Hochschule Neubrandenburg
University of Applied Sciences

RESERVA CLOUDBRIDGE NATURE RESERVE

Herpetofauna in a neotropical Cloudforest, Costa Rica

The Influence of Elevation and Habitat on Herpetofauna Species Abundance and Diversity in the Cloudbridge Nature Reserve

Abstract

In terms of global conservation efforts, reptiles and amphibians have long been overlooked, even though these animals are widely known as excellent bioindicators for a healthy ecosystem and habitat quality because they are highly sensitive to habitat disturbances and environmental pollution. Therefore, Herpetofauna is a good study target to measure the health of an ecosystem. This study will provide insight on whether elevation and habitat influence herpetofauna diversity and abundance in the Cloudbridge Nature Reserve. The Cloudbridge Nature Reserve is located in a neotropical cloud forest in Costa Rica. Five different sites in different forest types were conducted from October 2023 to January 2024. Herpetofauna populations are threatened by a variety of factors which is a major concern considering their critical ecological role. Studying how habitat and elevation influence herpetofauna populations will arm the Nature Reserve and other geographically similar cloud forests with insight on how to best advocate for conservation efforts that will increase the resilience of these species.

Keywords: Herpetofauna; Reptiles; Amphibians; habitat; elevation; cloud forest; Costa Rica

October-January 2023/24

Paula Hahn

Research Intern at Cloudbridge Nature Reserve, Costa Rica
Nature Conservation and land use Planning
University of Applied Sciences Neubrandenburg

Inhaltsverzeichnis

1. Introduction

> “Amphibians and reptiles are key bioindicators of environmental health and habitat quality and can be used to provide baseline information to help assess habitat conditions and evaluate restoration success” (Mifsud 2014).

In terms of global conservation efforts, reptiles and amphibians have long been overlooked, even though these animals are widely known as excellent bioindicators for a healthy ecosystem and habitat quality because they are highly sensitive to habitat disturbances and environmental pollution (Mifsud 2014). Terrestrial amphibians, lizards and snakes are also known as good indicators for the amounts of microhabitats in ecosystems (Cooperrider et al. 1986). The abundance and variety of lizards show for example a direct correlation with alterations in microhabitat composition and quantity. Aquatic amphibians and snakes serve as reliable indicators of the well-being of aquatic ecosystems. These species are particularly responsive to environmental pollution and the decline of aquatic habitats (Cooperrider et al. 1986). Additionally, amphibians and reptiles play crucial roles in various food chains and constitute significant proportions of vertebrate populations in specific ecosystems (Cooperrider et al. 1986). Numerous raptorial birds and carnivorous mammals depend on these animals as a food source (Cooperrider et al. 1986). Therefore, Herpetofauna is an excellent indicator for assessing the health of an ecosystem. The importance of studying herpetofauna and protecting the habitats of these animals becomes even more significant by looking at the increased numbers of endangered species because amphibians stand at the forefront of a global biodiversity crisis (Whitfield et al. 2007). 41% of the assessed amphibian species by the International Union for Conservation of Nature (IUCN) are Vulnerable, Endangered or Critically Endangered as well as 21% of the assessed reptile species worldwide are at risk of extinction (IUCN, n.d.). Reasons of risk are especially agriculture, deforestation, urban development, associated loss of habitat as well as cause of disease and climate change. More than 33% of amphibian species face global threats, and it's estimated that more than 120 species have become globally extinct since 1980 (Whitfield et al. 2007). The emergence of chytridiomycosis, a potentially deadly infection affecting the amphibian epithelium caused by the chytrid fungal pathogen *Batrachochytrium dendrobatidis*, has been identified as the reason for the disappearance of numerous species in upland moist-to-wet forests in Costa Rica (Wake 2007). The growth of *B. dendrobatidis* is inhibited by higher temperatures (Whitfield et al. 2007). It is hypothesized that a significant number of the documented declines occurred in mountainous regions due to this inhibiting factor, compounded by the influence of extreme climate events associated with ongoing climate change (Urbina-Cardona 2008). Although the risk of extinction shifted from 1980 until today from extinction because of disease to climate change effects (IUCN, n.d.).

