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|  An investigation into the factors that influence mammal abundance and diversity using camera trapping |
| Cloudbridge Nature Reserve Research Internship |
|  |
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# Abstract

Mammal abundance and diversity is a well-studied topic on a broad-scale but there are large knowledge gaps when applied to small-scale cloud forest habitats. In addition, the corridor that the Cloudbridge Nature Reserve provides to a wide range of vulnerable and near-threatened mammals, highlights the need to ensure the habitat preferences and interactions of these species is well documented. Particular attention will be paid towards felidae species which are some of the most vulnerable and controlling over the rest of the mammal population. The aim of this project is to assess the effectiveness of several factors at predicting mammal abundance and diversity. To do this, 10 camera traps were placed around Cloudbridge, ensuring that they provide good coverage and, hence, have differing factors. Every mammal recorded on each camera was recorded to provide the abundance and diversity at each camera. This was categorised by species and by month of recording. 9 factors were also measured at each camera. This included: elevation (metres above sea-level), gradient (%), canopy cover (%), canopy layers, forest type, deadwood cover, distance to nearest water source, food density, and human presence. Every factor was assessed based on their correlation with each other and with abundance and diversity before being added into generalised linear models (GLMs). In addition, the abundance of every mammal was also added into a GLM against felidae abundance. The factors found to be the best predictors of both mammal abundance and diversity are canopy cover, deadwood cover, human presence, gradient, and food density. Elevation and distance to nearest water source have no apparent correlation. The number of observations increased significantly from April to May. Collared peccaries represent over half of all observations from 19 different mammal species. 4 out of the 19 species are felidae with dice’s cottontail, pacas, white-nosed coatis, and collared peccaries being the favoured prey. Conservation techniques should aim to maintain and improve habitats by prioritising the best predictor-factors as indicated in this study when trying to improve the conditions for the majority of mammal species at Cloudbridge. This means maintaining high canopy cover, not removing deadwood, limiting human presence on trails at night, maintaining smooth and shallow gradients on trails, and maximising food density for a range of food sources but particularly fruit and herpetofauna. More studies need to be conducted with a focus on one environmental factor or one species of mammal in order to draw more precise recommendations and conclusions but data should be collected on a larger temporal and spatial scale as this would account for higher differentials in environmental factors such as elevation as well as long-term effects of climate change.

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# Introduction

## Background

The abundance and diversity (or species richness) of any given community is fundamental to understanding the ecological processes and the link between biodiversity and anthropogenic pressures (Gonzáles-Maya et al., 2015)\*. Defining the importance of any given species’ population size and distribution is fundamental to defining the vulnerability of that species to ecological changes (Potts et al., 2020). Krebs (1985) discusses the general consensus among ecologists being that population changes occur as a result of environmental changes including habitat structure, resource availability, predation, and competition, and which have an impact upon species performance in terms of growth, reproduction, survival, and migration. Diversity itself is often associated with rainfall, resource diversity, and competition (Heaney, 2008), while the factors that contribute to abundance is even more complex (Krebs, 1985). While there are many studies that examine the relationships between mammal abundance and diversity with different environmental factors, there are many contrasting conclusions being drawn.

To discover which ecological mechanisms are involved in determining mammal population dynamics, the different environmental factors both biotic and abiotic that infringe upon any given population need to be examined and compared extensively (Batzli, 2001). There are many biotic and abiotic factors which can influence mammal abundance, diversity, and behaviours, with McCain (2003) proving a link between elevation and climatic conditions on small mammal diversity patterns, with higher concentrations being observed at mid-range elevation of 1000-1300 m. McCain’s (2005) later study presented additional data that stated higher diversity was seen at high elevation but only on a regional scale. There is still a lack of data interpretation on local elevation diversity comparisons pertaining to cloud forests and larger mammals. The factors that influence mammal distributions and their associated habitat preference include temperature, moisture, elevation, light intensity, water and food availability, and nutrient levels, biotic factors refers more to the intra- and inter-species interactions (e.g. predator-prey behaviours) and competition (Potts et al., 2020). It is the balance between habitat preference (particularly resource availability) and the threat of predators and competition that defines population dynamics (Batzli, 2001).

Forest structure is also one of the most important factors in determining community structure and providing microhabitats that support a range of mammals (Tews et al., 2004; cited in Pardini et al., 2005). One example of a microhabitat that can have a significant influence on mammal abundance on a small-scale is tree-fall gaps which have been proven to accelerate growth in understory fruits by extending the growing season (Levey, 2009). These gaps in canopy can encourage more frugivores such as the white-nosed coati which would capitalise on higher fruit density, especially when in a patchy distribution typical of tree-fall gaps (Gompper, 1996). Canopy cover is an important environmental factor as it provides shelter, resources, breeding and nesting opportunities, and helps prey and predators remain hidden (Spencer et al., 2005). Tree-fall gaps also provide deadwood which are home to many other food sources such as saproxylic beetles that rely on deadwood to survive (Lassauce et al., 2011). The number and size of deadwood logs have been proven to be associated with higher mammal abundance in some studies due to the associations with increased insect biomass and fruiting trees (Lambert et al., 2006). Forest structure needs to be accounted for when determining the links between environmental factors and mammal populations with canopy cover, canopy layers, and deadwood cover being the crucial components.

Tree-fall gaps like many other features in cloud forests represent one form of micro-habitat that could also be described as a keystone habitat; hence, it is important to note the quantity of deadwood and canopy cover at any given site in relation to food density and mammal presence (Levey, 2009). It is vital that different micro-habitats are assessed based on their function in the wider ecosystem as well as their ability to support a range of species, including mammals. Sinclair (2003) highlighted how resource availability is the most significant regulator of mammal populations. This means that for felidae predators such as pumas, the abundance and diversity of prey available is crucial to determining their population dynamics particularly when considering the migration patterns of their dominant prey (Sinclair, 2003).

Human presence must also not be ignored when it comes to monitoring mammal abundance, especially when using limited camera trap monitoring as you are relying on a small snapshot of the study site (Ouboter et al., 2021). This becomes apparent in areas with lots of tourists choosing to hike amongst nature, with a proven link between increased hikers and decreased mammals detected on camera traps (Ouboter et al., 2021). Mammals are known to either leave areas with dense human activity or adopt more nocturnal and arboreal behaviours (Griffiths & Schaik, 1993). An apparent example of this is felidae such as pumas which have been forced into more marginalised habitat due to urban expansion (Peter & Nowell, 1996). Not all reports indicate a clear link between human density and mammal deterrence (Porras et al., 2016). Suggesting that that different species exude different responses to human presence and this will depend heavily on the exact densities observed in any given habitat (Porras et al., 2016).

Seasonal changes can also have an adverse effect upon mammals mainly due to seasonal breeding but also adverse weather changes can alter resource availability and competition (Batzli, 2001). Kaufman et al. (1995) observed significant variation in mammal abundance across several years of monitoring and between several sites. However, many habitats and mammals can exude a slow response to seasonal impacts, meaning that the effects of which are hard to observe in the short term. Assessing how specific individual species as well as broader communities are influenced by environmental factors can tell us how easily they will adapt to changes to those same factors due to natural and anthropogenic pressures in climate change and land use.

The future of mammal populations in Neotropical forests including the cloud forests found in Costa Rica is still mostly uncertain as continuing trends in climate change and land use threaten to diminish already fragmented populations (Daily et al., 2003). Felidae have disproportionally suffered due to habitat fragmentation and declines in prey populations, this is partly due to their habitat ranges being very large and also being extensively hunted by humans due to the perceived threats of safety (Peter & Nowell, 1996).One way to offset this decline is to establish protected reserves where nature can thrive without harmful human practices (Daily et al., 2003). Costa Rica has one of the largest proportions of protected areas in the world (Gonzáles-Maya et al., 2015). Gonzáles-Maya et al. (2015) discovered that approximately 98.5% of all mammals in Costa Rica reside in protected areas; however, this covers a significantly smaller area (approx. 28.2%) than anticipated. This highlights the importance of continuously monitoring these areas to identify any declines as well as maintaining, expanding, and improving habitats for these mammal populations.

