found which advised that due to the biases of a non-random site selection, it can make the results less representative of the true community. On the other hand, being able to obtain as much information on species as possible can greatly help to watch and understand these mammals, especially behaviourally, showing how this is really dependent on study design. As a result, more research is required to determine the most effective method for this study.

Nevertheless, this report provided a good baseline for future studies and displayed where knowledge gaps lie, highlighting significant limitations that should be avoided (if possible) if this study is repeated in the future.

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Appendix A: Results

A1: The results of the initial camera trap set-up from the 15th of October to the 15th of January 2023.

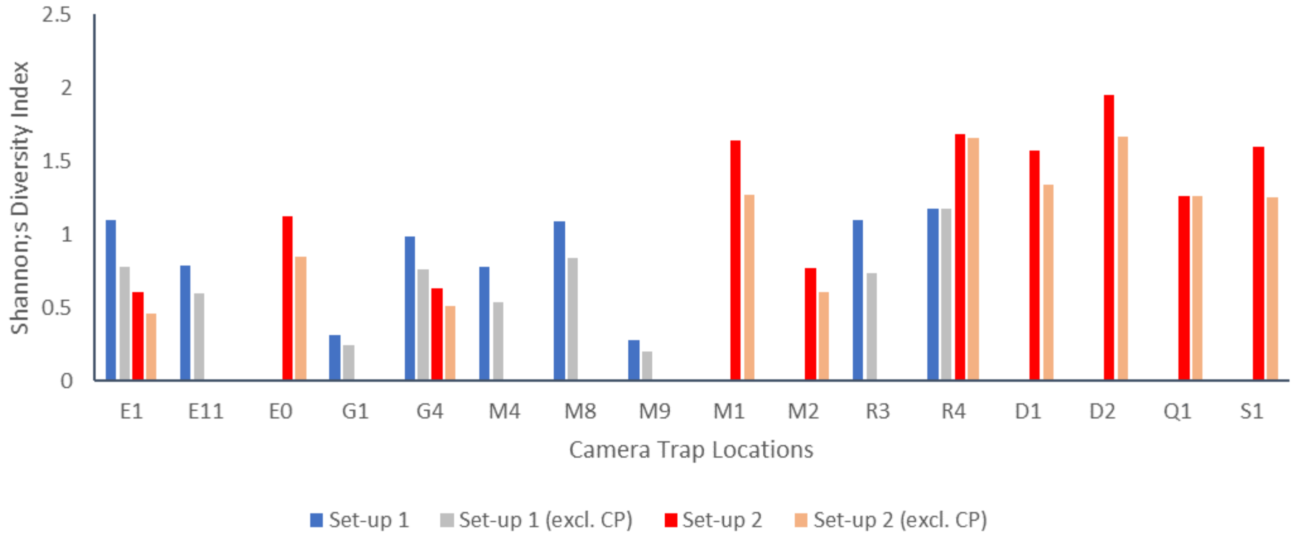
		Location									
Common Name	Scientific Name	**E11**	**E1**	**G1**	**G4**	**M4**	**M8**	**M9**	**R3**	**R4**	Total Per Species
Collared Peccary	*Pecari tajacu*	1	109	50	217	45	6	5	36	0	469
Gray Four Eyed Opossum	*Philander opossum*	0	0	0	0	0	0	0	0	12	12
Dice's Cottontail	*Sylvilagus brasiliensis*	3	7	2	7	12	0	0	1	0	32
Kinkajou	*Potos flavus*	0	0	0	2	0	0	0	0	0	2
Long-tailed Weasel	*Mustela frenata*	0	1	0	0	0	0	0	1	1	3
Northern Tamandua	*Tamandua mexicana*	0	0	0	0	0	0	0	0	4	4
Ocelot	*Leopardus pardalis*	0	1	0	1	0	0	1	1	0	4
Paca	*Cuniculus paca*	0	0	0	11	0	2	0	0	0	13
Puma	*Puma concolor*	0	0	0	5	0	1	0	0	0	6
Red-tailed Squirrel	*Sciurus granatensis*	0	9	2	16	0	30	222	5	4	288
Striped Hog-nosed Skunk	*Conepatus semistriatus*	0	0	0	1	0	0	0	0	0	1
Tayra	*Eira barbara*	0	5	0	0	0	0	2	1	0	8
White-nosed Coati	*Nasua narica*	9	61	0	34	6	10	5	39	26	190
Total Per Camera Trap		13	193	54	294	63	49	235	84	47	1032
Camera Trap Nights		52	73	63	92	65	69	92	92	35	633

A2: The results of the second camera trap set-up from the 19th of January to the 19th of April 2023.

