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(Cloudbridge Nature Reserve, 2018)

The Influence of Habitat Factors on Species Richness and Abundance of Animals in a Montane Cloud Forest

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The Influence of Habitat Factors on Species Richness and Abundance of Animals in a Montane Cloud Forest

A research report investigating the influence of different habitat factors on animal species richness and abundance of Cloudbridge Nature Reserve using camera traps

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Preface

In the context of my Animal Management studies in the Netherlands, I completed a 5-month internship at Cloudbridge Nature Reserve in Costa Rica. As part of the program, all second year students from the university of applied sciences Van Hall Larenstein go on an orientation internship, which is matched to their choice of Major. As I decided on the Major 'Wildlife Management', Cloudbridge was an ideal place for me. I was working at the reserve as a camera trap intern, running the project of collecting and entering camera trap data. In addition, I was conducting an individual study, which is the content of this report. In my study, I was looking into the influence of different habitat factors on the species richness and abundance of the animals in the reserve.

I would like to thank my internship supervisor, Berend van Wijk, for his help in organizing my internship placement. I would further like to thank my on-site supervisor and scientific coordinator, Jennifer Powell, for her help in assembling my study, helping out with everyday challenges, and for providing any support I needed. I would also like to thank the director of Cloudbridge, Tom Gode, and his wife, Linda Moskalyk, for their hard work and dedication.

Alena Frehner

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Abstract

During the past few years, camera traps have been becoming increasingly popular as a research tool in the wildlife management sector. The influence of the camera trap placement on species richness and abundance of observed animals has come to the attention of many researchers in recent years and is proving to be a complex issue. What is more poorly explored however, is the impact of general habitat factors on species richness and abundance, especially of terrestrial mammals. The aim of this research is therefore, to further explore the influence of different habitat factors on species richness and abundance of mammals with the use of camera traps.

For this purpose, four factors were investigated: forest types (i.e. old growth forest, natural regeneration and planted areas), canopy closure, slope of the area, and tree characteristics (considering arboreal species exclusively). Habitat data was collected in Cloudbridge Nature Reserve in Costa Rica by doing a broad habitat assessment at each of the camera trap locations. The data for species richness and abundance was collected with the use of the trap cameras. For analyses, chi-square tests of goodness-of-fit and correlation tests were applied.

While the numbers of observed species were roughly as expected, the numbers of recorded individuals differed significantly at each location. Contrary to expectations, species abundance was significantly lower in the old growth. The canopy closure as well as the slope differential seemed to have no impact on either species richness or on abundance. Similarly, testing tree characteristics on a relationship with arboreal species richness and abundance delivered no significant results. However, when testing the tree height in relation to arboreal species abundance, distinct trends were seen. This suggests a possible positive correlation between tree height and the abundance of arboreal animals. Finally, the highest species diversity, as well as arboreal species diversity, were both recorded in the old growth forest.

Despite those results, the term ‘habitat’ remains a broad and complex matter. It is difficult to truly examine whether or not one specific habitat factor influences species richness and abundance of animals. However, the finding of some significant results in this research and the trends that were seen underline the importance of taking the habitat complexity into account when conducting studies on species richness and abundance.

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Introduction

During the past few years, camera traps have been becoming increasingly popular as a research tool in the wildlife management sector. When carrying out research concerning factors such as population dynamics, biodiversity or animal behavior, camera traps are hard to avoid (O'Connell et al., 2011; O'Brien et al., 2010). Most commonly, the cameras are placed either randomly or with the use of a grid, spreading the cameras evenly throughout a designated area, mostly in such a way that they either face a trail or other habitat features. One frequent problem that occurs when placing cameras in such a manner is the biased nature of the set-up, putting the reliability of the data into question (Kolowski & Forrester, 2017). This applies mostly to studies on unmarked species, which is much more common in terrestrial mammals, compared to the capture-recapture method. The capture-recapture method delivers a more stable picture of population dynamics, working with individual markings, however, is usually less feasible (Sollmann et al., 2013).

The influence of the camera trap placement on species richness and abundance of observed animals has come to the attention of many researchers in recent years and is proving to be a complex issue. Biological factors such as the home range size of a species is known to have an impact on their capture probability on a camera (Campos-Candela et al., 2017). In addition to that, a number of habitat features were shown to have a similar influence. Certain species have a noticeably larger capture rate when cameras are placed at roads. Carnivores especially tend to be significantly more abundant around roads, implying a strong bias and unreliability for relative abundance measurements at such locations (Mann et al., 2014) (Cusack et al., 2015). In addition to carnivores, terrestrial mammals in general are captured in higher abundances as well as richness on on-road cameras, compared to the off-road counterpart (Di Bitetti et al., 2014). Besides large habitat features like roads, also smaller-scale habitat features, such as game trails or tipped over logs, also influence detection rates. Species abundance as well as richness increase significantly around such features (Kolowski & Forrester, 2017).

More poorly explored is the impact of general habitat factors on species richness and abundance of terrestrial mammals. For other vertebrates such as fish, or invertebrates such as wasps and bees, the habitat and its complexity have formerly proved to have a significant influence on species richness and abundance (Gratwicke & Speight, 2005; Steffan-Dewenter, 2003; Roberts & Ormond, 1987). A study on bats delivered similar results in the past (Estrada et al., 1993) and certain predators have shown habitat selection from different types of forest, discovered through camera trap studies (Kelly & Holub, 2008). The methods of such studies, however, are very inconsistent and it is unclear how they affect the results (Tews et al., 2003).

The aim of this research is, therefore, to further explore the influence of different habitat factors on species richness and abundance of mammals with the use of camera traps. In order to particularize the broad term of 'habitat', the following four factors were investigated: three different successional forest types (i.e. old growth forest, natural regeneration areas, and planted areas), canopy closure, slope of the area, and tree size characteristics (considering arboreal animals exclusively). It was hypothesized that species abundance and richness would be the highest in old growth forest, where habitat might be larger and refuge easier (Brown et al., 2016). In alignment with the first hypothesis, species richness and abundance was expected to yield the highest numbers in areas with high canopy closure. It was further assumed that species richness and abundance is higher in areas where the relative slope of the trail when compared to the surrounding slope is smaller (Reichmann & Aitchison, 1981). Finally, species richness and abundance of arboreal animals was expected to be higher in areas with taller, thicker trees, again providing a more generous habitat for the animals.

1 Materials and methods

1.1 Study site

Data was collected in Cloudbridge Nature Reserve, Perez Zeledon, Costa Rica. The seven cameras used for collecting data on species richness and abundance were spread throughout the reserve of 283 hectares as shown in Figure 1. Purchased as deforested agricultural land in 2002, Cloudbridge's main focus has been on reforestation, combined with efforts in conservation, education, and research. This montane cloud forest is oak-dominated and planting still takes place yearly, where a number of different seedlings of pioneer and climax species from the old growth are planted (CNR, 2018).

The specific location of the camera traps were predefined, as camera trapping is an on-going project at Cloudbridge Nature Reserve and cameras were not replaced for this particular research. They were situated in the three different forest types, namely two cameras in the old growth forest, four in natural regeneration areas and one in a planted section. All of the cameras were placed at a trail.

Figure 1: Map of Cloudbridge Nature Reserve with Camera Trap Locations (McKay, 2018)

1.2 Data collection

Habitat factors

For collecting the necessary data for the four habitat factors in question, a broad habitat assessment was performed at each of the seven camera trap locations. The camera trap was taken as the center point and using compass, measuring tape and flagging tape, a plot with a 25-meter diameter was set up. At the camera trap, and 8 meters into each cardinal direction, the canopy closure was measured. This was done with the use of a spherical densitometer, taking 4 measurements at each point (again each cardinal direction). The amount of dots on the incurved mirror of the densitometer, which were in the shade were counted and recorded. Canopy closure measurements were averaged to obtain a single measurement for each location.

At the same locations as for canopy closure, measurements of the slope were taken. To get the general slope of the area, a stick was set on the ground, across the trail and an inclinometer was put on top to record the angle of the slope. This was done at each eight-meter mark to average out the slope of the area. For the average slope of the trail, the stick was placed on the trail, and measurements taken at three different points on the trail – in front of the camera, 8 meters up and 8 meters down the trail. To get the slope differential, the average slope of the trail was then divided by the average slope of the area.

To get a picture of the tree characteristics at each plot, tree diameter and height were measured. Within the plot, all trees with a DBH (Diameter at Breast Height) of 10 cm and above were included and recorded. Using a DBH tape, the diameter of each tree was measured at 1.37 m from the ground. For the tree height, a stick, which marked the eye height of the observer, a measuring tape and an inclinometer were used (Figure 2). One person holding the stick and the measuring tape would stand by the tree, holding the measuring tape at the eye level mark. The observer would walk upslope away from the tree, until the crown of the tree was in sight. Looking up at the treetop through the inclinometer and down to the eye level mark on the stick, angles and distance to tree were recorded. Tree height was then calculated as follows (Powell, 2018):

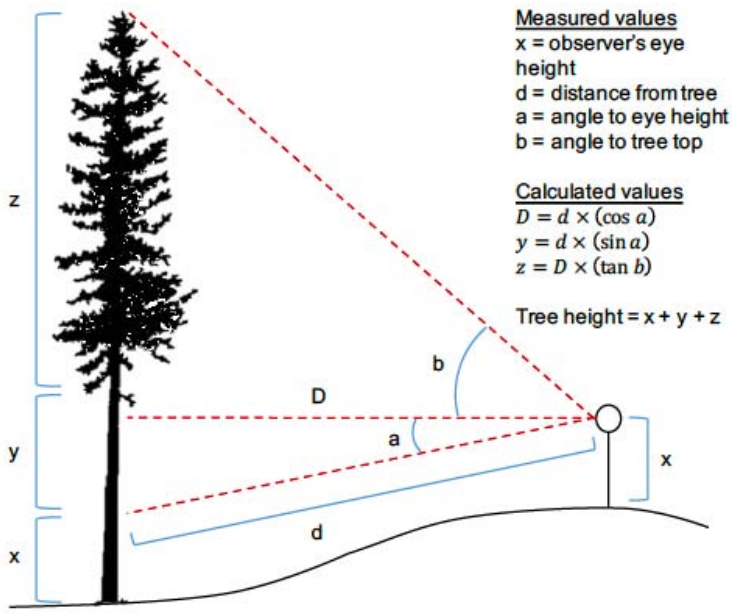

Figure 2: Tree height measurement technique.