The Neotropics are home to about half of the world’s amphibian species and at the same time contains approximately 48% of amphibian species, the most threatened area (IUCN, n.d.). Costa Rica's recognized herpetofauna comprises 396 amphibian and reptile species, spanning 37 families and 140 genera. This includes 174 amphibians and 222 reptiles. Notably, 16% of these species, accounting for 44 amphibians and 17 reptiles, are endemic to Costa Rica (Savage 2002).

The study was conducted in the Cloudbridge Nature Reserve located in the Talamanca mountains. The Reserve inherits 52 known species of herpetofauna. Due to the elevation of the Nature Reserve (5085- 8530 ft; 1550-2600 m) the abundance of herpetofauna is quite small compared to lower elevation areas in Costa Rica. Although the nature Reserve inherits species that can only be found in higher elevation terrain such as *Craugastor melanostictus, Cerrophidion sasai* and *Bothriechis nubestris*. Cloudbridge inherits 16 families of herpetofauna in total. 8 Families of Reptiles with 34 known species, and 8 known Families of Amphibians with 18 species.

The Reserve is located in a tropical cloud forest. A cloud forest, situated in the highlands and covered in clouds, maintains consistently high humidity ranging from 75-100% throughout the year. The cool moist conditions and lush vegetation present an optimal habitat for many species of amphibians and reptiles, especially anurans (Duellman 1966). Within tropical ecosystems, a variety of opportunities arises for the formation of niches and microclimates. This dynamic environment fosters the development of distinctive ecological pockets that serve as habitats for amphibians and reptiles. The abundance of habitat niches, coupled with notable variations in elevation, provides ample chances for speciation and the specialization of habitats for herpetofauna (Hankin 2022). The forest relies on evapotranspiration, where water vapors accumulate on the forest floor and in epiphytic aerial plants. If clouds form at higher altitudes, they remain above rather than within the forest, depriving plants of crucial mists essential for their survival. While extensively studied in Monteverde, Costa Rica, this threat likely extends to cloud forests in other regions (Hannah 2011).

Additionally, the cloud forest's topsoil or humus layer lacks natural fertilizers, impeding the rapid decomposition of fallen leaves and hampering nutrient replenishment to the trees (Cloudbridge n.d.). The temperature and moisture levels in the environment have a direct impact on the body temperature and hydration of amphibians (Mitchell & Bergmann 2015). These factors, in turn, influence their preferences for the environment and their performance in various tasks (Mitchell & Bergmann 2015). The combined effects of temperature and moisture are crucial considerations in the study of animal conservation, especially given the current climate changes (Mitchell & Bergmann 2015). Amphibian development, survival, reproduction, and persistence may be disproportionately influenced by alterations in the thermal and moisture conditions, owing to their highly permeable skin (Mitchell & Bergmann 2015). Examining the impact of habitat and elevation on herpetofauna populations will provide the nature reserve with valuable information. This knowledge will empower conservation efforts, enabling the reserve to advocate for strategies that enhance the resilience of these species. Past studies also hypothesized that the abundance of frog individuals would fluctuate as a response to changes in habitat and elevation (Hankin 2022).

According to the IUCN amphibian assessment and the reptile assessment the forest is the most preferred habitat for herpetofauna (Cox et al. 2022). Climate change poses a threat to cloud forests, as shifts in temperature and rainfall may limit their range to higher altitudes where the characteristic conditions are maintained (Foster 2001). Monteverde, situated in the Talamancan mountain range in Costa Rica, exhibits indications of adverse effects from climate change, manifested by a decrease in cloud immersion (Foster 2001). Earlier research has established a strong correlation between precipitation and the distribution and abundance of reptiles, with a particular emphasis on amphibians (Foster 2001). Precipitation, wind, sunlight, humidity, and temperature can all be influenced by elevation, meaning that conditions have the potential to vary significantly even at slight elevation differences (Hankin 2022). Because herpetofauna species are extremely sensitive to environmental changes, factors like elevation can greatly influence the population makeup of a given area (Hankin 2022). This, coupled with the comparatively moderate climate within the nature reserve, may alleviate the adverse effects of climate change on species (Mi et al. 2023).

This study will provide insight on (Hypothesis I) whether elevation and habitat influence herpetofauna diversity and abundance in the Cloudbridge Nature Reserve. Herpetofauna populations are threatened by a variety of factors which is a major concern considering their critical ecological role. Studying how habitat and elevation influence herpetofauna populations will arm the Nature Reserve and other geographically similar cloud forests with insight on how to best advocate for conservation efforts that will increase the resilience of these species (Hankin 2022).