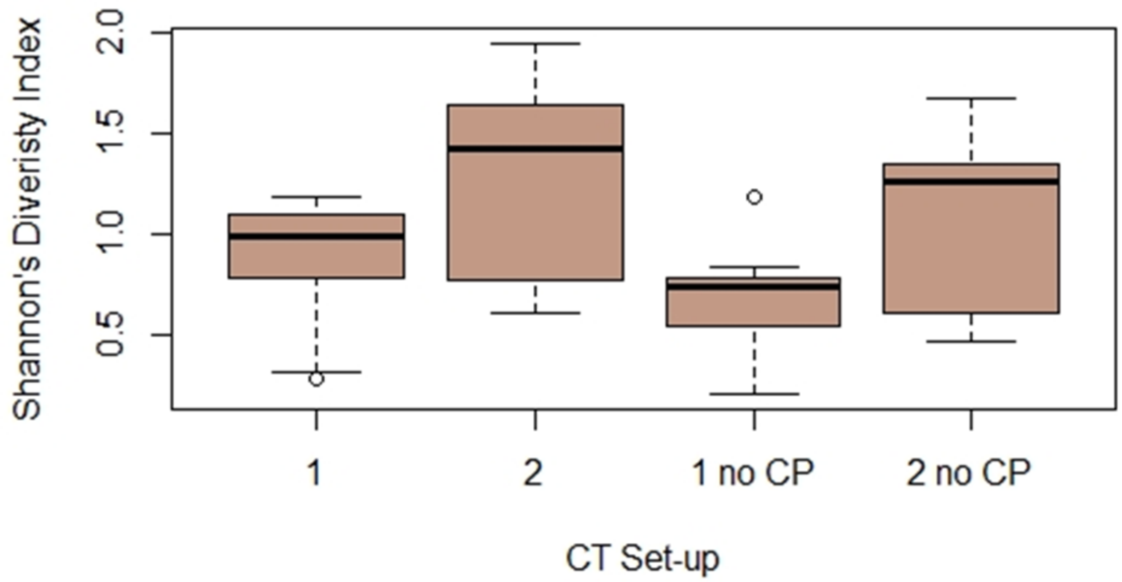
Common Name	Scientific Name	D1	D2	E0	E1	G4	M1	M2	Q1	R4	S1	Total Per Species
Central American Agouti	*Dasyprocta punctata*	0	0	0	0	3	0	0	0	0	0	3
Alston's Mouse Opossum	*Marmosa alstoni*	1	0	0	0	0	0	0	0	0	0	1
Collared Peccary	*Pecari tajacu*	15	11	89	429	257	9	95	0	1	32	938
Gray Four Eyed Opossum	*Philander opossum*	0	0	0	0	0	0	0	0	40	0	40
Common Opossum	*Didelphis marsupialis*	0	2	1	1	0	0	0	0	7	2	13
Coyote	*Canis latrans*	0	0	0	0	0	6	4	0	0	1	11
Dice's Cottontail	*Sylvilagus brasiliensis*	44	20	1	10	2	2	2	91	0	0	172
Jaguarundi	*Herpailurus yagouaroundi*	0	1	2	0	0	0	0	0	0	0	3
Kinkajou	*Potos flavus*	0	0	0	0	0	0	0	0	3	0	3
Long-tailed Weasel	*Mustela frenata*	0	0	0	0	0	0	0	0	8	1	9
Mexican Hairy Dwarf Porcupine	*Coendou mexicanus*	0	0	0	0	0	0	0	0	6	1	7
Northern Tamandua	*Tamandua mexicana*	0	0	0	0	0	0	0	0	4	0	4
Ocelot	*Leopardus pardalis*	0	0	2	0	0	2	1	2	0	0	7
Oncilla	*Leopardus tigrinus*	3	7	0	0	0	0	0	4	0	0	14
Paca	*Cuniculus paca*	61	4	8	0	2	0	0	8	5	2	90
Pocket Gopher	*Orthogeomys sp.*	0	0	0	0	0	0	0	0	0	2	2
Puma	*Puma concolor*	2	2	0	0	9	4	7	3	0	3	30
Red-tailed Squirrel	*Sciurus granatensis*	16	18	24	19	8	3	0	7	74	3	172
Striped Hog-nosed skunk	*Conepatus semistriatus*	0	0	0	0	2	0	0	3	0	0	5
Tayra	*Eira barbara*	5	10	1	2	1	0	0	7	2	2	30
White-faced Capuchin	*Cebus imitator*	0	0	0	0	0	0	2	0	0	0	2
White-nosed Coati	*Nasua narica*	4	2	6	50	13	0	5	9	56	16	161
Total Per Camera Trap		151	77	134	511	297	26	116	134	206	65	1717
Camera Trap Nights		83	92	92	92	92	92	71	92	92	92	890