Species richness and abundance

The data for species richness and abundance was collected with the use of the camera traps. The cameras were deployed on a 14-day schedule, deploying 3 or 4 respectively per week. The cameras were run on rechargeable batteries, which were exchanged on deployment days along with the SD cards. The camera brands used were Bushnell (Trophy Camera Brown, Trophy Cam HD, Trophy Cam Aggressor Camo) and Browning (Strike Force Model). As the available data collection time for this research was restricted (roughly 4 months), a larger data set, including all previously collected data from those same locations, was used. There was no influence on assuring consistent data settings for the pre-existent data. The mode varied between video and photo, with a majority of videos. Video length was between 5 and 10 seconds, image/video quality was consistently held at the highest possible (HD/ultra). As for the data collected for the duration of this study, the mode was set to photo with the highest possible quality, a 5 second delay between images, an automatic sensor level, and a capture number of 3 photos consistently. All cameras were fixed to a tree trunk, approximately 40 cm above ground.

Target species did not exist for this research. All animals caught on camera were entered into the database, including humans. All photos and videos were given an individual number and entered into excel spreadsheets where all information was written down, such as: location, image type, scientific and common name of the species, date and time of image. In addition to that, the images were further organized into hourly occurrences. The same individual or group of animals that passed the camera more than once within the same hour was considered one occurrence. This was done to try to prevent double counting of the same individuals.

1.3 Data analysis

The only recorded species excluded from analyses was humans. Although the focus of this research was on mammals, birds were not excluded. Because the large dataset containing the pre-existent data was very inconsistent and patchy, strategy had to be determined carefully. Total operational days for the cameras was between 290 and 540 days. For species abundance, this was a minor issue as total number of individuals could easily be divided by total number of operational days to get an average/day. For species richness however, it was more complicated. Calculating an average/day would not deliver a correct daily number of species. In order to get an understanding of how many species were captured on average each day, the number of species captured each day had to be counted, summed up, and divided by the number of operational days. For the large dataset, which added up to almost 2500 operational days, this was not feasible considering the time available. Strategy was reassessed and a smaller dataset was chosen. This smaller dataset consisted of 14 survey days from the dry season and 14 survey days from the rainy season, respectively 7 sequential days each. As for the rainy season, where data was collected by the author and consistency could be assured, it was possible to choose the same 14 dates for each camera trap. For the dry season however, data was still patchier and cameras failed regularly. For two locations (H1, V1) 14 different dates had to be chosen in the dry season, but they were kept as close as possible to the time period chosen for the other cameras.

One of the locations (M2), was a fairly recent camera trap location and it was the most problematic concerning camera failure. For the small dataset (species richness), it was impossible to find sufficient operational days in the given time period and it was thus excluded from analyses. Its total operational number of days was 22, compared to the couple of hundred days for the other locations. For the first few tests for species abundance, M2 was included in the analyses. After realizing it was falsifying results and altogether was not comparable to the rest, it was excluded from all further analyses. The number of locations thus decreased from 7 to 6.

All statistical analyses were performed with the use of the Handbook of Biological Statistics (http://www.biostathandbook.com). The confidence interval was consistently held at 95%. For the first sub-question, 'Does species richness and abundance increase in old growth forest compared to planted or natural regeneration areas?', a chi-square test of goodness-of-fit was used. Since this test works with expected proportions, the total species richness/abundance was a count and the expected proportions were accordingly. For richness, expected proportions were equal (1/6th each), since all cameras ran for the same amount of time. As for abundance, expected proportions were adjusted according to the number of operational days.

The second sub-question, 'Does species richness and abundance increase along with increasing canopy closure?', was analysed using a correlation test. Because proportions are not accounted for in this test, averages per day for richness and abundance were used rather than total counts. As for canopy closure all measurements of one location were averaged out to get one indicator for canopy closure per camera station. Same as above, the third sub-question 'Does species richness and abundance increase at locations where the difference between the slope on the trail and the general slope of the area is large?' was also tested with correlation. Values for species richness and abundance stayed the same and for slope differential, a ratio was used (average slope of the area ÷ average slope of the trail).

Also sub-question 4, 'Does species richness and abundance of arboreal species increase along with increasing tree diameter and tree height?' was analyzed with a correlation test. Since fully arboreal species rarely come to the ground and thus were rarely captured on camera, the term 'arboreal' was widened in order to get a bigger dataset. Considered as arboreal animals were the following: fully arboreal, as well as semi-arboreal animals (animals which are considered skillful climbers and spend a notable time in trees on a daily basis for foraging, sleeping, etc.) (Reid et al., 2010). The values for arboreal species richness and abundance were tested for potential correlation with six features. The two main features were average DBH and average tree height. As the tree size distributions were right-skewed, median DBH and tree height as well as maximum DBH and tree height were included and tested. This resulted in 12 correlation tests, each of the 6 features tested for correlation with species richness as well as abundance.

Ultimately, species diversity was calculated for each location using the Simpson's Index of Diversity. The Simpson's Index of Diversity is calculated as shown in Equation 1.

$$D = \frac{\Sigma\, n(n-1)}{N(N-1)} \tag{1}$$

Where:
D = Simpson's Index of Diversity
n = count of an individual species
N = total count of all individuals of all species

For this research, the outcome represents the probability of two random samples (individuals) at a certain location belonging to different species. The values can be anything between 0 and 1, whereby a higher value indicates a higher diversity (Offwell Woodland & Wildlife Trust, 2018).

2 Results

For the large dataset, which was used for species abundance, the cameras ran for a total of 2364 days, unevenly distributed over the 6 locations. Over all, 3835 individuals of 57 different species were captured on the cameras within that time period. For the smaller dataset, which was used for species richness, the cameras ran for a total of 168 days equally distributed over the 6 cameras (28 days each). There was a total of 298 individuals and 23 different species recorded. For species abundance, all tests were executed with the large as well as the small dataset. As more data generally delivers more reliable results, tables and figures of the large dataset are displayed in this chapter (Table 1). For comparison, a few tables and figures of the small dataset can be found in appendix VI.I – VI.IV. No results were notably different between the two datasets.

Results of the habitat assessment for each location are summarized in Table 2.

Table 1: Averages per day for richness and abundance used for analysis.

Dataset ->	Large (2364 camera days)	Small (168 camera days)
Location	**Abundance/Day**	**Richness/Day**
E1	3.10	2.04
G1	1.07	0.46
G2	2.13	1.46
H1	1.14	0.68
S1	1.44	1.32
V1	0.45	0.61

Table 2: Habitat features of each location.

Location	Habitat Type[1]	Average Canopy Closure	Slope Differential	Ave.		Median		Max.	
				DBH[2] (cm)	Tree Height (m)	DBH[2] (cm)	Tree Height (m)	DBH[2] (cm)	Tree Height (m)
E1	NR	90.4	0.36	20.69	9.89	17.91	8.93	43.88	37.84
G1	OG	96.1	0.41	22.96	12.12	16.60	9.75	88.00	22.41
G2	PL	67.3	0.52	18.02	10.75	16.75	9.09	36.80	20.72
H1	NR	96.3	0.19	22.70	7.61	23.19	6.19	34.30	82.77
S1	OG	94.8	0.61	30.71	18.04	18.80	13.33	136.50	11.31
V1	NR	70.4	0.38	24.04	6.05	22.25	5.49	48.28	37.84

1, NR = Natural Regeneration, PL = Planted, OG = Old Growth; 2, DBH = Diameter at Breast Height

2.1 Forest type

Sub-question 1: Does species richness and abundance increase in old growth forest compared to planted or natural regeneration areas?
The first sub-question was analyzed using a chi-square test of goodness-of-fit.

For species richness, the null hypothesis and alternative hypothesis for this test were as follows:
H_0: The number of recorded species is equal to the expected number of species.
H_1: The number of recorded species is different to the expected number of species.
This is an extrinsic hypothesis, as the expected numbers were clear before running the test.

The test delivered a p-value = 0.323 meaning the numbers were not significantly higher or lower than expected (Table 3, Figure 3). The highest number recorded was at location E1 with a total of 18 different species, the lowest richness was recorded at location H1, where 8 species were seen.

To figure out whether or not numbers were as expected, locations were grouped into old growth (OG) (G1 and S1), natural regeneration (NR) (E1, H1 and V1) and planted (PL) (G2). Comparison with

chi-squared yielded a p-value = 0.252 showing no significant differences. Table and figure can be found in Appendix I.I.

For species abundance the null and alternative hypothesis read:
H_0: The number of recorded individuals is equal to the expected number of individuals.
H_1: The number of recorded individuals is different to the expected number of individuals.

Here the p-value was 7.29E-245. This indicates that the abundance at each location was either significantly higher or significantly lower than expected (Table 4, Figure 4). At location E1 the recorded number of individuals was almost twice as high as expected, while V1 was roughly 3.5 times lower than expected.

Since the result was significant, post-hoc tests were executed. This test has the purpose of figuring out which location by itself rejects the null hypothesis, thus yielding a p-value < 0.05. Each location is therefore tested against the sum of all other locations. Each post-hoc test delivered a significant result meaning each location rejects the null hypothesis. Locations E1 (natural regeneration) and G2 (planted) were significantly higher than expected, locations G1, H1, S1 and V1 were all significantly lower than expected. Tables of the post-hoc test can be found in Appendix I.II.

Same as for species richness, locations were grouped into forest types and tested again. Table 5 and Figure 5 show the significant result of p = 5.16E-37, and post-hoc tests found each forest type differs significantly from the null hypothesis. Post-hoc tests can be found in Appendix I.III. Species abundance in the old growth forest was significantly lower than expected; species abundance in natural regeneration, as well as planted areas, was significantly higher than expected.