Corridors are very effective at increasing the population size and gene flow of mammals in tropical forests but there are still large knowledge gaps in regards to species richness and distribution (Pardini et al., 2005). This project focuses on mammal populations in the Cloudbridge Nature Reserve in the Talamancan mountain range that extends through central Costa Rica and represents an important corridor for many mammals; particularly several species of felidae. Many species and numbers of mammals have been recorded in the reserve over the years but little is known on the current abundance, diversity, and distribution of these species. Cloudbridge and Costa Rican cloud forests by extension are home to many microhabitats (Gradstein et al., 2001). Cloudbridge has several forest types with significant differences in the age and structure of each type (Cloudbridge, 2017). Alongside other variables such as elevation and gradient, it can be inferred that Cloudbridge has a range of habitats that would attract a range of mammals with different habitat and diet preferences.

By using several camera traps in varying locations around the reserve set to monitor mammal presence, the difference in each measureable environmental factor at each camera can be compared to the difference in mammal abundance and diversity observed. This would provide an idea on which factors are more strongly correlated with mammal abundance and diversity of the whole community in Cloudbridge as well as for each individual species recorded. In addition, species found to be present across multiple camera traps can be assumed to have greater habitat ranges and are less vulnerable to environmental changes such as climate change likely to increase in its impact in subsequent decades.

## Aims and Objectives

The aim of this project is to determine felidae and other mammal abundance and diversity in a range of sites around the Cloudbridge Nature Reserve, and to assess which factors have the greatest influence upon this.

The objectives are as follows:

1. To determine which factor(s) are the best predictors of mammal abundance and diversity
2. To assess which species are the most abundant and at which camera trap(s)
3. To assess which camera trap(s) have the highest and lowest mammal abundance and diversity
4. To establish how mammal abundance changes over time
5. To analyse the habitat and prey preference of Felidae species in Cloudbridge

# Methodology

## Experimental Site

The study area is situated in the Cloudbridge Nature Reserve, a heterogeneous cloud forest environment between 1500 – 2600 m above sea level situated in the Talamanca Mountain range in Southern Costa Rica. The reserve has 371 hectares of riparian and high-altitude montane primary forest that is able to support a significant range of flora and fauna. The reserve also lies along the western border of the Chirripó National Park which is part of the largest protected area in Central America. Cloudbridge contains the valleys of the Chirripó Pacifico and Uran Rivers, providing an essential corridor for many species.

10 camera traps were installed across the reserve as shown in *Figure 1.* The exact locations and models of each trap are listed below:

* *E0* (coordinates: N09°28.170 W083°34.721) is next to the Jilguero trail. Model:
* *E1* (coordinates: N09°28.122 W083°34.500) is on the Jilguero trail. Model:
* *G4* (coordinates: N09°28.058 W083°34.261) is on the Gavilan trail. Model:
* *M1* (coordinates: N09°28.281 W083°34.045) is on the Montaña trail. Model:
* *M2* (coordinates: N09°27.980 W083°33.926) is on the Montaña trail. Model:
* *S1* (coordinates: N09°28.292 W083°34.274) is on the Sentinel trail. Model:
* *R4* (coordinates: N09°28.409 W083°34.333) is on the Rio trail. Model:
* *D1* (coordinates: N09°28.690 W083°34.080) is next to the Don Victor trail. Model:
* *D2* (coordinates: N09°28.855 W083°33.996) is next to the Don Victor trail. Model:
* *Q1* (coordinates: N09°28.847 W083°34.004) is on the Los Quetzales trail.

Figure 1: Locations of every camera trap in the Cloudbridge Nature Reserve

Successional habitat types include:

1) Secondary forest (planted forest) – actively planted areas,

2) Secondary forest (young growth forest) – natural regenerated areas under 30 years,

3) Secondary forest (old growth forest) – naturally regenerated areas over 30 years,

4) Primary forest – natural existing forest

## Sampling Strategy

The ten camera traps were set up in locations that were far enough apart to provide good coverage of the entire reserve and to cover a range of different habitats that would be expected to attract different species. The cameras remained in the exact same position throughout and were replaced with different cameras if they stopped functioning correctly. The cameras were set to record mammal presence for the full 15-week duration of the study from April 4th to July 17th. The traps were set to record video footage of anything that triggered their infrared sensor regardless of the time of day.

In order to ensure that the sites have differing factors, stratified sampling was used. This meant that out of the 10 camera traps being monitored, each one must be a considerable distance from each other, to represent every forest type and microhabitat within the Cloudbridge Reserve. This would also ensure that the abiotic and biotic factors are more likely to be significantly different between each camera trap as there is greater diversity in their surrounding environment.

## Sampling Analysis

Each individual camera trap was checked at 1 or 2-week intervals to obtain the data from the SD cards and ensure they are operating correctly throughout the survey period. Every animal recorded by the camera trap was organised into files separated by species and added to the ongoing presence datasheet. Only mammal data would be used for further analysis but it was important to take note of other species that may impact mammal behaviours and distributions. The datasheet takes into account the video number, date, time, species (common and Latin), count, age (adult/juvenile), sex, and direction of travel from the camera (left or right). Due to the difficulty in identifying the sex of many species, this column was left empty and not included in any analysis.

Using the Garmin GPS device (software version 2.3, satellite – GPS and GLONASS), a 50 m transect was marked out for each camera trap which led 25 m up and down the trail from the point of the camera. The transects lied almost entirely along the main trails in the reserve, but some sections had to be off-trail due to the location of the camera traps being off-trail. This included cameras E0, D1, and D2. However, some areas off-trail were deemed too dangerous too search extensively and were instead viewed from a safe distance. This included areas that crossed rivers, over steep and slippery slopes, and in dense vegetation. The transects would be used to carry out measurements for every factor included in the data analysis required to assess the relationship with mammal abundance and diversity. These factors and the methods used to measure them are as follows:

1. Elevation: measured in metres above sea-level at the exact location of each camera trap using the GPS device. Particular care was taken to ensure the device had enough time to calibrate before taking a reading. In some cases the device produced several different values, in which case an average of several readings was taken. This was conducted at the start of the project.
2. Gradient: measured as a percentage. Using the GPS device, the elevation was measured at two points 10 metres either side of each camera trap. The gradient was then calculated using the equation (Elevation1 – Elevation2 / horizontal distance between them) x 100. This was conducted at the start of the project.
3. Canopy cover: measured as the percentage of light reaching the phone camera. Using the CanopyViewer app, the light percentage was measured at 13 different points along the 50 m transect. 1 point was measured at the camera trap itself and then 3 points on both sides of the trail in both directions along each transect. This was conducted at the start of the project.
4. Forest layers: measured as the maximum number of forest layers observed within the 50 m transect. These layers include all levels from the emergent layer down to the understory layer. This was conducted at the start of the project.
5. Forest type: used Cloudbridge records to determine the forest type at each camera trap. The forests were categorised into four types: planted, young growth, old growth, and primary forests. It is possible that parts of the transects encompass more than one type. This was conducted at the start of the project.
6. Deadwood cover: measured as the number of deadwood logs/trees > 20 cm in diameter observed along the 50 m transect. The deadwood was categorised into 3 types based on the length: < 1 m, 1-3 m, and > 3 m. When tallying the deadwood count, each type was given a different weighting of 0.5, 1, and 2; respectively. This gave more value to large fallen trees which provide more benefit than small logs. This was conducted at the start of the project.
7. Distance to nearest water source: measured as the distance in metres from each camera trap to the nearest point of the nearest water source using the GPS device. Only river sources were accounted for as no other sources were mapped or observed close to the cameras. This was conducted at the start of the project.
8. Food density: measured as the number of fauna sightings and calls counted by walking along each 50 m transect. Fauna was categorised into invertebrates, herpetofauna, fruits, and mammals. This transect survey was carried out 6 times in 1 or 2 week intervals for each camera trap from May 1st to July 17th.
9. Human presence: measured as the number of people spotted on video walking past each camera trap. This includes both tourists and researchers but does not include the same people walking past in the same day nor the person who checks each camera every 1-2 weeks.
10. Time of year: measured as the number of individual mammals spotted on each camera in each month of recording (April-July).