2. Methodology

2.1 Study Site

Cloudbridge is a 283 hectare (700 acres) tropical cloud forest Nature Reserve in the Talamanca mountains of Pérez Zeledón, Costa Rica. Elevation stretches from 1550 to 2600m (5085-8530 ft) above sea level. Average monthly temperature ranges from about 15°C (59°F) at night to about 25°C (77°F) in the day, and annual precipitation averages 2,000mm (Jarvis & Mulligan 2010). Cloudbridge is situated on the Pacific side of the Talamanca mountain range. Unlike the typical "dry" season lasting for four to five months (December to April) in many areas along the Pacific, Cloudbridge experiences a distinctive climate with warmer temperatures and heavier rainfall from May to November and cooler temperatures with lighter rainfall from December to April. Cloudbridge has different types of forest including 255 hectares reforested formerly used pastureland. The Reserve consists of old-growth forests (70-150+ years old), naturally regenerated forests (30-70 years old) and replanted forests (<20 years old).

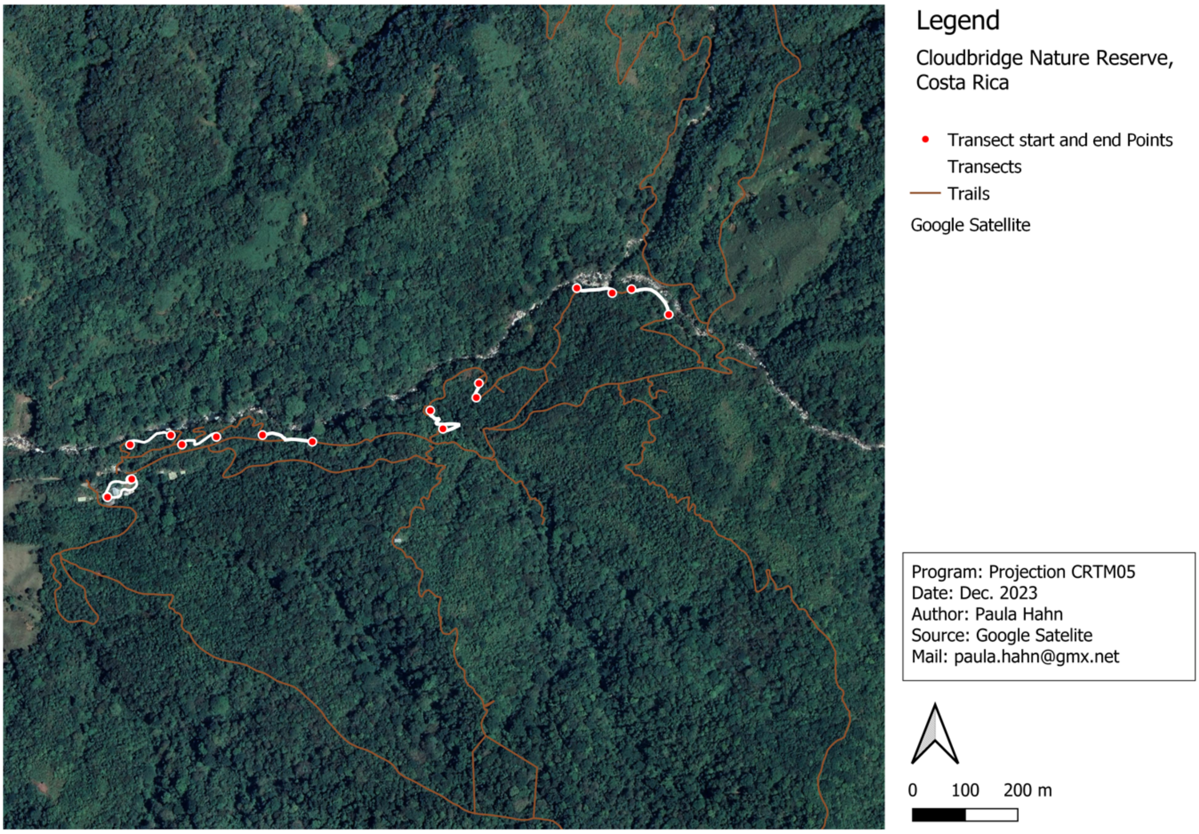

Figure 1: Map of the study site with the transects at different sites.