Table 3: Species richness per location

Location	Total Richness	Expected proportions	Expected numbers	Degrees of freedom (extrinsic hypothesis)	chi-square	P-value (two-tailed)	P-value (one-tailed)
E1	18	16.67	12	5	5.833	0.323	0.161
G1	9	16.67	12				
G2	13	16.67	12				
H1	8	16.67	12				
S1	14	16.67	12				
V1	10	16.67	12				

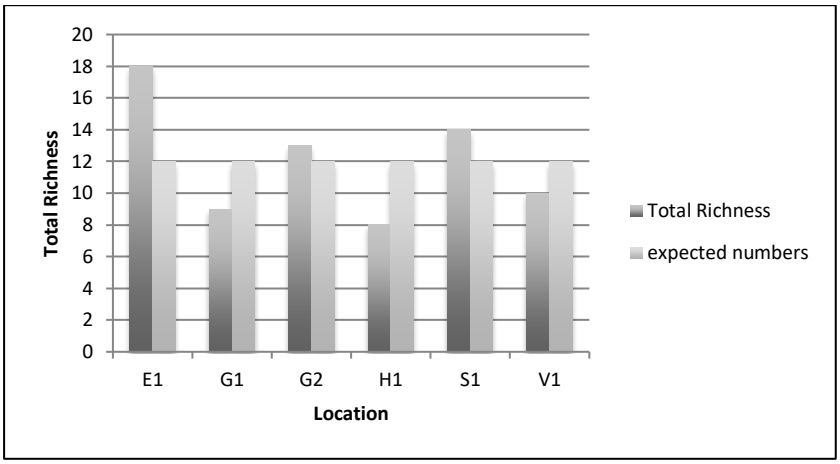

Figure 2: Species richness per location

Table 4: Species abundance per location.

Location	Total Abundance	Expected proportions	Expected numbers	Degrees of freedom (extrinsic hypothesis)	chi-square	P-value (two-tailed)	P-value (one-tailed)
E1	1491	20.35	780	5	5.833	0.323	0.161
G1	579	22.89	878				
G2	793	15.78	605				
H1	330	12.22	469				
S1	490	14.44	554				
V1	152	14.32	549				

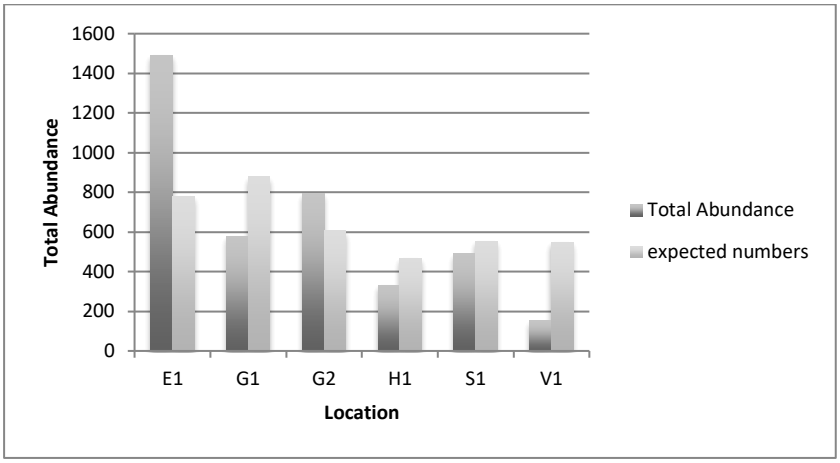

Figure 3: Species abundance per location.

Table 5: Species abundance and forest types.

Location	Total Abundance	Expected proportions	Expected numbers	Degrees of freedom (extrinsic hypothesis)	chi-square	P-value (two-tailed)	P-value (one-tailed)
OG	1069	37.33	1432	2	167.108	5.16E-37	2.58E-37
NR	1973	46.89	1798				
PL	793	15.78	605				

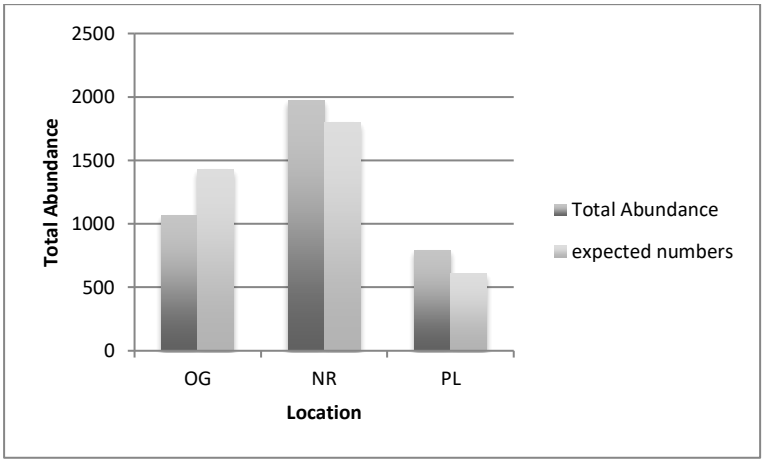

Figure 4: Species abundance and forest types.

2.2 Canopy closure

Sub-question 2: Does species richness and abundance increase along with increasing canopy closure? The second sub-question was examined by the use of a correlation test.

Data was no longer analysed with counts as above, but rather with a ratio. For species richness and abundance, averages per day were calculated and used for the correlation tests (Table 1).

For species richness, the null hypothesis and alternative hypothesis for this test were:
H_0: There is no relationship between species richness and canopy closure.
H_1: There is a relationship between species richness and canopy closure.

This test resulted in a p-value = 0.863, suggesting no relationship between the two variables (Figure 6).

For species abundance, the null and alternative hypothesis read:
H_0: There is no relationship between species abundance and canopy closure.
H_1: There is a relationship between species abundance and canopy closure.

Again, this test delivered a high p-value of 0.922, which indicates no relationship between species abundance and canopy closure. Table and Figure are found in Appendix II.

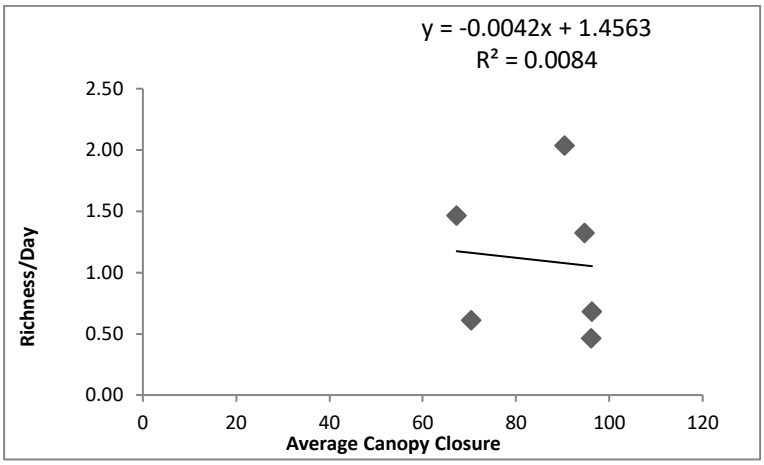

Figure 5: Correlation between species richness and canopy closure.

2.3 Slope differential

Sub-question 3: Does species richness and abundance increase at locations where the difference between the slope on the trail and the general slope of the area is large?

Same as the second sub-question, the third sub-question was analyzed using the correlation test.

The null and alternative hypothesis for species richness read:
H_0: There is no relationship between the number of recorded species at a specific location and the slope differential.
H_1: There is a relationship between the number of recorded species at a specific location and the slope differential.

The resulting p-value was 0.518 suggesting no relationship between these variables. The Table and Figure can be found in Appendix III.I.

As for species abundance, the null and alternative hypothesis were as follows:
H_0: There is no relationship between the number of recorded individuals at a specific location and the slope of the area.
H_1: There is a relationship between the number of recorded individuals at a specific location and the slope of the area.

Here the p-value was 0.795. Similar as above, this result suggests no relationship between species abundance and the slope differential. The null hypothesis cannot be rejected, as the large p-value indicates not strong enough evidence. Appendix III.II holds table and figure for this test.

2.4 Tree characteristics

Sub-question 4: Does species richness and abundance of arboreal species increase along with increasing tree diameters and tree height?

The fourth and last sub-question was also examined using the correlation test. For this sub-question, there were 6 tree features, which were looked at and tested (Table 2). The features were average DBH and average tree height, median DBH and median tree height, and maximum DBH and maximum tree height. All of these 6 features were tested on correlation for both species richness and species abundance, resulting in 12 correlation tests.

The null and alternative hypothesis for species richness were:
H_0: There is no relationship between the number of recorded arboreal species at a specific location and average tree diameter/tree height.
H_1: There is a relationship between the number of recorded arboreal species at a specific location and average tree diameter/tree height.

The same hypotheses applied to median and maximum respectively. The p-values yielded are shown in Table 6. All of these p-values are far away from being significant thus the null hypothesis cannot be rejected in any of these cases. Tables and Figures for all of these tests can be found in Appendix IV.I – IV.VI.

For species abundance the null and alternative hypothesis read:
H_0: There is no relationship between the number of recorded arboreal individuals at a specific location and average tree diameter/tree height.
H_1: There is a relationship between the number of recorded arboreal individuals at a specific location and average tree diameter/tree height.

Again, the same applied to median and maximum. Test results are shown in Table 6. Although all p-values are rather high and reject any null hypothesis, some figures showed interesting trends, which are displayed in Figures 7 through 10. All tables and remaining figures of these tests are shown in Appendix IV.VII – IV.XII.

In each of the Figures 7 through 10, 5 out of the 6 points align, suggesting a potential correlation between the variables. Also in each of the figures there is one outlier, which is location E1. The tests therefore all resulted in rather high p-values and their null hypothesis could not be rejected, the trends formed are nonetheless notable. To figure out whether or not the correlation was indeed due to tree height, the three tests were executed again, now excluding E1. Still, none of the p-values were under 0.05, however, several were extremely close. Average tree height yielded a p-value of

0.056, median tree height got 0.054 and maximum tree height 0.128 (Table 6, Appendix IV.XIII – IV.XV). Seeing that the significance level was set at 5%, a 5.4% chance of the correlation not being due to the suggested variables is very low. Even though the correlation cannot be guaranteed, the trend is noticeable.