Mammal abundance was determined as the number of individual mammals spotted on the camera. Any mammals that were present across multiple videos on one camera within a very small time frame were considered to be the same individual. It is likely that many of the mammals recorded outside of this time frame are the same individuals but are considered separate for the purpose of this study due to the immense difficulty in distinguishing individuals for many species.

## Data Analysis

### Descriptive

Some descriptive data analysis will be used by sorting the data into tables based on the camera trap and species. This meant that mammal abundance will be categorised based on species, which camera trap the sighting occurred, and during which month. Totals for each as well as standard deviation will be calculated and compared.

Boxplots and bar charts will be used to present datasets and relationships between different factors and measurements.

### Diversity

Shannon’s Diversity Index (ShDI) will be used to calculate the species richness of each camera trap using the species sighting counts from the camera trap records. The proportion (pi) of each individual species in each site multiplied by the natural log of the same proportion is added up to calculate the ShDI or H of the site. Sigma is the sum of all the calculations and s is the number of species recorded.



The ShDI does, however, assume that every species is represented in a sample and that they are all randomly sampled. Due to this, the Simpson Diversity Index (SiDI) will also be calculated.

The SiDI or D of any given site is represented by the table below. pi is the proportion of n number of individuals of one particular species recorded divided by the total number of species found. Sigma is the sum of all the calculations and s is the number of species recorded.



The SiDI gives more weight to dominant and common species on any given site, meaning that rarer species are not considered to affect diversity. The combination of ShDI and SiDI should provide enough indication of which camera traps have higher mammal diversity.

### Statistical analysis

The measurements of each factor will be sorted into a table and imported into R studio for analysis. Each factor will undergo a test for skewness to determine if the presence of outliers is significant. The skew.2Se (skew value divided by 2 standard errors) and kurt.2Se (kurtosis value divided by 2 standard errors) determine how common the level of skew or kurtosis for that factor is. Positive skew values indicate that most of the data lies to the left of the distribution, while negative skew values indicates more to the right. If skewness is <-1 or >1, the distribution is highly skewed. If skewness is between -1 and -0.5 or 0.5 and 1, the distribution is moderately skewed. If skewness is between -0.5 and 0.5, the distribution is approximately symmetric. Kurtosis values between -2 and 2 are considered acceptable to prove a normal and univariate distribution (George & Mallery, 2010).

The Shapiro-Wilk statistical test for normality will calculate whether the dataset for each factor resembles a normal distribution. Similar to skewness, this will provide a insight into the shape and evenness of each distribution. If the p-value of the test is > 0.005, the data is normal. If the p-value is < 0.05, the data is significantly different from a normal distribution.

It will then be necessary to assess the relationship between each factor and mammal abundance and diversity. This will require a correlation test. Pearson’s correlation test measures the linear relationship between two variables but can only be used when these variables have normal distribution. For factors that are non-normal, a non-parametric Spearman rho correlation test will be used. The Pearson’s product-moment correlation coefficient (R) from the tests will indicate the strength of correlation, the higher the value the stronger the relationship. For ordered factors such as forest type and forest layers, polyserial tests were used instead.

Finally, to define the best predictor factor, all the factors will be entered into a generalised linear model (GLM). The Variance Inflation Factors (vifs) produced by the model will indicate how effective each factor is at predicting mammal abundance and diversity. After the model is run, the factor with the highest vif will be removed sequentially until all vifs remain below 3. Vifs below 3 signify that the factor is somewhat effective as a predictor. The factors can then be ranked and compared by their final vifs.

 It will then be important to create another GLM but instead assess which mammal species are best at predicting felidae presence. This will indicate which species the felidae are most likely to hunt as being a good predictor means they are more commonly found at the same camera trap which suggests a correlation with the felidae diet preference as well as habitat suitability similarities between different species. The process will be the same but with the mammal abundance dataset separated by species instead.

# Results

## Factor analysis

All factors were successfully measured during field surveys, a full summary of the data is presented in Table 1 and 2. It is clear that most elevations are grouped around mid-elevation from 1650-1850 m above sea level. The elevation (2098) M2 is particularly higher than the other cameras, which explains why it is the only outlier in the entire factor dataset (as shown in Figure 2). It will still be included in further analysis as each factor requires all 10 measurements in order for the GLM to function. Unexpectedly, lower elevations typically have higher gradients but this is indicative of the specific area around the camera and not the elevation level on a broad scale. It can also be inferred that higher elevations also produce more deadwood cover. Gradient has larger range than expected from 11.9 % at Q1 to 67.1 % at E0. Only a positive moderate correlation is observed between gradient with deadwood and food density, other correlations are not significant enough to state.

Canopy cover has a much smaller range than anticipated, ranging from 65.58 % at D2 to 85.35 % at S1. In addition, more canopy cover produced more canopy layers and is higher in older forests. This may indicate inaccuracies in only measuring more than just the canopy layer when determining canopy cover. However, canopy cover does have a positive correlation with deadwood cover, indicating that they represent healthy forests where both factors are higher. Canopy layers have only 4 different values with a very small range between 6 and 3. There is a small positive correlation observed between canopy layers and food density implying causation that more shade reduces food availability for some sources. The camera traps are spread relatively evenly between the four forest types but there are no significant correlations observed with other factors.

Table 1 – Summary of the results of the factor measurements for each camera trap

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Camera trap | Elevation (m) | Gradient (%) | Canopy cover (%) | Canopy layers | Forest type |
| E0 | 1524 | 67.1 | 82.58 | 5 | Planted forest |
| E1 | 1788 | 47 | 77.77 | 3 | Old growth forest |
| G4 | 1826 | 23.3 | 78.46 | 6 | Primary forest |
| M1 | 1913 | 44.7 | 70.74 | 3 | Planted forest |
| M2 | 2098 | 32.9 | 81.94 | 5 | Old growth forest |
| S1 | 1675 | 53.9 | 85.35 | 6 | Young growth forest |
| R4 | 1577 | 54.2 | 80.85 | 5 | Primary forest |
| D1 | 1740 | 15.28 | 81.54 | 4 | Young growth forest |
| D2 | 1701 | 52 | 65.58 | 3 | Primary forest |
| Q1 | 1832 | 11.9 | 74.61 | 4 | Young growth forest |



Figure 2: Boxplot to present elevation distribution for all camera traps

Deadwood cover has a moderate range from 18 at M2 to 1 at D1. There is a low-moderate positive correlation between deadwood cover and food density. Distance to water has a large range from 1 m at R4 to 380 m at M2. Despite this, there are few correlations with other factors aside from a small positive relationship with food density and a strong positive relationship with human presence. Cameras with no humans tend to be closer to water due to the structure of the trails in the reserve.