2.2 Data Collection

This study specifically targeted all reptile and amphibian species within the Reserve. The objective is to examine the impact of variations in elevation on herpetofauna communities. Transects were chosen based on distinct habitat characteristics, and surveys were conducted during both day and night for a predetermined duration daily. The collection of data and nocturnal herpetofauna surveys during night hikes were evenly distributed across the transects. Due to variations in elevation among locations, there is a likelihood that herpetofauna populations may respond differently to climatic differences.

Site	Forest Type	Elevation (m)
Catarata	Human, Planted	1560
Classroom	Human	1576
Rio	Natural Regrowth, Secondary Forest	1676
Garden	Human	1554
Sentinel	Planted, Natural Regrowth, Secondary Forest, Old Growth	1749

Table 1: Elevation and Forest Types at the surveyed Sites.

Data was collected on five different sites in the nature reserve. The encounters were conducted in 12 different transects. The time of the survey was specified for each transect. Night surveys were conducted once a week for each trail and every two weeks during the day. Furthermore, data was collected during the weekly communal night walks on different trails, those are called opportunistic night surveys. For those surveys the coordinates of the start and end were marked, and the timer was set for 30 minutes constantly. This is the average time of the other transects for approximately 90m length. The surveys were conducted using visual encounter surveys (VES) and lifting leaf litter. This method is widely used for sampling of amphibians and reptiles throughout the tropics and is considered as one of the best ways to capture reptiles and amphibians (Whitfield et al. 2007; Doan 2003). Ecologists use visual encounter surveys to assess the diversity and abundance of herpetofauna in a specific area. For safety reasons, the night search was conducted by a minimum of two people using headlamps and a bamboo stick to lift leaf litter. The VES included a thorough examination for herpetofauna across the ground, tree trunks, and within vegetation like branches and leaves. This search extended to a height that allowed for visual observation on both sides of the trail, within the limits of physical reach. Accessibility on each trail constrained the areas on which transects could be conducted, therefore up to one meter off trail, maximum, was surveyed. Date, site number, species, scientific name, family, number of individuals, weather condition, temperature and time were recorded. In addition, the survey start time, survey end time and total individuals were recorded. Identifying herpetofauna can be challenging at times since certain species can only be differentiated by subtle morphological features. Close-up photographs of key features such as the head, hands, feet, and other relevant characteristics were also captured for identification purposes when required and for future reference. The Field Guides by Twan Leenders were used for identification as well as correspondence with the staff (Leender 2016; 2019). Coordinates for each transect's start and end points were recorded using a GPS tracker and additionally marked with flagging tape.