Table 6: Results of correlation tests and tree characteristics.

	p-values, All Locations		p-values, Excluding E1
Tree Characteristics	**vs. Abundance**	**vs. Species Richness**	**vs. Abundance**
Average DBH	0.805	0.771	-
Average Tree Height	0.996	0.591	0.056
Median DBH	0.531	0.355	-
Median Tree Height	0.826	0.439	0.054
Max DBH	0.823	0.977	-
Max Tree Height	0.917	0.763	0.128

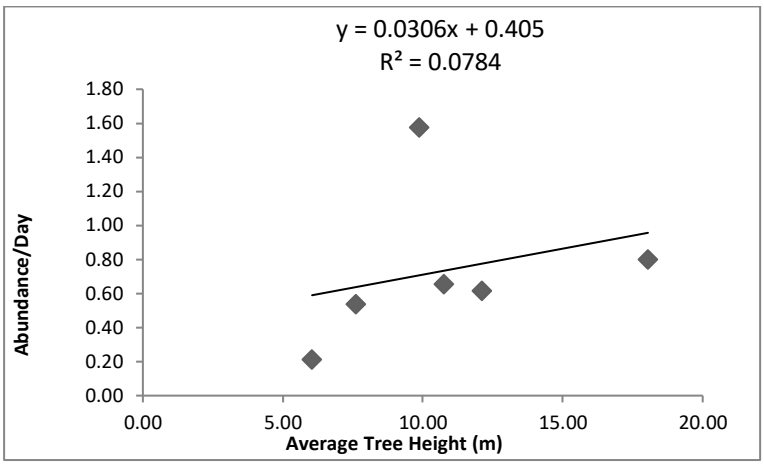

Figure 6: Correlation between abundance and average tree height.

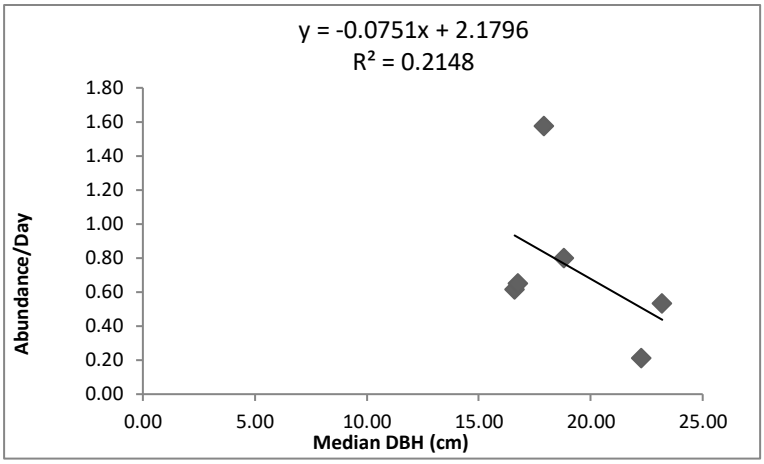

Figure 7: Correlation between abundance and median DBH.

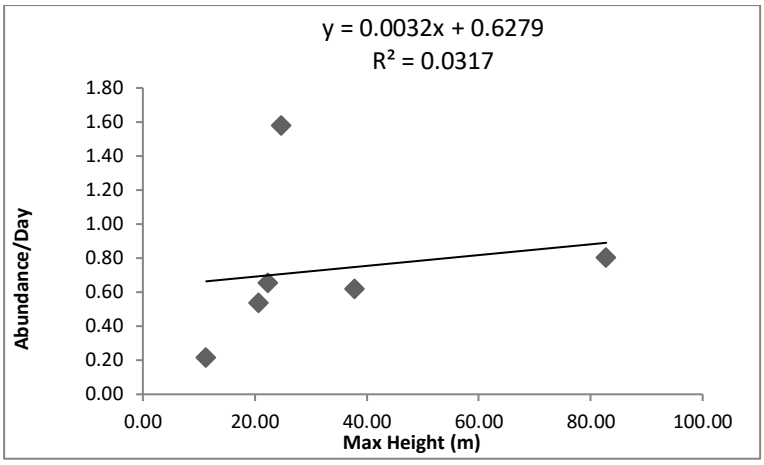

Figure 8: Correlation between abundance and median tree height.

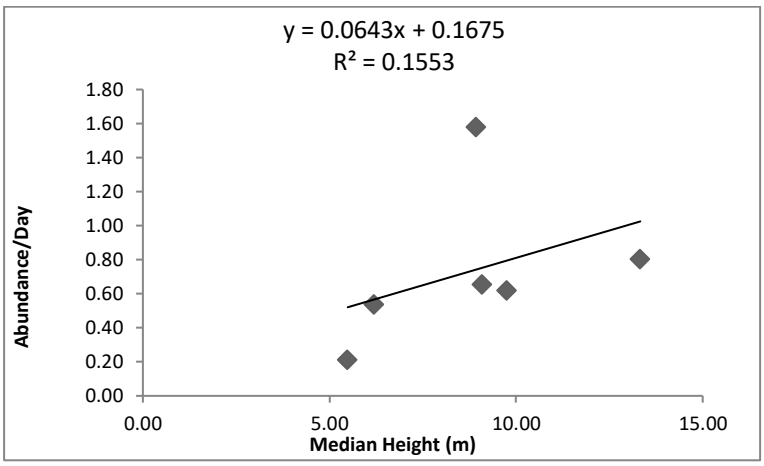

Figure 9: Correlation between abundance and max tree height.

2.5 Species diversity

Simpson's index of diversity was applied to species richness and abundance of all animals recorded as well as of arboreal animals only, using the small dataset. Figure 11 and 12 below show the results. The tables belonging to these figures can be found in appendix V.I and V.II.

Over all, the numbers for all species included are quite high, indicating a high diversity. The highest species diversity was recorded at location S1, which is in the old growth forest. The second highest diversity was at E1 followed directly by the other old growth location G1. As for the arboreal species, the highest species diversity was recorded at the two old growth stations. Location H1 yielded a considerably lower diversity compared to all other locations.

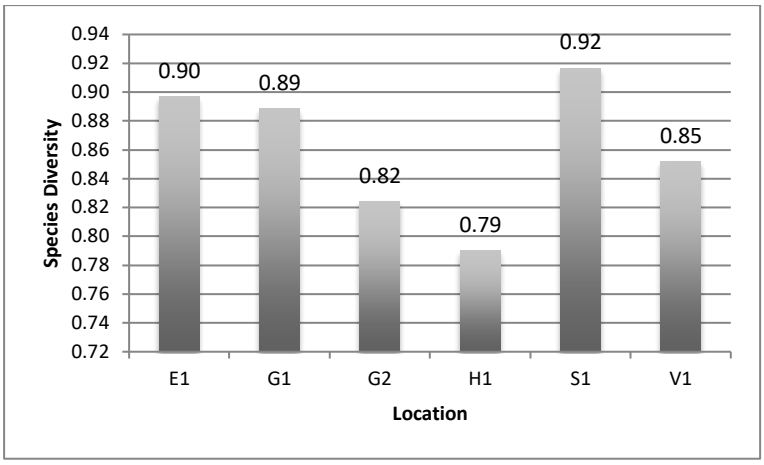

Figure 10: Species diversity (Simpson's Index of Diversity) of all species.

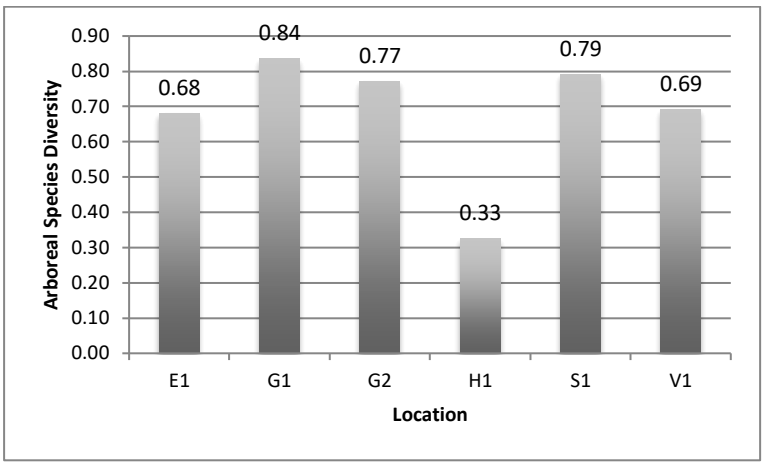

Figure 11: Species diversity (Simpson's Index of Diversity) of arboreal species.

3 Discussion

While the numbers of observed species were fairly even between the sites, the numbers of recorded individuals differed significantly at each location. This proves that the species abundance between the different locations varies strongly according to certain factors. Species richness was slightly higher than expected in the old growth forest, while species abundance was significantly lower there. The canopy closure as well as the slope differential seemed to have no impact on either species richness or abundance. Similarly, tree size characteristics were found to have no relationship with arboreal species richness and abundance. However, a clear trend formed when looking at the tree height in relation to species abundance. Finally, the highest species diversity as well as arboreal species diversity were both found in the old growth forest, suggesting that animals do indeed prefer certain forest types to others. In this situation, the old growth forest was found to be home to the largest diversity of animal species compared to natural regeneration with the second highest diversity, and planted areas with the lowest diversity of animal species.