Table 2: Summary of the results of the factor measurements for each camera trap

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Camera trap | Deadwood cover | D to water (m) | Food density | Human presence |
| E0 | 16.5 | 14 | 60 | 0 |
| E1 | 8 | 178 | 51 | 137 |
| G4 | 17.5 | 185 | 61 | 91 |
| M1 | 4 | 255 | 72 | 372 |
| M2 | 18 | 380 | 38 | 426 |
| S1 | 7.5 | 113 | 59 | 70 |
| R4 | 4 | 1 | 64 | 0 |
| D1 | 1 | 25 | 31 | 0 |
| D2 | 2 | 17 | 23 | 0 |
| Q1 | 4.5 | 71 | 22 | 287 |

Table 3 indicates the individual distribution of all 10 measurements for each factor including mammal diversity. The kurtosis for each variable resembles a univariate distribution except for abundance and human presence which have respective Kurt.2Se values (-3.92 and -5.16) that lie outside the 2 to -2 range. This assumes that each factor has a normal distribution, from which abundance and human presence do not; as shown in Table 4 by their respective p-values (0.03 and 0.023) being below 0.05. This Shapiro-Wilk test for normality shows that the abundance and human presence data differs significantly from a normal distribution. These factors are still included in further analysis due to the respective importance and strength of correlation with other factors observed. Every factor also has a high W-statistic, which implies that each factor’s quantile closely fits the standard normal quantiles, with a value of 1 being a perfect match. Forest type and canopy layer are not included due to the binary nature of the data.

Diversity (-0.287), elevation (0.275), gradient (-0.194), deadwood (0.35), food density (-0.204), and human presence (0.476) all have Skew.2SE values that signify negligible skew in the data distribution. Abundance (0.585), canopy cover (-0.54), and distance to water (0.518) have Skew.2SE values that signify low-moderate skew when rounded to 3 decimal places.

Table 3: Summary of a statistic description test for all factors including mammal diversity and abundance. Skew.2SE and Kurt.2SE signify the respective skewness and kurtosis divided by 2 standard errors

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Factor | Diversity | Abundance | Elevation | Gradient | Cover | Deadwood | Water | Food | Human |
| Mean | 0.550 | 250 | 1770 | 40.2 | 77.9 | 8.3 | 124 | 48.1 | 139 |
| Standard deviation | 0.230 | 273 | 1660 | 18.5 | 6.05 | 6.59 | 125 | 18.2 | 164 |
| Skew | -0.395 | 0.804 | 0.378 | -0.266 | -0.747 | 0.485 | 0.712 | -0.281 | 0.654 |
| Skew.2SE | -0.287 | 0.585 | 0.275 | -0.194 | -0.544 | 0.353 | 0.518 | -0.204 | 0.476 |
| Kurtosis | -1.69 | -1.05 | -0.711 | -1.51 | -0.757 | -1.63 | -0.862 | -1.70 | -1.38 |
| Kurt.2SE | -0.635 | -3.92 | -0.266 | -0.568 | -0.284 | -0.611 | -0.323 | -0.638 | -5.16 |

Table 4: Results for the Shapiro-Wilk statistical test of normality.

|  |  |
| --- | --- |
| Shapiro test for normality |  |
| Factor | W | p-value |
| Diversity | 0.87 | 0.09 |
| Abundance | 0.83 | 0.03 |
| Elevation | 0.97 | 0.91 |
| Gradient | 0.93 | 0.45 |
| Cover | 0.91 | 0.31 |
| Layer | 0.88 | 0.12 |
| Forest | 0.88 | 0.12 |
| Deadwood | 0.84 | 0.05 |
| Water | 0.89 | 0.15 |
| Food | 0.9 | 0.21 |
| Human | 0.82 | 0.023 |

A Pearson’s correlation test for each factor against mammal diversity is shown in Table 5. Non-parametric tests are presented for forest type and canopy layers due to the binary nature of the datasets. Abundance (R =-0.59), Deadwood (R = -0.71), and Water (R = -0.69) are the only factors with a significant relationship with diversity. Gradient has the weakest relationship (R = 0.003). The same correlation tests are presented in Table 6 but against mammal abundance instead. Only diversity (R = -0.59) has a significant relationship with abundance.

Table 5: Results for the Pearson’s correlation statistical test to assess the relationship of each factor with mammal diversity. R and R2 are regression coefficients used to signify the strength of relationship

|  |  |  |
| --- | --- | --- |
| Diversity correlation test |  |  |
| Factor | R | R2 | p-value |
| Abundance | **-0.59** | **0.344** | **0.075** |
| Elevation | -0.45 | 0.206 | 0.18 |
| Gradient | 0.05 | 0.003 | 0.88 |
| Cover | -0.42 | 0.178 | 0.22 |
| Deadwood cover | **-0.71** | **0.500** | **0.022** |
| Distance to water | **-0.69** | **0.478** | **0.027** |
| Food density | -0.34 | 0.118 | 0.33 |
| Human presence | -0.29 | 0.082 | 0.42 |
| Forest type | <0.001 | <0.001 | - |
| Canopy layer | <0.001 | <0.001 | - |

|  |  |  |
| --- | --- | --- |
| Abundance correlation test |  |  |
| Factor | R | R2 | p-value |
| Diversity | **-0.59** | 0.344 | 0.075 |
| Elevation | -0.15 | 0.023 | 0.67 |
| Gradient | 0.04 | 0.001 | 0.92 |
| Cover | 0.19 | 0.035 | 0.6 |
| Deadwood cover | 0.29 | 0.082 | 0.42 |
| Distance to water | 0.00 | 0.000 | 0.99 |
| Food density | 0.32 | 0.104 | 0.36 |
| Human presence | -0.23 | 0.053 | 0.52 |
| Forest type | <0.001 | <0.001 | - |
| Canopy layer | <0.001 | <0.001 | - |

The diversity GLM as shown in Table 6 indicates that distance to water and elevation have little to no effectiveness as mammal diversity predictors. In contrast, all other listed factors have vifs < 2 which highlights a strong effectiveness as predictors with Abundance having the lowest vif of 1.45. For the abundance GLM as shown in Table 7, distance to water and elevation also have negligible effectiveness as mammal abundance predictors. Diversity has a moderate-high effectiveness as a predictor (vif = 2.42), but all other factors are highly effective with human presence being the best predictor (vif = 1.42).

Table 6: The variance inflation factors of the generalised linear model to test each factor as predictors against mammal diversity

|  |  |
| --- | --- |
| Diversity GLM | Vif |
| Abundance | 1.45 |
| Canopy cover | 1.55 |
| Deadwood cover | 1.67 |
| Human presence | 1.72 |
| Gradient | 1.9 |
| Food density | 1.93 |
| Distance to water | 5.58 |
| Elevation | 268.20 |

Table 7: The variance inflation factors of the generalised linear model to test each factor as predictors against mammal abundance

|  |  |
| --- | --- |
| Abundance GLM | Vif |
| Human presence | 1.42 |
| Deadwood cover | 1.48 |
| Canopy cover | 1.51 |
| Food density | 1.64 |
| Gradient | 1.69 |
| Diversity | 2.42 |
| Distance to water | 14.7 |
| Elevation | 285.6 |

## Diversity

Table 8 and Figure 3 present the results of both diversity indices for each camera trap as well as the total number of mammal species recorded. Cloudbridge diversity data represents the average of all camera traps. The higher the value of H, the higher the diversity at that camera. This means that Q1 (H = 1.76) has the highest diversity and M2 (H = 0.5) the lowest. Higher number of species does not mean higher diversity as the evenness in abundance of each individual species is taken into account. Conversely, the higher the value of D, the lower the diversity at that camera. Hence, G4 (D = 0.22) has the highest diversity, while D2 (D = 0.82) has the lowest. Simpson’s diversity is more important for interpretation due to the non-random nature of data collection for this project.