A3: The completed species inventory during this study.

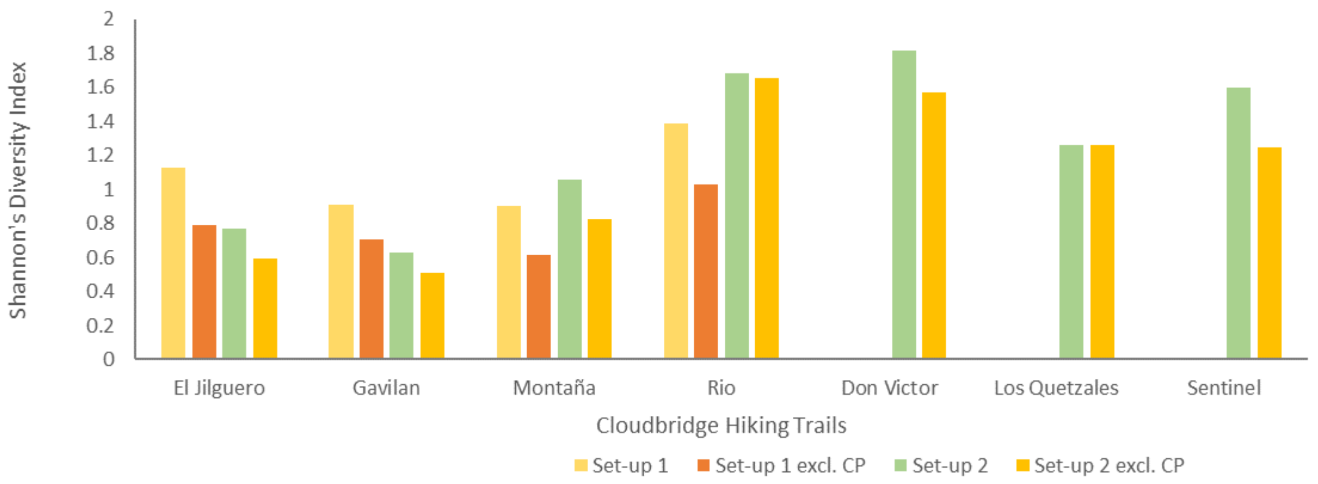
Order	Family	Common Name	Scientific Name
Artiodactyla	Tayassuidae	Collared Peccary	*Pecari tajacu*
Carnivora	Canidae	Coyote	*Canis latrans*
Carnivora	Felidae	Ocelot	*Leopardus pardalis*
Carnivora	Felidae	Oncilla	*Leopardus tigrinus*
Carnivora	Felidae	Puma	*Puma concolor*
Carnivora	Felidae	Jaguarundi	*Herpailurus yagouaroundi*
Carnivora	Mephitidae	Striped Hog-nosed Skunk	*Conepatus semistriatus*
Carnivora	Mustelidae	Tayra	*Eira barbara*
Carnivora	Mustelidae	Long-tailed Weasel	*Mustela frenata*
Carnivora	Procyonidae	White-nosed Coati	*Nasua narica*
Carnivora	Procyonidae	Kinkajou	*Potos flavus*
Didelphimorphia	Didelphidae	Common Opossum	*Didelphis marsupialis*
Didelphimorphia	Didelphidae	Gray Four-eyed Opossum	*Philander opossum*
Didelphimorphia	Didelphidae	Alston's Mouse Opossum	*Marmosa alstoni*
Lagomorpha	Leporidae	Dice's Cottontail	*Sylvilagus dicei*
Pilosa	Myrmecophagidae	Northern Tamandua	*Tamandua mexicana*
Primates	Cebidae	White-faced Capuchin	*Cebus imitator*
Rodentia	Dasyproctidae	Central American Agouti	*Dasyprocta punctata*
Rodentia	Cuniculidae	Paca	*Cuniculus paca*
Rodentia	Erethizontidae	Mexican Hairy Dwarf Porcupine	*Coendou mexicanus*
Rodentia	Geomyidae	Pocket Gopher	*Orthogeomys sp.*
Rodentia	Sciuridae	Red-tailed Squirrel	*Sciurus granatensis*
Total			***22***