There is a number of camera trap studies, which, in the past have investigated big habitat features such as roads and trails (Mann et al., 2014) (Cusack et al., 2015) (Di Bitetti et al., 2014) as well as small habitat features such as game trails (Kolowski & Forrester, 2017), and their influence on recorded species richness and abundance. Studies on the influence of the general habitat on species richness and abundance are scarcer, especially for mammals. For other vertebrates, there are comparable studies, which have been executed in the past. Studies on fish showed strong relationships between the variety of marine habitats and species richness and abundance, and stressed the importance of taking into account the impact of the habitat when conducting research on biodiversity (Gratwicke & Speight, 2005) (Roberts & Ormond, 1987). As for bees and wasps, it was found not only habitat area, but also the connectivity of habitat has significant relationships with species richness and abundance (Steffan-Dewenter, 2003). And similar as for the fish, different habitats have proven to impact the species richness and abundance of bats significantly (Estrada, et al., 1993). Although similar studies on the influence of different habitat factors on species richness and abundance of mammals do exist, comparing them is difficult as methods and measurements of habitat factors vary significantly from each study to the other (Tews et al., 2003).

As all cameras in this research were placed on human-used trails, this can be considered a consistent bias. Although it is likely that the recorded numbers were influenced by this, it can be assumed that in proportion results would stay the same if the cameras were placed randomly and off-trail. Further, the data was not as consistent and sequential as would be ideal. The dataset stretched over 2 years with more than 10 different researchers working on it over the time. The cameras did not always run smoothly, partially due to technical issues, and data was not collected and entered consistently or without error. Although the dataset was reworked, it cannot be guaranteed to be error-free due to its size and complexity. While this was not much of an issue for species abundance as an average/day was easily calculated, calculations for species richness were not possible. Choosing a much smaller but consistent dataset solved this problem. However, the 28 days of data are most likely insufficient for analysing such a complex question. In addition, an equal distribution of the cameras between the three forest types (old growth, natural regeneration, planted) would have been important considering the first sub-question. This further compromised the amount of comparable data, especially for the planted area, which was only represented by one camera.

The habitat factors examined in this research do not clearly explain the strikingly high numbers of species richness as well as abundance at location E1. This location sets itself apart from all the others, however, the suggested habitat factors do not seem to be the reason. When testing arboreal species abundance with tree characteristics for example, all other locations showed a positive correlation to tree height. The higher the number for average, median or maximum tree height, the higher the number of recorded arboreal individuals. Only at E1 this trend was broken as observed

individuals were surprisingly high for rather medium tree heights. One possible yet vague explanation for E1's high numbers might be the challenging terrain, forming a pinch point. It is not only extremely steep on both sides of the trail, but the shrubs are very dense on top of that, making it especially difficult for larger animals to pass through. Using the trail might be the only quick and safe way to get by this area. Also noticeable is a large boulder, which lies opposite of the camera. This might offer refuge and attract many animals and thus lead to the high capture numbers.

The term 'habitat' remains a broad and complex matter. It is difficult to truly examine whether or not one specific habitat factor influences species richness and abundance of animals. Habitat consists of millions of little factors, all interplaying with one another. It is not impossible that a factor of significant influence is examined, which however gets cancelled out by another factor influencing richness and abundance in an opposite way. As all these factors make up 'habitat' as a whole, extracting and analysing one specific factor remains an interesting challenge. However, the finding of some significant results in this research and the trends that were seen stress the importance of taking the habitat complexity into account when conducting studies on species richness and abundance.

4 Conclusion and recommendation

The main question of this research was: 'Which habitat factors are of influence considering the richness and abundance of species recorded at specific camera trap locations?'. For the first sub-question concerning richness and abundance in the different forest types, it was hypothesized that the numbers would be the highest in the old growth and this is only partially true. While species richness was indeed proportionally higher in the old growth as well as higher than expected, species abundance was notably lower compared to expected numbers and compared to the other forest types. Sub-question 2 investigated the relationship between species richness and abundance and canopy closure. The second hypothesis was proven wrong since species richness and abundance showed no correlation to canopy closure. Similarly, with the third sub-question looking into slope differential, results were contrary to expectations. Species richness and abundance showed neither a positive nor a negative relationship to the slope. For the fourth sub-question, which concerned the impact of tree characteristics on arboreal animals, the hypothesis was for arboreal species richness and abundance to increase along with increasing tree diameter and tree height. While none of the results were significant, distinct trends formed for all tests concerning abundance and tree height. There is a suggested positive correlation between arboreal species abundance and tree height, but it was not proven. Finally, species diversity as well as arboreal species diversity were the highest in the old growth forest. Separately, neither richness nor abundance were, contrary to expectations, higher in the old growth. But when looking at species diversity as a whole, it was indeed the highest in the old growth forest, which partially confirms those hypotheses.

Altogether, the forest type does influence the richness and abundance of animal species while canopy closure and slope differential have no influence. Tree diameter showed no influence on arboreal species richness and abundance and while arboreal species richness is not affected by tree height, arboreal species abundance is potentially influenced by tree height. For the reasons mentioned above, drawing conclusion form these findings is to be done with caution.

For potential future research in this area, a few recommendations were put together. First and foremost, making sure the data is consistent and sequential is possibly the most important and crucial first step. Only then reliable results can be presented. Secondly, it is recommended to collect data over a minimum of 6 months in order to eliminate chance as a possible falsification factor. It is generally recommended to place the camera traps randomly instead of choosing trails or other habitat features. In a situation similar to the one of this research, it would be advantageous to place the same number of cameras in the different forest types. That way the amount of data collected would be regulated. Last but not least, narrowing down the area of interest as much as possible and wording very specific research questions is of great importance, especially when working with broad terms such as 'habitat'.

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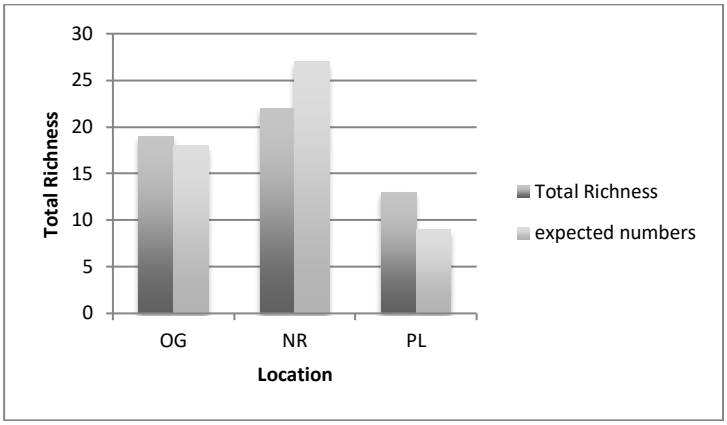
Appendices

Appendix I

I.I: This table and figure show species richness for the grouped forest types.

Location	Total Richness	Expected proportions	Expected numbers	Degrees of freedom (extrinsic hypothesis)	chi-square	P-value (two-tailed)	P-value (one-tailed)
OG	19	33.33	18	2	2.759	0.252	0.126
NR	22	50	27				
PL	13	16.67	9				



I.II: Post-hoc tests from sub-question 1, species abundance per location.

Location	Total Richness	Expected proportions	Expected numbers	Degrees of freedom (extrinsic hypothesis)	chi-square	P-value (two-tailed)	P-value (one-tailed)
E1	1491	20.35	780	1	812.301	1.14E-178	5.71E-179
Rest	2344	79.65	3055				

Location	Total Abundance	Expected proportions	Expected numbers	Degrees of freedom (extrinsic hypothesis)	chi-square	P-value (two-tailed)	P-value (one-tailed)
G1	579	22.89	878	1	131.913	1.56E-30	7.82E-31
Rest	3256	77.11	2957				

Location	Total Abundance	Expected proportions	Expected numbers	Degrees of freedom (extrinsic hypothesis)	chi-square	P-value (two-tailed)	P-value (one-tailed)
G2	793	15.78	605	1	69.265	8.61E-17	4.30E-17
Rest	3042	84.22	3230				

Location	Total Abundance	Expected proportions	Expected numbers	Degrees of freedom (extrinsic hypothesis)	chi-square	P-value (two-tailed)	P-value (one-tailed)
H1	330	12.22	469	1	46.699	8.28E-12	4.14E-12
Rest	3505	87.78	3366				

Location	Total Abundance	Expected proportions	Expected numbers	Degrees of freedom (extrinsic hypothesis)	chi-square	P-value (two-tailed)	P-value (one-tailed)
S1	490	14.44	554	1	8.569	0.003	0.002
Rest	3345	85.56	3281				

Location	Total Abundance	Expected proportions	Expected numbers	Degrees of freedom (extrinsic hypothesis)	chi-square	P-value (two-tailed)	P-value (one-tailed)
V1	152	14.32	549	1	335.446	6.26E-75	3.13E-75
Rest	3683	85.68	3286				

I.III: Post-hoc tests from sub-question 1, species abundance for the forest types

Location	Total Richness	Expected proportions	Expected numbers	Degrees of freedom (extrinsic hypothesis)	chi-square	P-value (two-tailed)	P-value (one-tailed)
OG	1069	37.33	1432	1	146.493	1.01E-33	5.06E-34
NR & PL	2766	62.67	2404				

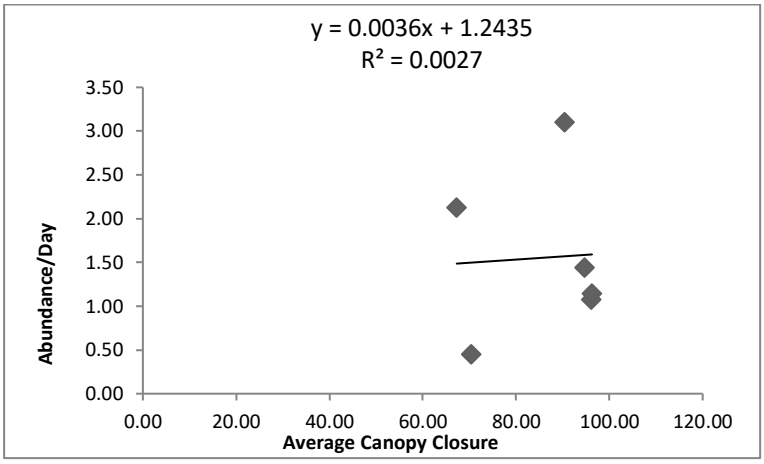
Location	Total Richness	Expected proportions	Expected numbers	Degrees of freedom (extrinsic hypothesis)	chi-square	P-value (two-tailed)	P-value (one-tailed)
NR	1973	46.89	1798	1	31.938	1.59E-8	7.96E-9
OG & PL	1862	53.11	2037				

Location	Total Richness	Expected proportions	Expected numbers	Degrees of freedom (extrinsic hypothesis)	chi-square	P-value (two-tailed)	P-value (one-tailed)
PL	793	15.78	605	1	69.265	8.61E-17	4.30E-17
OG & NR	3042	84.22	3230				

Appendix II

This table and figure of sub-question 2 show the correlation between species abundance and canopy closure.