Table 8: The results of the Shannon-Weiner and Simpson’s Species Diversity Index. The H and D values are presented as the result of each respective diversity equation alongside the number of mammal species recorded at each camera trap

|  |  |  |  |
| --- | --- | --- | --- |
| **Camera trap** | **Shannon's (H)** | **Simpson's (D)** | **Number of species** |
| **E0** | 1.38 | 0.67 | 9 |
| **E1** | 0.62 | 0.27 | 12 |
| **G4** | 0.54 | 0.22 | 9 |
| **M1** | 1.24 | 0.67 | 5 |
| **M2** | 0.5 | 0.24 | 5 |
| **S1** | 0.86 | 0.49 | 4 |
| **R4** | 1.44 | 0.62 | 15 |
| **D1** | 1.54 | 0.74 | 8 |
| **D2** | 1.6 | 0.82 | 6 |
| **Q1** | 1.76 | 0.77 | 10 |
| **Cloudbridge** | 1.49 | 0.63 | 19 |

Figure 3: Bar chart to present data shown in Table 8. Results from the Shannon-Weiner diversity equation are indicated in blue and Simpson’s diversity equation in orange

## Species analysis

Table 9 outlines the abundance of each mammal species. The abundance is based solely on the number of animal sightings on all camera traps. If the same species is sighted within the same hour, they are considered the same individuals. Evidently, collared peccaries take up a vast proportion of the total mammals counted (58%). Collared peccaries, small rodents, red-tailed squirrels, white-nosed coatis, and Dice’s cottontail take up 92% of all mammals recorded across the 15 weeks of data collection. This is important for analysis as trends will be dominated by the preferences and behaviours of mainly these species. Table 10 and Figure 4 present the total abundance recorded at each camera trap. A total of 2495 suspected individuals (or mammal sightings) have been recorded. E1, G4, and R4 are the most abundant camera traps with 783, 603, and 466 mammal sightings; respectively. This is a significant difference to M1 and D2 with only 16 sightings each. The South-West area of the reserve encompassing Jilguero and Gavilan trails (E0, E1, G4; see Figure 1) has a considerably higher abundance than the north area which includes Don Victor and Los Quetzales trails (D1, D2, Q1). The Montaña trail (M1 and M2) also sees comparatively less sightings (16 and 84; respectively).

Table 9: Summary of mammal abundance data as categorised by each species, alongside the percentage of each species as part of the total mammal abundance

|  |  |  |
| --- | --- | --- |
| **Species** | **Abundance** | **Percentage** |
| Collared Peccary | 1457 | 58.40 |
| Small rodent (unidentified) | 306 | 12.26 |
| Red-tailed squirrel | 217 | 8.70 |
| White-nosed coati | 209 | 8.38 |
| Dice's cottontail | 116 | 4.65 |
| Paca | 49 | 1.96 |
| Common opossum | 42 | 1.68 |
| Puma | 27 | 1.08 |
| Tayra | 24 | 0.96 |
| Long-tailed weasel | 8 | 0.32 |
| Coyote | 7 | 0.28 |
| Oncilla | 6 | 0.24 |
| Kinkajou | 6 | 0.24 |
| Agouti | 5 | 0.20 |
| Common grey four-eyed opossum | 5 | 0.20 |
| Mexican hairy-dwarf porcupine | 4 | 0.16 |
| Ocelot | 3 | 0.12 |
| Northern tamandua | 3 | 0.12 |
| Jaguar | 1 | 0.04 |
| **Total** | **2495** | **100** |

Table 10: The total number of mammal sightings recorded at each camera trap

|  |  |
| --- | --- |
| Camera trap | Number of mammals |
| E0 | 235 |
| E1 | 783 |
| G4 | 603 |
| M1 | 16 |
| M2 | 84 |
| S1 | 49 |
| R4 | 466 |
| D1 | 84 |
| D2 | 16 |
| Q1 | 159 |
| Total | 2495 |

Figure 4: Bar chart presenting the number of mammal sightings at each camera trap

Table 11 highlights the effectiveness of the abundance of each mammal species (only species with more than 10 abundance are included as any less is too insignificant to draw conclusions) at predicting felidae species abundance. The felidae abundance includes pumas, oncillas, ocelots, and a jaguar. The common opossum and small rodent have negligible effectiveness, while red-tailed squirrels and tayras have very small effectiveness with vifs barely exceeding 6. However, the Dice’s cottontail, paca, white-nosed coati, and collared peccary are all very effective predictors of felidae abundance. This applies to the total abundance of each species from all camera trap records, hence, applies to Cloudbridge as a whole.

Table 11: Variance inflation factors of different mammal species abundance against Felidae species abundance from a generalised linear model

|  |  |
| --- | --- |
| Felidae GLM | Vif |
| Cottontail | 1.15 |
| Paca | 1.17 |
| Coati | 1.91 |
| Peccary | 1.93 |
| Tayra | 6.91 |
| Squirrel | 6.91 |
| Rodent | 70.9 |
| Opossum | 221.5 |

# Discussion

## Factor analysis

### Elevation

Elevation is a factor assumed to be very important to mammal population dynamics; however, it is the least effective predictor of both abundance and diversity as shown in the GLMs. Factors require a vif-value below 3 to be labelled ‘good predictors’, but the elevation vifs are well over 200. This may highlight several inaccuracies in the field methods for this project as well as the small scale of the experimental site. The GPS device used to measure elevation was proven to be temperamental due to the dense canopy cover overhead, the signal was largely inconsistent even though an average of several readings was used for each camera trap. Another issue lies in the limited range of elevations between the camera traps. The highest elevation is at M2 with 2098 m and the lowest at R4 with 1524 m, giving a relatively small range of 574 m. In addition, half of the camera traps also only lie in the 1700-1900 m range. A limited range means that it is harder for elevation to have an effect on abundance and diversity as many species will operate within a much larger range of elevation (Rowe, 2009). Cloud forests can exist anywhere between 1000-3000 m, hence, a 574 m range lacks the scale to accurately represent the population trends expected (Rehm & Feely, 2015). However, mammal diversity would be expected to clearly change between elevations as the associated changes in climate and food sources governs mammal populations, although this cannot be attributed to elevation alone (Rowe, 2009).

Despite no overall trends being observed regarding elevation, some individual species are still evidently more abundant at specific elevations. For example, larger mammals such as pumas and peccaries are more abundant at higher elevations compared to smaller mammals such as opossums and dice’s cottontails being more common at lower elevations. This supports the general consensus on the impact of elevation-gradients upon different sized-mammals, with smaller mammals favouring elevations between 1000-1300 m in Central-American forests (McCain, 2003). Despite a clear link between elevation and mammal distribution, the lack of any trends observed in this project reinforces the need for cloud forests to be studied in more depth but with larger ranges in elevation. By analysing the habitat preferences of mammals in relation to elevation, the impact of climate change, land use, and urban expansion on forcing populations into higher elevations can be better predicted (Rehm & Feely, 2015; Foster, 2001). Species unable to thrive at lower elevations due to the unfavourable climate are the most vulnerable as the warmer temperatures move upwards (Rehm & Feely, 2015; Foster, 2001). This means the larger mammals such as pumas are in need of the most protection and study going forwards.

### Gradient

Despite having no correlation with both abundance and diversity as shown by the low Pearson’s correlation coefficient values, the GLMs indicate that gradient is a very effective predictor with both vifs below 2. The gradient measurements have a range of 55.2, with Q1 having the shallowest gradient at 11.9% and E0 the steepest at 67.1%. It is hard to spot a pattern between gradient and diversity but generally the diversity is lower at the mid-gradient values e.g. G4 with 23.3% and 0.22 on the diversity index whereas Q1 and E0 have 0.77 and 0.67; respectively. Abundance is higher at mid-gradients with the three highest abundances lying between 23% and 54%. It would be expected that shallower gradients attract higher abundance and diversity as it means the path is easier to traverse and requires less energy when moving around the reserve (Newmark & Rickart, 2012; Dunford et al., 2020). Larger mammals are particularly known to prefer shallow gradients such as the trails around Cloudbridge (Nemark & Rickart, 2012). This is apparent with E1, G4, M2, Q1 having the lowest gradients and higher proportions of large mammals such as pumas, peccaries, and coatis. It is important to note how much the ease of travel influences small-scale migrations for mammals as it highlights the impact of ecotourism from trails on behaviour and community structure. When increased human presence forces mammals into increasingly small areas, it is likely that these areas with have increasingly steeper terrain (Dunford et al., 2020). This may cause large mammals to decline further as energy expenditure increases and effects predator-prey relationships.