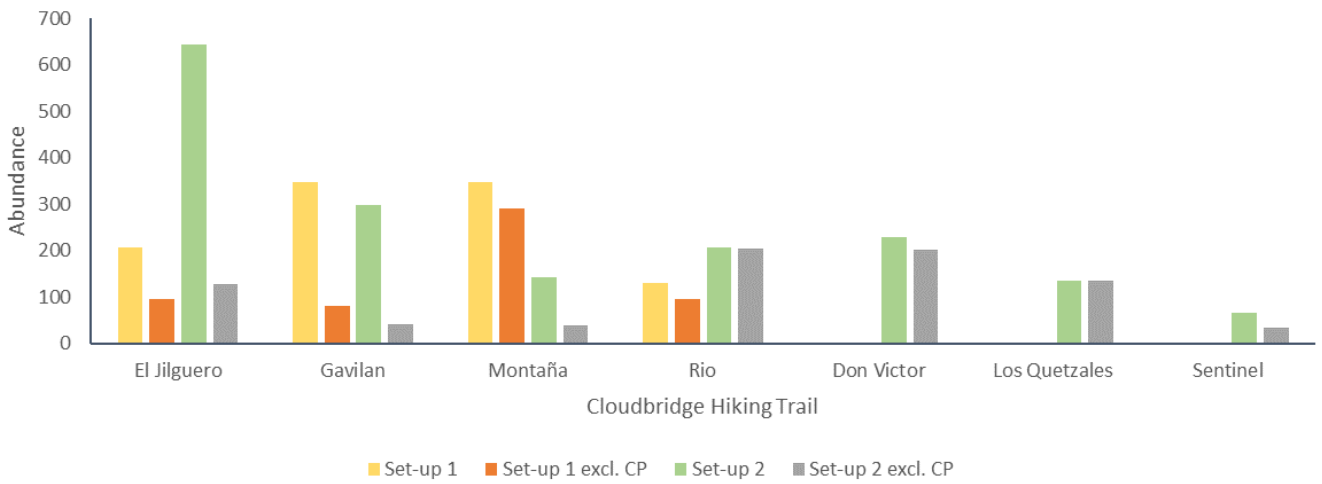
A4: Shannon's Diversity Index across all the different camera trap locations within set-up 1 (Blue) and set-up 2 (Red). Also included data for both set-ups excluding Collared Peccaries (CP).



A5: Comparison of the Shannon's Diversity Index across both the set-ups and both the set-ups excluding data collected on Collared Peccaries.



A6: Comparison of the Shannon's Diversity Index across all the different hiking trails in Cloudbridge Nature Reserve, it also includes the diversities excluding data collected on Collared Peccaries (excl. CP)



A7: Comparison of the abundance across all the different hiking trails in Cloudbridge Nature Reserve, it also includes the abundances excluding data collected on Collared Peccaries (excl. CP)

Appendix B: Discussion

B1: Placement of the D1 camera trap off-trail. The blue arrow indicates a run.

B2: Placement of the D2 camera trap off-trail. The blue arrow indicates a run.