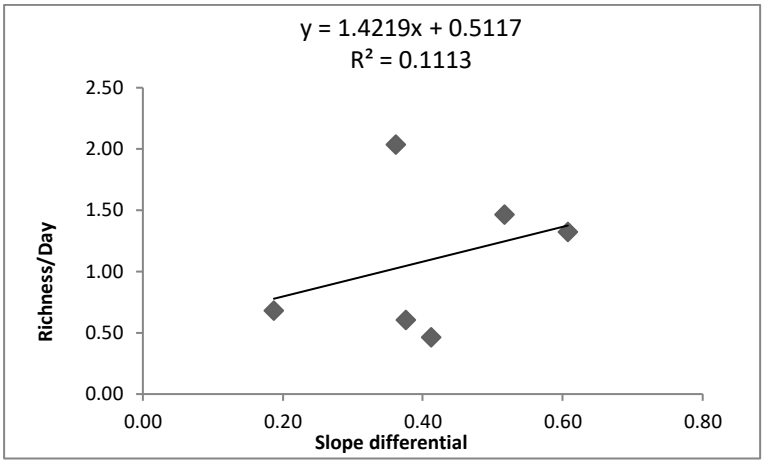
Location	Ave. Canopy Closure	Abundance/Day	p-value
E1	90.44	3.10	0.922
G1	96.10	1.07	
G2	67.28	2.13	
H1	96.26	1.14	
S1	94.80	1.44	
V1	70.40	0.45	



Appendix III

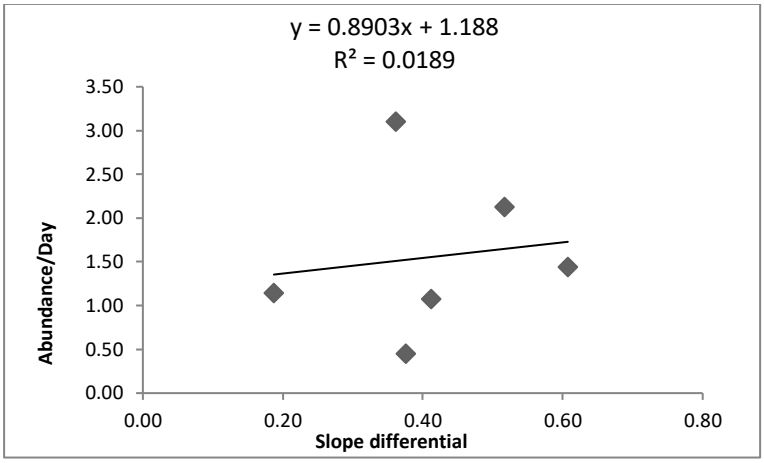
III.I: This table and figure show the correlation between species richness and slope differential.

Location	Slope Differential	Richness/Day	p-value
E1	0.36	2.04	0.518
G1	0.41	0.46	
G2	0.52	1.46	
H1	0.19	0.68	
S1	0.61	1.32	
V1	0.38	0.61	



III.II: This table and figure show the correlation between species abundance and slope differential.

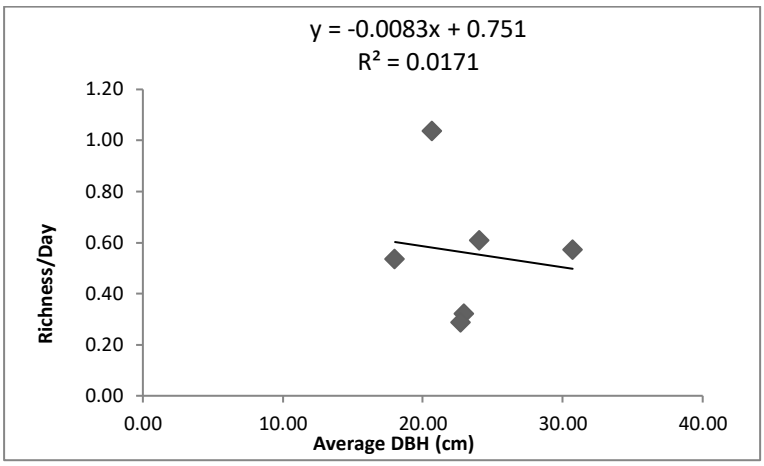
Location	Slope Differential	Abundance/Day	p-value
E1	0.36	3.10	0.795
G1	0.41	1.07	
G2	0.52	2.13	
H1	0.19	1.14	
S1	0.61	1.44	
V1	0.38	0.45	



Appendix IV

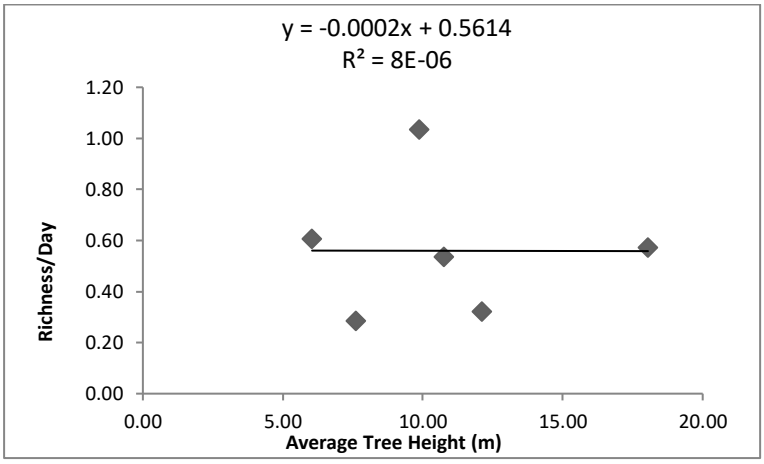
IV.I: This table and figure show the correlation between arboreal species richness and average DBH.

Location	Ave. DBH (cm)	Richness/Day	p-value
E1	20.69	1.04	0.805
G1	22.96	0.32	
G2	18.02	0.54	
H1	22.70	0.29	
S1	30.71	0.57	
V1	24.04	0.61	



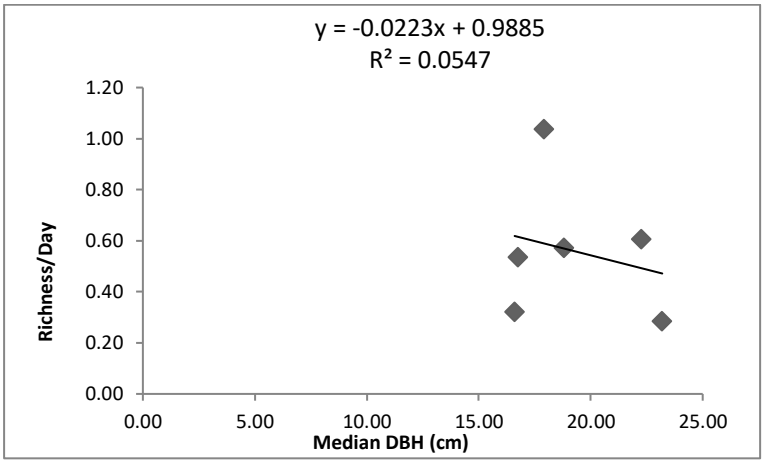
IV.II: This table and figure show the correlation between arboreal species richness and average tree height.

Location	Ave. DBH (cm)	Richness/Day	p-value
E1	9.89	1.04	0.996
G1	12.12	0.32	
G2	10.75	0.54	
H1	7.61	0.29	
S1	18.04	0.57	
V1	6.05	0.61	



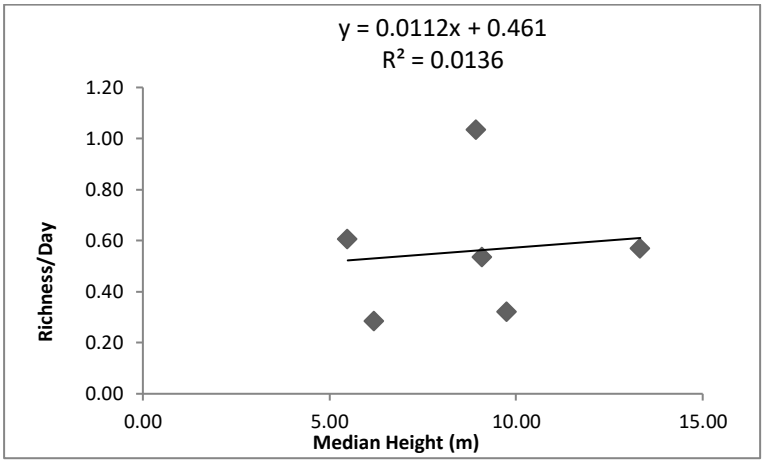
IV.III: This table and figure show the correlation between arboreal species richness and median DBH.

Location	Median DBH (cm)	Richness/Day	p-value
E1	17.91	1.04	0.531
G1	16.60	0.32	
G2	16.75	0.54	
H1	23.19	0.29	
S1	18.80	0.57	
V1	22.25	0.61	



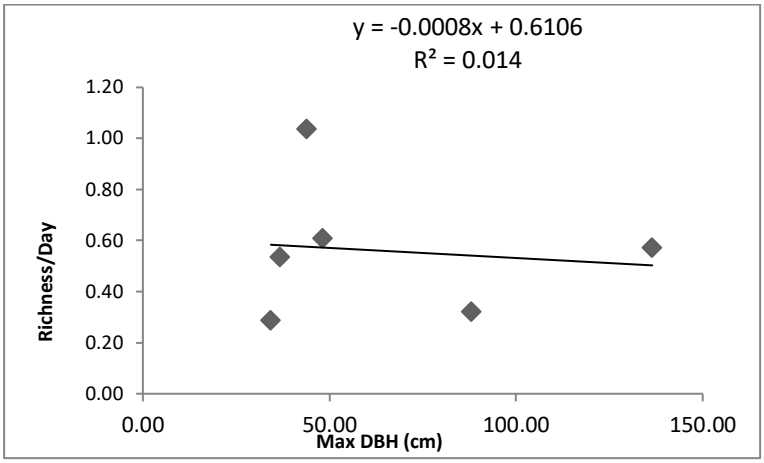
IV.IV: This table and figure show the correlation between arboreal species richness and median tree height.