Due to the hazardous terrain around the majority of the camera traps, the gradient couldn’t be measured going in directions off-trail, this meant the much shallower gradients along the trails are used instead. This doesn’t truly represent the terrain at each camera and reduces the validity in these results and might explain why there is a lack of a clear pattern in the relationship with abundance and diversity. Future studies should ensure a method of safely measuring gradient going in more directions around each camera, perhaps camera trap placement should put more weight on safe access to ensure a suitable radius around each trap can be investigated rather than restricting to just the trails themselves.

### Canopy cover

Canopy cover is proven to be one of the best predictors of both mammal abundance and diversity. It is the second best predictor of diversity with a vif of 1.55 and the third best for abundance with a vif of 1.51. Both vifs being below 2 indicates that canopy cover has a significant impact on mammal populations in Cloudbridge. Generally, as canopy cover decreases the diversity of mammals increases. D2 has the lowest cover (66%) but the highest diversity (0.82) whereas S1 with 85% cover only has diversity of 0.49. A less clear trend can be seen against abundance where abundance typically increases as the cover increases with the three sites with highest abundance having cover over 77%. This agrees with Lambert et al., (2006) who observed greater abundance under closed canopies. Pardini et al. (2005) suggests a negative correlation between abundance and forest age in plots where understory vegetation is denser and the canopy cover is more open. While decreases in canopy cover has a proven link in reducing small mammal abundance, more tenuous links are drawn with larger mammals and mammal community structures (Spencer et al., 2005). This might explain why the correlation between canopy cover is not always clear despite the general positive trend.

However, the same correlation has not been observed for mammal diversity (Pardini et al, 2005). The general consensus is that decreases in canopy cover should decrease the species richness in turn as open areas often have less food availability and reduce canopy connectivity needed for arboreal species (Cudney-Valanzuela et al., 2022). The same cannot be interpreted from the results of this study. Areas with open canopy had much lower concentrations of large mammals which might explain why higher diversities are seen as the species mix is made up of small mammals. While limitations in the spatial and temporal scales of the study could explain the trend (Cleery et al., 2018), it is more likely that the small range in canopy cover of just 20% with half of the sites having 80-85% cover limits the validity in the tends observed. It is also possible that the understory cover of sites with higher diversity is likely to have a significant effect on small mammal behaviours especially on species that aren’t arboreal as the food diversity is a crucial component of understory foliage (Carey et al., 2001). Carey et al. (2001) noted how open canopies did not decrease the species richness in forest-floor small mammals. Future studies analysing the impact of canopy cover should aim to increase the range and standard deviation.

It is also important to address while environmental factors impact mammal population dynamics, this works both ways (Krebs 1985). Mammals are referred to as ecological landscapers in their ability to modify vegetation succession as well as the broad ecological function of the community (Sinclair, 2003). This means that while canopy cover may influence mammal behaviours in favouring shadier areas, mammals themselves will also alter the botanical structure around them as some plants are favoured more in some diets (Krebs, 1985). Studying mammal relationships with canopy is a big diver of conservation as it highlights the importance of forest restoration and regeneration in cloud forest habitats in enhancing mammal abundance and diversity (Pardini et al., 2005). The abundance of studies that assess mammal population dynamics in forests highlights the need to analyse and measure all the other parameters that make up forest structure, this includes tree height, age, density, diversity, and understory cover. This will paint a better picture of the impact that deforestation would have on a complex ecosystem such as Cloudbridge (Cudney-Valanzuela et al., 2022).

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### Canopy layers

The number of canopy layers measured only ranged from 3 to 6, meaning there are only 4 different values it could take for all ten camera traps. This is one reason to explain the absence of any patterns and correlation with mammal abundance and diversity. The counting process was also flawed as it was hard to determine the maximum number of layers observed from each transect due to some areas being too dark or bright as well as too sparse or dense in foliage to accurately define the layers. While the highest count could be much higher on one transect, this might only be true for a very small proportion of the forest observed and not be representative of that habitat as a whole. An average taken at several points would be more effective. A result of these inaccuracies and the fact that no correlation was observed using the regression tests, canopy layers were left out of the subsequent GLMs. Cameras with the lowest and highest abundance have the same number of canopy layers while diversity also has no trend. Canopy layers are fundamentally linked with canopy cover which is proven to be one of the best mammal predictors in this study. In addition, canopy layers have been proven to have an impact upon mammal species richness in several studies before (Zhang et al., 2020; Viera & Monteiro-Filho, 2003; Wells et al., 2004). More canopy layers generally correlates to a greater height of the highest layer, which in turn supports a greater abundance and diversity of food and mammals (Zhang et al., 2020). However, these studies emphasise that canopy height is the more crucial component rather than the number of canopy layers as well as results coming from much larger spatial scales. The maximum and average canopy height at each camera trap should be focused on instead for future studies.

### Forest type

Similar to canopy layers, forest type showed no correlation with both mammal abundance and diversity, hence, it was also left out of the GLMs. A good example of this is the fact that both E1 and M2 are in old growth forest but have vastly different abundances while the same can be said for G4 and D2 which are both in primary forest but have the lowest and highest diversities; respectively. This is in clear contrast with what would be expected from this type of study as forest type is a factor assumed to be very important to mammal population dynamics (Galetti et al., 2009). This could be due to the fact that camera traps were located along forest type boundaries and the transects from which most factors were measured actually encompassed more than one type. Consequently, the data collected would be influenced by both types at an individual camera trap and not be representative of the type associated with the precise location of the camera. A lot of habitat features indicative of each type is also not as evident along the boundaries as the types merge together compared to if surveys were conducted towards the centre of each forest type. Galetti et al. (2009) emphasises the importance in assessing the impact of different forest types on mammal populations as more fragmentation occurs across many tropical forests. This is particularly apparent for smaller mammals which rely on specific food sources that are distinctive of different forest types (Jensen, 1982). The impact of forest types on mammal population dynamics in Cloudbridge remains largely unknown. Future studies looking at forest type influence must ensure that camera traps are placed a significant distance away from each boundary to provide more representative data.

### Deadwood cover

Deadwood cover is evidently an important factor to consider when analysing mammal population dynamics in Cloudbridge as shown by the GLM results. It is the second best predictor of mammal abundance with a vif of 1.48 and the third best predictor of diversity (vif = 1.67). A strong negative correlation can be seen with diversity, as the two sites with the lowest diversity had the most deadwood. Conversely, a strong positive correlation can be seen with abundance. A key explanation behind this addresses how deadwood provides a habitat to such a diverse and dense mix of invertebrates and herpetofauna which make up a big proportion of many mammal diets in cloud forests, while also being a habitat which many small mammals use themselves for shelter and breeding (Radu, 2006; Morgan, 2005). This applies to both the size and number of deadwood logs which are strongly correlated with insect biomass and fruiting trees (Lambert et al., 2006; Lasauce et al., 2007). Species such as the red-tailed squirrel (amongst all small rodents) and Oncilla will rely on hollowed trees in old growth and primary forests (Radu, 2006; Morgan, 2005). This explains why a higher abundance of mammals is associated with more deadwood but with a stronger correlation with larger mammals than expected. It would be more beneficial to study the impact of deadwood presence higher up on trees on larger mammal abundance, especially felidae species such as oncillas and jaguars (Szymañski et al., 2021).