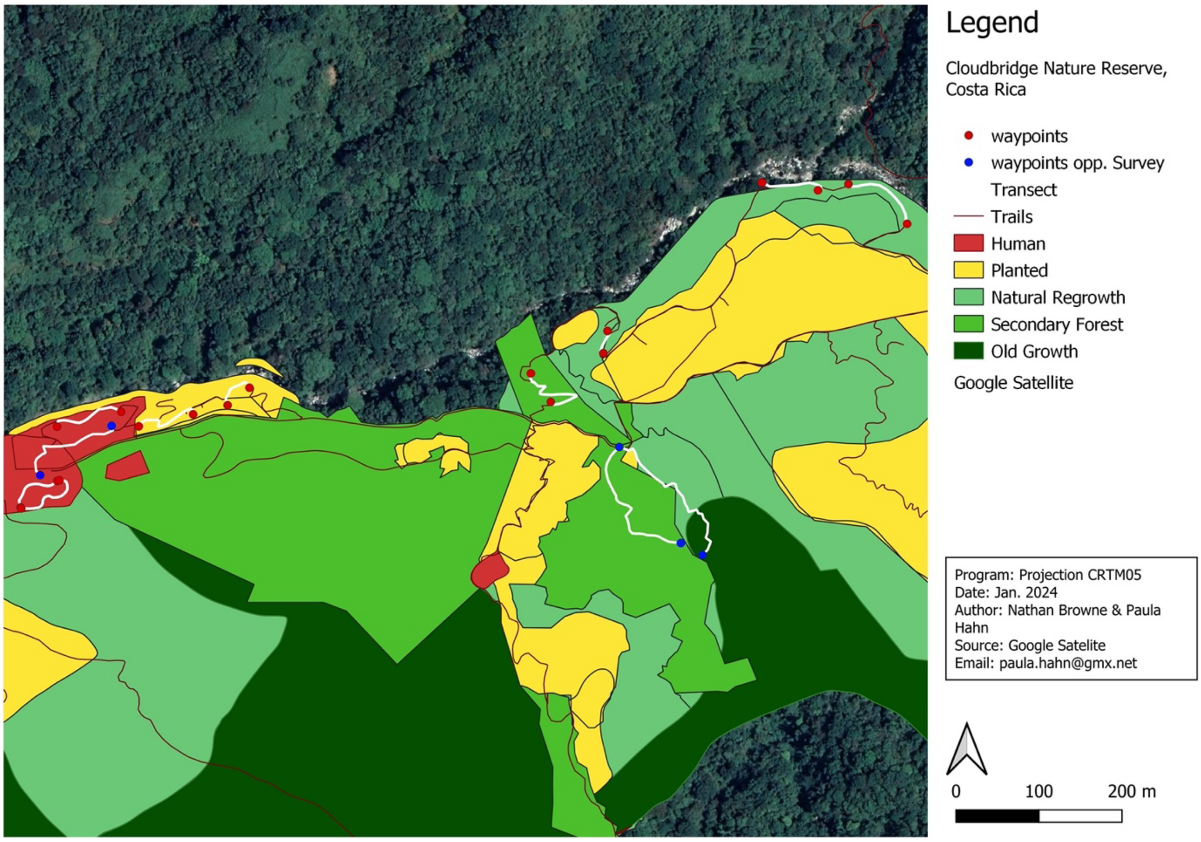

Figure 2: Map of the different forest types at the study site.

By surveying at different locations, this study will include sampling from a range of habitats throughout the corridor and make use of the elevational disparity to compare the sites and investigate the differences in herpetofauna populations between the sites. Surveying was conducted in different habitat and forest types and are considered as human and planted areas as well as natural regrowth, secondary regrowth and old growth area. Targeting and distinguishing herpetofauna species diversity between the habitats will provide insights on habitat preferences. The surveyed transects exhibit variations in vegetation composition, forest density and sunlight exposure as well as different survey times during the day. Herpetofauna typically reflect these distinctions, with species composition frequently influenced by the landscape and type of forest.

Effort during the surveys was determined by the number of people actively searching multiplied by the number of hours surveyed.

Total Effort = # Hours x #

The reason behind the effort calculation is to see the chance of seeing something compared to the actual survey hours. It is more likely to have more results when more people are joining the survey. The chance to see every reptile and amphibian when doing the survey alone or with two people is less than with five people. Scouring every leaf along the trail on the ground and in the trees on each site it is rather unlikely to observe every individual. But the chance of individuals being observed increases with the number of people doing the survey.

2.3 Data analysis

All recorded Data was entered in Excel-Sheets.

2.3.1 Calculations

In order to estimate the species diversity of the sites surveyed and draw comparisons, the Shannon-Wiener Index and the Simpson-Diversity Index were calculated. The Shannon-Wiener Index emphasize on the species diversity and the Simpson-Diversity Index emphasize on the evenness component. The Shannon index was calculated with the formula below:

$$H = -\sum[(pi) * \ln(pi)].$$

The Simpson-Diversity Index was calculated with the formula below:

$$D = 1 - \left(\frac{\sum n(n-1)}{N(N-1)}\right).$$

Furthermore, the Jaccard similarity Index was calculated to see if there is a similarity of species between sites. The Jaccard similarity Index was calculated with the formula below:

$$J\,(A, B) = \frac{|A \cap B|}{|A \cup B|}$$

The spearman´s rank test was calculated to compare different valuables and to see whether the null hypothesis is true or disproved. For calculating the tests an online calculator was used (https://geographyfieldwork.com/SpearmansRankCalculator.html) with the formula below:

$$R_S = 1 - \left(\frac{6\sum d^2}{n^3 - n}\right)$$

3. Results

Amphibian and reptile species richness

During the whole investigation between October 2023 and January 2024 a total of 334 individuals from 20 species were observed across the five sites from 68 hours (187 total effort hours) of active searching, including the opportunistic surveys. These included 211 amphibian individuals from ten species and 123 reptile individuals from ten species. At the Rio site, there were 43 individuals found from ten species. At the Catarata site 59 individuals have been encountered from nine species and at the Classroom site, there were a total of 164 individuals found from 12 species. There were 21 individuals found from seven species at Sentinel and 47 individuals from nine species at the Garden site. There were nine out of the 20 species that only have been found at one of the three sites. Amphibians were observed more frequently than reptiles. Lizards were conserved far more frequently with 119 sightings than snakes with only nine sightings.