Location	Median Height (m)	Richness/Day	p-value
E1	8.93	1.04	0.826
G1	9.75	0.32	
G2	9.09	0.54	
H1	6.19	0.29	
S1	13.33	0.57	
V1	5.49	0.61	



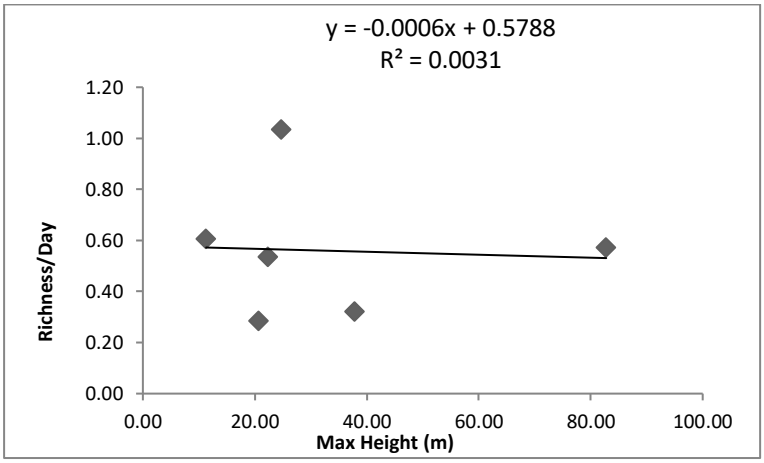
IV.V: This table and figure show the correlation between arboreal species richness and maximum DBH.

Location	Max DBH (cm)	Richness/Day	p-value
E1	43.88	1.04	0.823
G1	88.00	0.32	
G2	36.80	0.54	
H1	34.30	0.29	
S1	136.50	0.57	
V1	48.28	0.61	



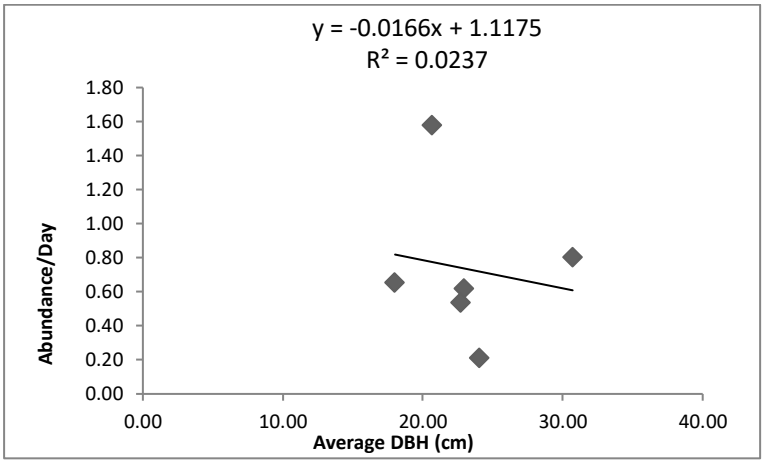
IV.VI: This table and figure show the correlation between arboreal species richness and maximum tree height.

Location	Max Height (m)	Richness/Day	p-value
E1	24.73	1.04	0.917
G1	37.84	0.32	
G2	22.41	0.54	
H1	20.72	0.29	
S1	82.77	0.57	
V1	11.31	0.61	



IV.VII: This table and figure show the correlation between arboreal species abundance and average DBH.

Location	Ave. DBH (cm)	Abundance/Day	p-value
E1	20.69	1.58	0.771
G1	22.96	0.62	
G2	18.02	0.65	
H1	22.70	0.54	
S1	30.71	0.80	
V1	24.04	0.21	



IV.VIII: This table shows the correlation between arboreal species abundance and average tree height.

Location	Ave. Tree Height (m)	Abundance/Day	p-value
E1	9.89	1.58	0.591
G1	12.12	0.62	
G2	10.75	0.65	
H1	7.61	0.54	
S1	18.04	0.80	
V1	6.05	0.21	

IV.IX: This table shows the correlation between species abundance and median DBH.

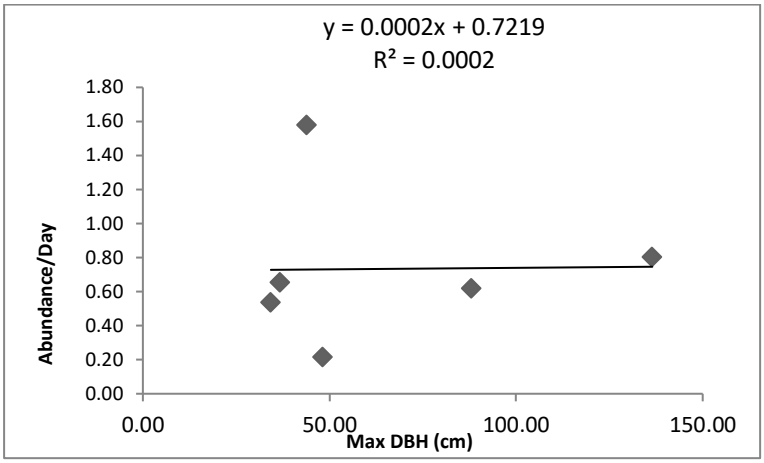
Location	Median DBH (cm)	Abundance/Day	p-value
E1	17.91	1.58	0.355
G1	16.60	0.62	
G2	16.75	0.65	
H1	23.19	0.54	
S1	18.80	0.80	
V1	22.25	0.21	

IV.X: This table shows the correlation between arboreal species abundance and median tree height.

Location	Median Tree Height (m)	Abundance/Day	p-value
E1	17.91	1.58	0.439
G1	16.60	0.62	
G2	16.75	0.65	
H1	23.19	0.54	
S1	18.80	0.80	
V1	22.25	0.21	

IV.XI: This table and figure show the correlation between arboreal species abundance and maximum DBH.

Location	Max DBH (cm)	Abundance/Day	p-value
E1	43.88	1.58	0.977
G1	88.00	0.62	
G2	36.80	0.65	
H1	34.30	0.54	
S1	136.50	0.80	
V1	48.28	0.21	

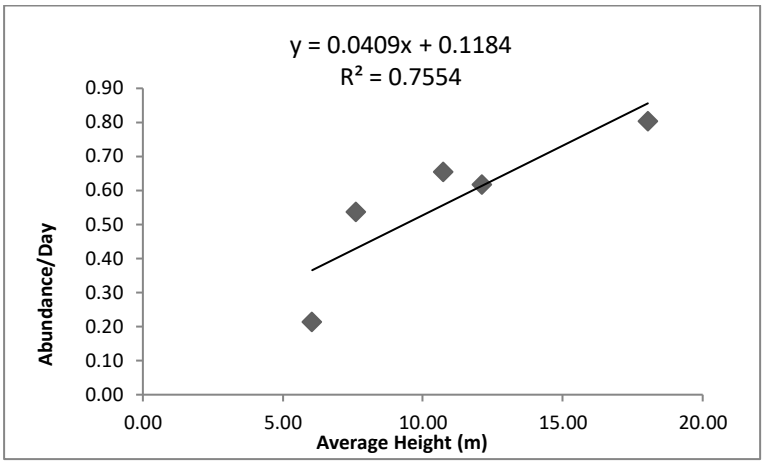


IV.XII: This table shows the correlation between arboreal species abundance and maximum tree height.

Location	Max Tree Height (m)	Abundance/Day	p-value
E1	24.73	1.58	0.736
G1	37.84	0.62	
G2	22.41	0.65	
H1	20.72	0.54	
S1	82.77	0.80	
V1	11.31	0.21	

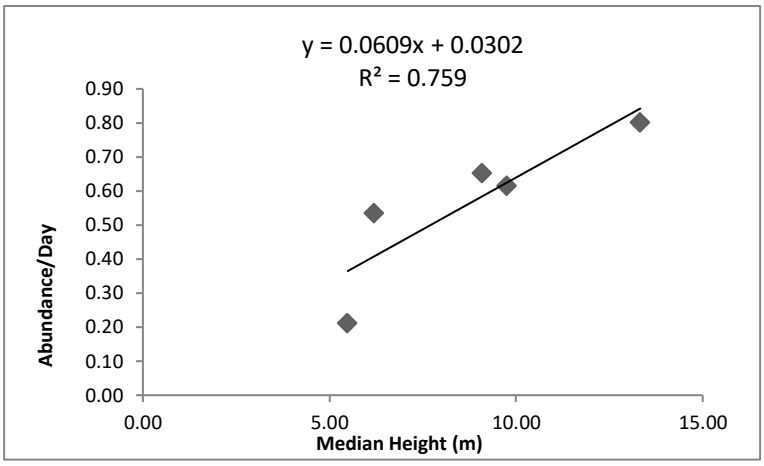
IV.XIII: This table and figure show the correlation between arboreal species abundance and average tree height, excluding E1.