The inverse relationship between deadwood and diversity is a difficult trend to determine the cause of. Some studies have even stated that deadwood microhabitats can support up to a quarter of all forest biodiversity (Dudley & Vallauri, 2005). Spatial limitations regarding only deadwood seen in close proximity to the survey transects along from each camera trap could provide some solution to this conundrum but it is more likely that in this study area deadwood microhabitats are dominated by larger mammals which scare off smaller mammals from using them for shelter. Szymañski et al. (2021) highlighted how removing deadwood from their study site actually increased taxonomic diversity as deadwood can reduce the presence of some plants that are important food sources for some mammals. However, this relationship is complex and exceeds the scope of this study. The broader impacts of deadwood on ecosystems are extensive, from nutrient cycles to carbon budgets and soil morphology, the need to preserve these microhabitats goes well beyond the benefit to just mammals (Radu, 2006). Heavily managed cloud forests in particular need to take into account the impact that removing deadwood has on many species of fauna and flora, and the overall health of a habitat (Dudley & Vallauri, 2005).

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### Food density

The GLMs indicate that food density does have a large impact on mammal abundance and diversity, as it is the fourth best predictor of mammal abundance with a vif of 1.64. While it may only be the sixth best predictor of diversity, the vif is still below two (1.93) which implies a strong correlation. It is clear that as food density increases, so does abundance but with one anomaly being M1 which has the lowest abundance but highest food density. This anomaly indicates the important in the abundance of particular of different food types, where invertebrates are very common at sites with comparably lower mammal abundance. This is more important for larger mammals which require more sustaining food sources such as smaller mammals and fruits. Fruits and herpetofauna are clearly more favoured food sources for mammals in Cloudbridge because they are much more abundant at sites with more mammals e.g. E1 which has the second highest herpetofauna abundance and highest mammal abundance, and R4 with the highest fruit abundance and third highest mammal abundance.

It is clear that food density is not as significant an influential factor for some larger mammals such as pumas. This can easily be attributed to the types of food taken into account during the food density surveys which emphasised less sustaining foods such as invertebrates which are easier and more likely to spot along each transect than the favoured mammal-prey (Robinson & Redford, 1986). While the density of mammals and fauna in general is heavily influenced by the density of food and the associated energy available from that food (Brock & Harvey, 1978; Robinson & Redford, 1986). This applies much more heavily to smaller mammals but only when predation is taken into account, the balance between low-energy invertebrate density and puma density at M1 and M2 might explain why the food density is much higher than mammal abundance. Prevedello et al. (2013) observed a 1.5-fold increase in small mammals in response to food supplementation at several sites which increased further when predation was reduced and immigration increased. This highlights just how important food density can be but also how other environmental factors such as the ease of travel between habitats determined by gradient and ability to avoid predators due to shadiness from canopy cover can induce these patterns (Prevedello et al., 2013). Future studies should consider food supplementation with camera trapping as a potential effective technique to explore this relationship further.

The opposite trend is seen with mammal diversity where a negative correlation is displayed with food density. This is mainly due to sites with higher food densities having lower food diversity, e.g. M1 has over 75% of food sources from invertebrates. For many mammal species, there is an indirect relationship with food resource availability when other habitat features are considered. In this study this seems more apparent when considering diversity but more analysis would need to be done looking at individual species to draw conclusive results (Wilco, 2011). With the data that could be collected on a longer timescale, it would also be interesting to identify the impact of food density on group size dynamics (particularly for peccaries and coatis which are so abundant at Cloudbridge) as this addresses the impact of predation, vigilance, and social dynamics all in relation to food density (Beachamp, 2009).

### Distance to nearest water source

After elevation, the distance to the nearest water source is the least effective predictor of mammal abundance and diversity. A vif-value of less than 6 for diversity indicates that there is some correlation with diversity albeit less significant than the other remaining factors whereas a vif of almost 15 for abundance indicates negligible correlation. It is evident from the GPS measurements taken that half the camera traps are within 100 m of the nearest water source while the other half sit within 400 m, with only one camera exceeding 300 m. This means that the difference in distance between most cameras is very minimal whereas the abundance and diversity changes significantly. R4 with an abundance of 466 mammals is only 1 m from the river, but D2 that has only 16 recorded mammals is also only 17 m from the river. Another explanation for the unexpected lack of correlation is due to the inaccuracies of the GPS device struggling to get a stable reading. A better explanation would be the lack of water sources displayed on the device’s map where it is entirely possible that there are smaller tributaries and ponds that are closer to the camera traps than the larger rivers displayed on the map. It is also possible that while some traps close to water may have low abundance, this could be due to the turbulent water flow at that section of river being less favourable than sections much further away which may attract much higher numbers to drink safely, especially for smaller mammals which are more commonly found at the lower elevations in Cloudbridge.

Water is widely known as one of the most important factors in determining mammal population dynamics both in terms of habitat preference as well as intra- and inter-species interactions (Potts et al., 2020). Close proximity to water sources generally equates to greater access to a wider range of food sources as water overflow from rivers and runoff from rainfall help fruits and flowers to thrive and attract larger populations of herpetofauna and invertebrates which make up a big proportion of mammalian diets in Cloudbridge (Soto-Shoender et al., 2018). This might explain why mammal diversity is mostly but not entirely higher at camera traps closer to a water source as greater resource availability generally attracts greater diversity for most forms of fauna (Ferrer-Castán et al., 2016; Newmark & Rickart, 2012). A greater range and spread of distances to the nearest water sources as well as an updated map is required for future studies that focus on the impact that this has on mammal populations.

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### Human presence

Human presence is a very influential factor for both mammal abundance and diversity, with it being the best predictor of abundance with a vif of 1.42 and the fourth best for diversity with a vif of 1.72. It is clear that when more humans are present on a trail, the abundance in mammals decreases, generally the diversity also decreases as the human presence increases. It is possible that an even stronger relationship would be observed if the closeness of the cameras to the trail was taken into account. D1 and D2 are especially close to the Don Victor trail but have no humans recorded due to the direction the camera is facing while it is also very likely that the same amount of humans are present on Don Victor as Los Quetzales. This would fit into the trend as a moderate human presence equates to moderate mammal presence. A count of every individual human was used instead of a count of the number of groups, while it is difficult to determine the impact this would have on correlation. Outboter et al. (2021) explores how mammal communities were most effected by hikers on the busiest trails. This clearly applies to M1 and M2 which have the largest difference between the number of hikers and mammals recorded. These two trails are the only trails where hikers are likely to be present regardless of the time of day, meaning that even nocturnal behaviours are not sufficient to avoid humans compared to other trails.

Outboter et al. (2021) managed to identify both a decrease in abundance and diversity in response to more human traffic but some specific species such as pacas and agoutis were more curious of hikers compared to pumas and jaguars. This highlights how much human presence can change the structure of mammal communities as more cautious species (especially apex predators) are forced into increasingly remote areas (Hoskins et al., 2018) whereas the curious species would benefit from more less competition and predation (Suraci et al., 2019). As many if not all recorded mammals are deterred by human presence, those which are more able to adopt arboreal and nocturnal behaviours and activities are more likely to be captured on the camera traps, especially since every camera is on or next to a trail used regularly by tourists and researchers (Griffiths & Schaik, 1993). This provides some explanation as to why peccaries and coatis are seen so regularly even on trails with high human presence. It is also possible that many of the recordings are the same individuals and that peccaries are just more active compared to more elusive species such as oncillas. Human presence evidently has a big impact on mammal population dynamics and management strategies should be considered in some areas to prevent marginalising species less adapted to nocturnal behaviours and those which are more cautious around humans. Future studies should explore the relationship further by placing cameras further away from trails assuming safety risk is accountable.