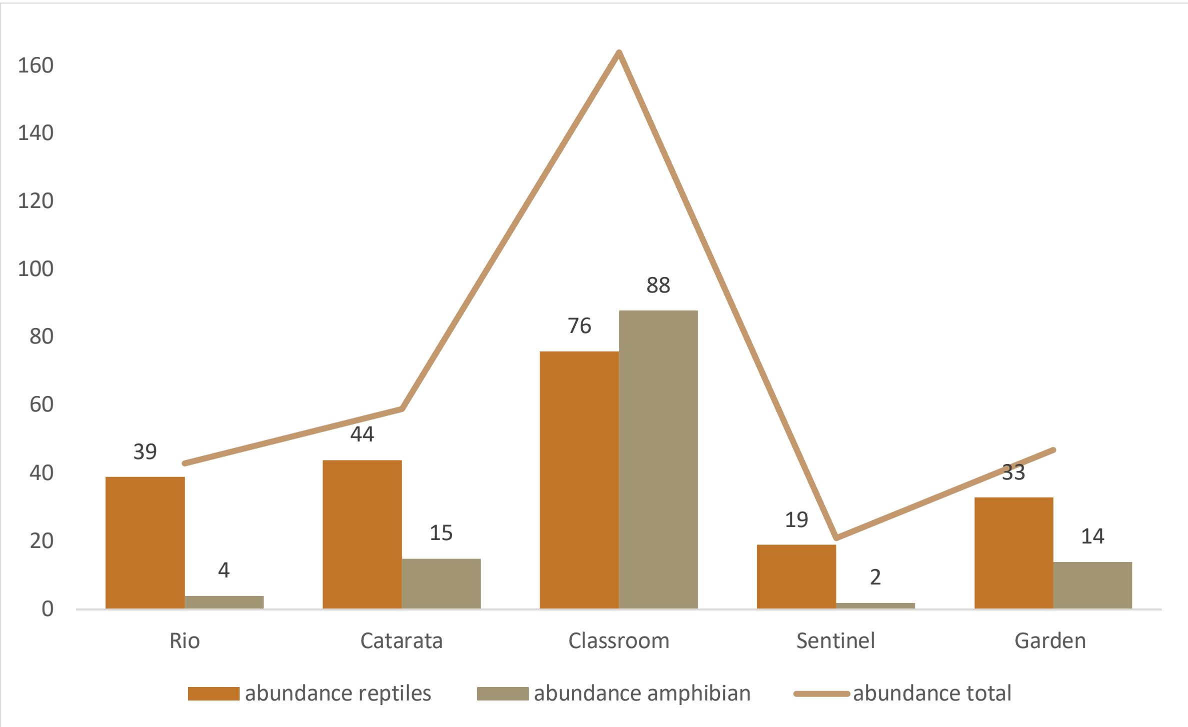

Figure 3: amphibian and reptiles observed at the different transects

The most often observed species during the survey period was *Craugastor crassidigitus* with 85 observations. Followed by other amphibian species such as *Espadarana prosoblepon* (44), *Pristimantis ridens* (41) and *Pristimantis cruentus* (37). The reptile species most often observed was *Anolis marsupialis* with 49 sightings, followed by *Anolis Polylepis* (42) and *Anolis limifrons* (14). Species from three amphibian orders have been observed: 10 species of Anura, one species of Caudata and one species of Gymnophiona. The species found are divided into seven families. Most species belong to the family Craugastoridae with four species and the Strabomantidae with two species. Other families, each with one species were Bufonidae, Centrolenidae, Ranidae, Eleutherodactylidae, Plethodontidae and Dermophiidae. Reptiles from two orders have been observed during the survey period: six species of Dactyloidae and four species of Serpentes. The found species are divided into three families. The lizard diversity belongs to the Sauria family with six species, and the found snake species are divided into the Dipsadidae with two species and the Viperidae also with two species. A variation of species in the three sites were identified. Although frog species of the genus Craugastoridae and Centrolenidae were found at every site as well as one species of the Sauria genus. Various species of *Anolis* lizards were common at many sites. A table of the observed species throughout the study can be seen in Appendix A, table 1.