Location	Ave. Tree Height (m)	Abundance/Day	p-value
G1	12.12	0.62	0.056
G2	10.75	0.65	
H1	7.61	0.54	
S1	18.04	0.80	
V1	6.05	0.21	



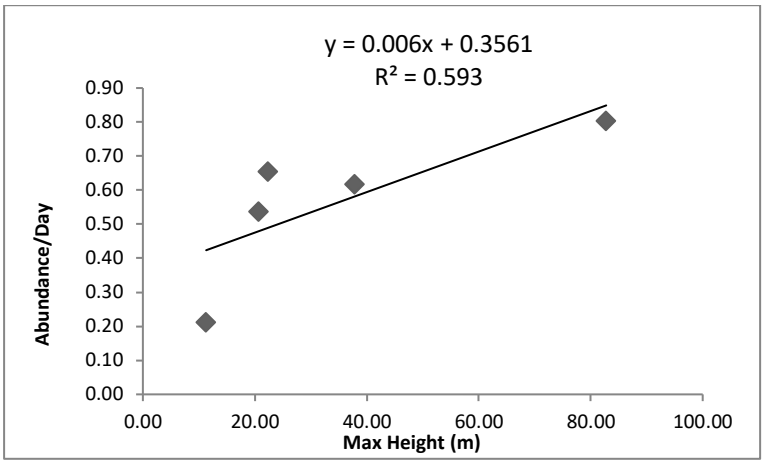
IV.XIV: This table and figure show the correlation between arboreal species abundance and median tree height, excluding E1.

Location	Median Height (m)	Abundance/Day	p-value
G1	9.75	0.62	0.054
G2	9.09	0.65	
H1	6.19	0.54	
S1	13.33	0.80	
V1	5.49	0.21	



IV.XV: This table and figure show the correlation between arboreal species abundance and maximum tree height, excluding E1.

Location	Max Height (m)	Abundance/Day	p-value
G1	37.84	0.62	0.128
G2	22.41	0.65	
H1	20.72	0.54	
S1	82.77	0.80	
V1	11.31	0.21	



Appendix V

V.I: This Table belongs to figure 10, showing the data of all species for the Simpson's index of diversity.

Species	E1		G1		G2		H1		S1		V1	
	n	n*(n-1)	n	n*(n-1)	n	n*(n-1)	n	n*(n-1)	n	n*(n-1)	n	n*(n-1)
Black Guan	1	0	0	0	0	0	1	0	2	2	2	2
Chest-nut capped Brush-finch	0	0	0	0	0	0	2	2	2	2	0	0
Chiriqui Quail-Dove	3	6	1	0	1	0	0	0	0	0	2	2
Collared Peccary	4	12	0	0	26	650	6	30	9	72	0	0
Common Opossum	22	462	0	0	3	6	3	6	4	12	5	20
Dice's Cottontail	7	42	0	0	3	6	1	0	0	0	0	0
Greater Grison	0	0	0	0	0	0	0	0	0	0	1	0
Long-tailed Weasel	1	0	0	0	1	0	0	0	0	0	0	0
Mouse or Rat	5	20	0	0	0	0	0	0	5	20	0	0
Nine-banded Armadillo	1	0	0	0	0	0	2	2	2	2	0	0
Oncilla	0	0	0	0	0	0	0	0	0	0	2	2
Paca	5	20	0	0	1	0	0	0	1	0	3	6
Puma	2	2	1	0	0	0	0	0	1	0	1	0
Quail-Dove	1	0	0	0	0	0	0	0	0	0	0	0
Red-tailed Squirrel	4	12	3	6	6	30	0	0	6	30	0	0
Slaty-backed Nightingale-Thrush	0	0	0	0	0	0	0	0	3	6	0	0
Spotted Wood-Quail	10	90	5	20	0	0	0	0	2	2	0	0
Squirrel	5	20	0	0	0	0	0	0	4	12	9	72
Swaison's Thrush	3	6	0	0	11	110	0	0	0	0	0	0
Tayra	0	0	3	6	3	6	0	0	0	0	0	0
Unidentified	3	6	1	0	4	12	4	12	0	0	1	0
Unidentified Bird	1	0	1	0	9	72	0	0	2	2	0	0
White-naped Brush-Finch	0	0	0	0	1	0	0	0	0	0	0	0
White-nosed Coati	11	110	3	6	3	6	13	156	7	42	1	0
White-faced Capuchin	0	0	1	0	0	0	0	0	0	0	0	0
Sum	89	808	19	38	72	898	32	208	50	204	27	104
N*(N-1)	7832		342		5112		992		2450		702	
SID	0.90		0.89		0.82		0.79		0.92		0.85	

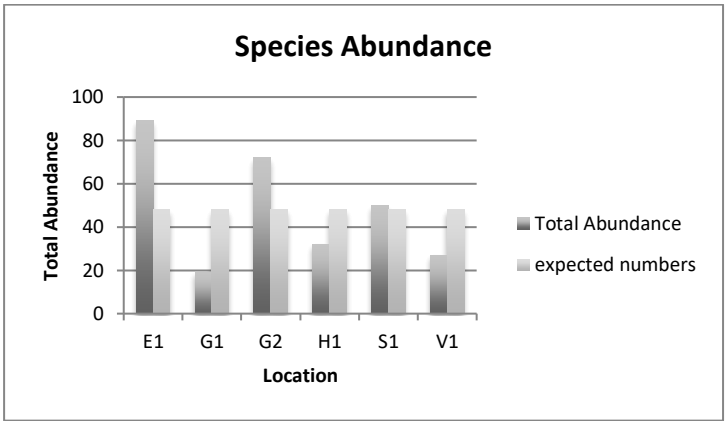
V.II: This table belongs to figure 11, showing the data of the arboreal species for the Simpson's index of diversity.

Arboreal species	E1		G1		G2		H1		S1		V1	
	n	n*(n-1)	n	n*(n-1)	n	n*(n-1)	n	n*(n-1)	n	n*(n-1)	n	n*(n-1)
Common Opossum	22	462	0	0	3	6	3	6	4	12	5	20
Oncilla	0	0	0	0	0	0	0	0	0	0	2	2
Puma	2	2	1	0	0	0	0	0	1	0	1	0
Red-tailed Squirrel	4	12	3	6	6	30	0	0	6	30	0	0
Squirrel	5	20	0	0	0	0	0	0	4	12	9	72
Tayra	0	0	3	6	3	6	0	0	0	0	0	0
White-nosed Coati	11	110	3	6	3	6	13	156	7	42	1	0
White-faced Capuchin	0	0	1	0	0	0	0	0	0	0	0	0
Sum	44	606	11	18	15	48	16	162	22	96	18	94
N*(N-1)	1892		110		210		240		462		306	
SID	0.68		0.84		0.77		0.33		0.79		0.69	

Appendix VI

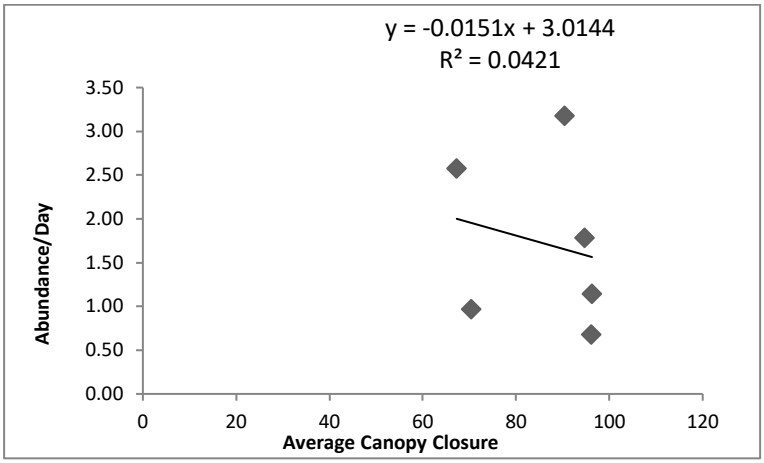
VI.I: This table and figure show species abundance per location using the small data set.

Location	Total Abundance	Expected proportions	Expected numbers	Degrees of freedom (extrinsic hypothesis)	chi-square	P-value (two-tailed)	P-value (one-tailed)
E1	89	16.67	48	5	78.869	1.45E-15	7.24E-16
G1	19	16.67	48				
G2	72	16.67	48				
H1	32	16.67	48				
S1	50	16.67	48				
V1	27	16.67	48				



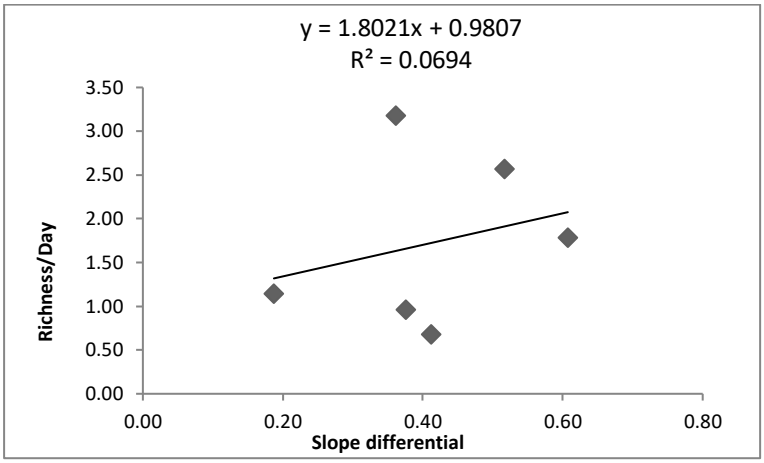
VI.II: This table and figure show the correlation between species abundance and average canopy closure using the small dataset.

Location	Ave. Canopy Closure	Abundance/Day	p-value
E1	90.44	3.18	0.697
G1	96.1	0.68	
G2	67.28	2.57	
H1	96.26	1.14	
S1	94.8	1.79	
V1	70.4	0.96	



VI.III: This table and figure show the correlation between species abundance and slope differential using the small dataset.

Location	Slope Differential	Richness/Day	p-value
E1	0.36	3.18	0.614
G1	0.41	0.68	
G2	0.52	2.57	
H1	0.19	1.14	
S1	0.61	1.79	
V1	0.38	0.96	



VI.IV: This table and figure show the correlation between species abundance and average tree height using the small dataset.

Location	Ave. Tree Height (m)	Abundance/Day	p-value
E1	9.89	1.57	0.979
G1	12.12	0.39	
G2	10.75	0.54	
H1	7.61	0.57	
S1	18.04	0.79	
V1	6.05	0.64