### Time of year

It is widely known that the dry season in Costa Rica ends in early-May, this implies that the start of the rainy season coincides with a significant increase in mammal abundance with May having roughly doubled the abundance compared to April. This abundance increases further into June before decreasing in July; although records in July ended halfway through the weighted average still shows a notable decrease. This supports how seasonal changes habitat suitability due to changes in weather, resources, competition, and breeding opportunities (Batzli, 2001). The increased rainfall experienced from early-May should allow more fruits and flowers to grow which extends up the trophic levels, and would evidently help frugivores to thrive (Dinterstein, 1986; Batzli, 2001). Dinerstein (1986) observed significant increases in breeding in frugivores in response to increased rainfall and resource availability, mammals especially require more energy in order to breed which coincides with more food intake not possible during most of the dry season. This might explain the significant increases in Cloudbridge’s frugivores such as peccaries in May compared to April. The importance of long-term effects became apparent when the typical rainfall intensity was not experienced during May as expected. It is possible that mammal abundance would have increased even more on a typical year in the past.

It may help to use ongoing camera trap records over several years to assess the seasonal impact on mammal population dynamics on a larger temporal scale. This would also help to identify how long-term climate changes have an effect compared to short-term anomalies. Many studies such as that conducted by Foster in 2001 already observed significant reduction in cloud immersion in the cloud forests of Monteverde, it is likely that Cloudbridge will also experience a similar trend in the coming decades increasing competition density and decreasing habitat suitability in the wider area. Resources such as figs which are less affected by seasonal climate (Kattan & Valanzuela, 2013), will become more and more essential to many frugivores diets in the years to come, making it a keystone resource and a priority amongst other resources to maintain mammal populations.

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## Felidae analysis

5 species of felidae were recorded. In order of descending abundance: puma, oncilla, ocelot, jaguar with pumas taking up over half of total felidae abundance. This means that most associations interpreted from the results mainly apply to pumas. G4, M2, and Q1 have the highest felidae abundance. These sites have elevation above 1800 m, reinforcing the consensus in larger mammals preferring habitats at higher elevations (McCain, 2003) as well as lower gradients as apex predators prioritise paths that take up the least energy to maximise hunting ability (Newmark & Rickart, 2012). The diversity is particularly very low at G4 and M2 which is important to most felidae as many of the mammals at Cloudbridge such as the smaller species more abundance at other sites such as R4 are too small to be prey. The exception being oncillas which are only found at Q1, D1, and D2 where diversity is higher due to an even spread of small mammals. Canopy cover and canopy layers are on the higher end of the range in the felidae abundant sites due to both the arboreal and elusive behaviours required to hunt prey and to also sleep (\_). The most surprising factor is human presence, which is particularly high at these sites which goes against the typical behaviour of felidae in response to higher human presence (Griffiths & Schaik, 1993). This might indicate that other factors such as prey density are too important to be outweighed by the deterrence from humans on this scale. It is likely that in a smaller and more fragmented habitat, human deterrence would be amplified (Peter & Nowell, 1996). Future studies should adopt different monitoring techniques for more detailed analysis on habitat preference for felidae such as GPS collars to keep track of how many individuals there are and their habitat ranges around the reserve (Prevedello et al., 2013).

The GLM which looks at which mammals are the best predictors of felidae abundance indicates that the best predictors are likely to be the favoured prey. Consequently, dice’s cottontail, paca, white-nosed coati, and the collared peccary are all very good predictors and important to felidae diet. This explains why the majority of pumas are found at G4 where there are abundant populations of peccaries and coatis, while oncillas reside where dice’s cottontail is most abundant. It is widely known that peccaries and pacas are a favoured prey for pumas and jaguars as they are large enough to provide enough sustenance, reside in large groups which make them easier to track and single out weaker individuals, often have similar habitat preferences such as elevation level, and they travel large distances in search of food (Sánchez-Pinzón et al., 2020; Foster et al., 2010; Scognamillo et al., 2003). Analysing predator-prey relationships is immensely important to not only understand complex ecological systems at different scales but to also improve conservation strategies and protection laws. This is particularly important for these felidae which are endangered and threatened by increasingly intense human pressures from hunting, agriculture, and general urban expansion that pushes them into increasingly marginalised habitats that restrict their typical habitat ranges, reducing the population further (Foster et al., 2010). Conservation efforts for felidae must support their favoured prey as much as the felidae themselves which means many fundamental changes need to be made to human activities such as hunting which can have detrimental long-lasting effects on these vulnerable and keystone species.

# Conclusion

This study highlights how complex the response of mammal populations to different environmental factors at a local-scale as seen in Cloudbridge. The focus is on a broad topic but in a small and distinct experimental site. While some factors such as forest type and elevation are insignificant predictors of mammal abundance and diversity due to the locations chosen for the camera traps, others such as canopy layers need redefining by taking into consideration understory cover, canopy height, plant diversity and density as well. In contrast, canopy cover, deadwood cover, food density, and human presence are very good predictors of both abundance and diversity. This can be explained by a plethora of reasons which relate to the behaviours and preferences of the mammals present but the differences between individual species is still contested as not enough data is present for many species. Collared peccaries represented over half of all recordings and 11 species with less than 1%. While this may indicate a small study area or disparity in habitat quality and survivability for different species, it is also possible that many of the recordings are the same individuals and that peccaries are just more active compared to more elusive species such as oncillas. The same issues with representation can be applied to the felidae analysis, where 3 out of the 4 felidae recorded have less than 10 observations throughout the entire study. However, despite the apparent lack of data, the conclusions drawn align with many studies of the past in that dice’s cottontail, collared peccaries, white-nosed coatis, and red-tailed squirrels are the favoured prey of pumas, oncillas, ocelots, and jaguars and this relates to habitat preferences such as canopy cover and food density influencing the predator-prey relationships.

Factors observed to be good predictors should be considered when undertaking mammal monitoring surveys and when trying to find hotspots to collect data more easily, while also indicating the key aspects of habitats that must be maintained and improved from a conservation perspective, e.g. not removing deadwood, and limiting human presence on trails. Cloud forests are complex ecological systems in need of continuous study, exacerbated by the increasingly severe impacts of climate change to which they are disproportionately vulnerable to. Cloudbridge is no exception, and with future studies exploring the specific relationships between these factors and mammal populations in more detail and on larger temporal and spatial scales. Management techniques seeking to counter the effects of climate change and other human and natural pressures can be tailored to benefit the majority of the species present going forward as the more important factors are now known.

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# Appendices

## Appendix A – Raw Data

Table 13: The results of food density observation surveys at each camera trap

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Camera trap | Invertebrates | Herpetofauna | Mammals | Rodents | Fruits  | Total  |
| E0 | 23 | 23 | 0 | 0 | 14 | **60** |
| E1 | 13 | 19 | 6 | 0 | 13 | **51** |
| G4 | 46 | 6 | 0 | 0 | 9 | **61** |
| M1 | 54 | 1 | 0 | 0 | 17 | **72** |
| M2 | 35 | 0 | 0 | 0 | 3 | **38** |
| S1 | 48 | 7 | 0 | 0 | 4 | **59** |
| R4 | 22 | 1 | 1 | 2 | 38 | **64** |
| D1 | 25 | 1 | 0 | 0 | 5 | **31** |
| D2 | 23 | 0 | 0 | 0 | 0 | **23** |
| Q1 | 21 | 0 | 0 | 0 | 1 | **22** |

Table 14: the number of humans recorded at each camera trap

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Camera | Early April | Late April  | Early May | Late May | Early June | Late June | Early July | Total |
| E0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| E1 | n/a | 25 | 29 | 9 | 1 | 45 | 28 | **137** |
| G4 | 4 | 22 | 18 | 7 | 1 | 16 | 23 | **91** |
| M1 | 40 | 68 | 88 | 35 | 18 | 45 | 78 | **372** |
| M2 | 38 | 79 | 100 | 39 | 21 | 58 | 91 | **426** |
| S1 | 15 | 10 | 19 | 4 | 5 | 11 | 6 | **70** |
| R4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| D1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| D2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| Q1 | 82 | 67 | 38 | 17 | 23 | 43 | 17 | **287** |
| Total | 179 | 271 | 292 | 111 | 69 | 218 | 243 | **1383** |