Survey Sites

Three sites were observed and divided into nine transects. Each transect has an abbreviation with the Trail name (e.g. C for Catarata) and the transect number (e.g. 1+2 is one transect). The transects are referred to below with the abbreviation of the transect number. All transects were in different habitat and forest types, in the human area (Classroom (CL 1+2, CL 3+4), Catarata (C 1+2), Garden), the planted forest (Catarata (C 3+4, C 5+6)), in the natural regrowth area (Rio (R 1+2, R 3+4, R 5+6), the secondary forest (Rio (R 7+8)) and the old growth forest (Sentinel (S 1+2)) with different habitat characteristics and elevation (Table 1). The opportunistic survey sites are in the human area (Garden) and in the natural regrowth forest (Sentinel (S1+2)), as well as in the secondary forest (Sentinel (S 3+4)) and the old growth forest (Sentinel (S 3+4)). The results show that there is a different species composition of herpetofauna between the sites (see Table 3). The species richness between the sites is with nine to 12 species each site relatively even as well as the species diversity at each site (see Table 2). The species distribution was relatively even at the Rio and Catarata Site, while the classroom site was dominated by three species, *Craugastor crassidigitus*, *Anolis marsupialis* and *Anolis Polylepis*.

Observed species

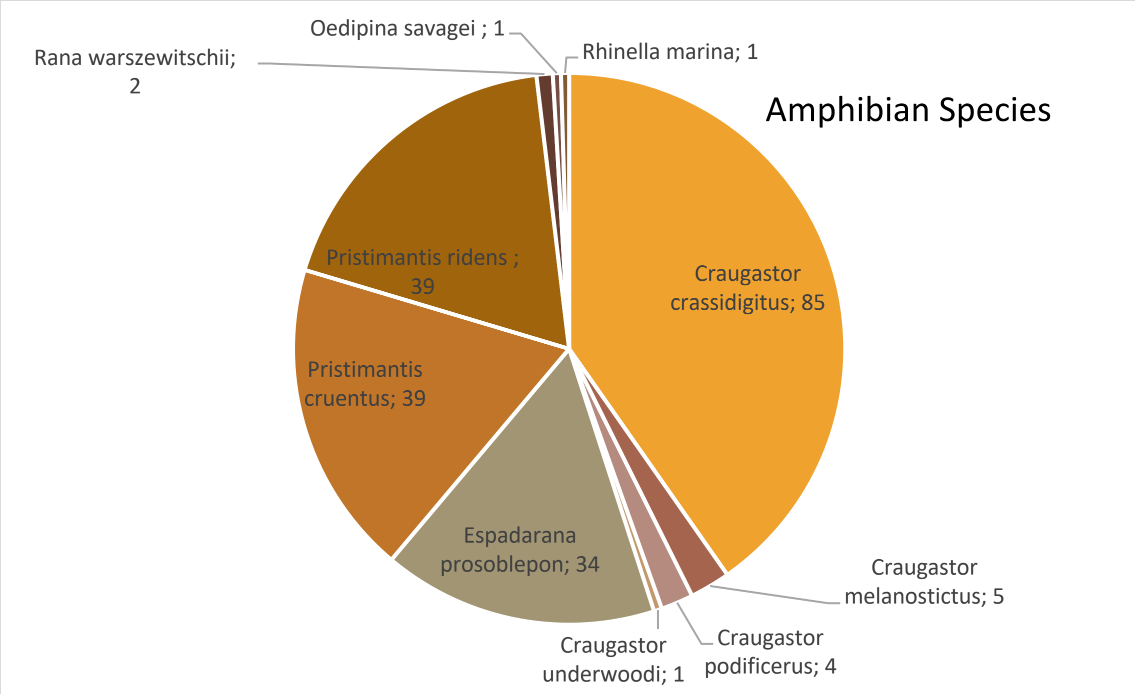

Figure 4: Amphibian species observed during the survey period.

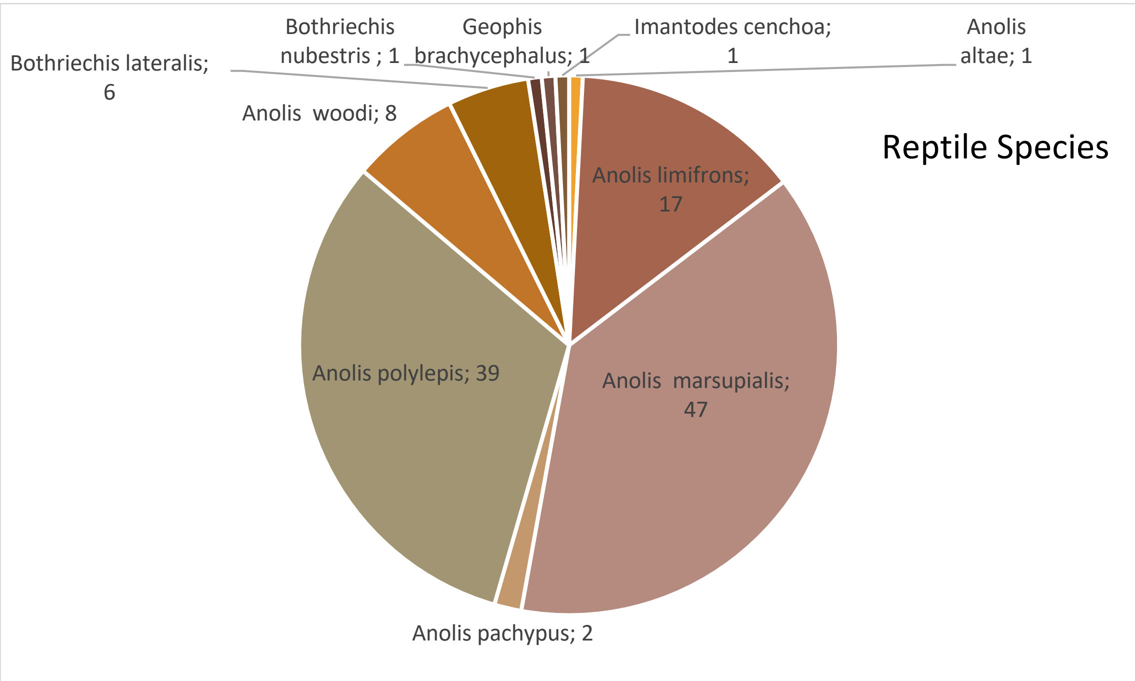

Figure 5: Reptile species observed during the survey period.

Measures of Diversity

Shannon-Wiener Index:

	Rio	Catarata	Classroom	Opp. Survey – Sentinel	Opp. Survey – Garden
Shannon-Wiener Index	1,901	1,904	1,818	1,731	2,035
Simpson-Diversity Index	0,832	0,844	0,806	0,833	0,873

Table 2: Shannon-Wiener Index and Simpson-Diversity Index.

The calculation of the Shannon-Wiener Index revealed that the site with the highest species diversity was the Rio Trail with a value of 2.512 (Table 2). The Catarata Trail had the lowest species diversity with a value of 1.82 (Table 2). The Shannon-Wiener Index of the opportunistic Surveys differs from a value of 1,73 at the Sentinel Trail to a slightly higher diversity of species at the Garden Trail with a value of 2.03 (Table 2).

Jaccard similarity Index:

	R - CL	R - C	CL - C	S- G	S - CL	S - C	S - R	G- R	G - C	G - CL
Jaccard Similarity Index	0,375	0,46	0,5	0,33	0,266	0,33	0,42	0,46	0,63	0,5

Table 3: Jaccard-similarity Test. Site locality are as follows: R = Rio, CL = Classroom, C = Catarata, S = Sentinel, G = Garden.

The Jaccard similarity test shows similarity between two data sets by determining the number of shared species between two sites. That allows the comparison of similarity of species richness between the sites. The Index ranges from 0 to 1, with 0 meaning there is no similarity in species between the sites and 1 meaning the sites have the same species present. The Jaccard similarity Index was conducted between each site. The results show a similarity of species between the sites from 0,33 to 0,63. The results between Classroom and Catarata as well as Garden and Classroom show that these sites share half of the species present. The results are relatively similar with Rio and Classroom with the least similarity in species present, and Catarata and Garden the most correlation in species present. The high Index between Catarata and Garden was to be expected due to the spatial proximity. The results show that the similarity of species present decreases with rising difference in altitude.

Spearman Rank correlation:

The Hypothesis H_0: There is no correlation in altitude related to diversity.

Hypothesis H_a: There is a correlation between diversity and altitude at least two different sites.

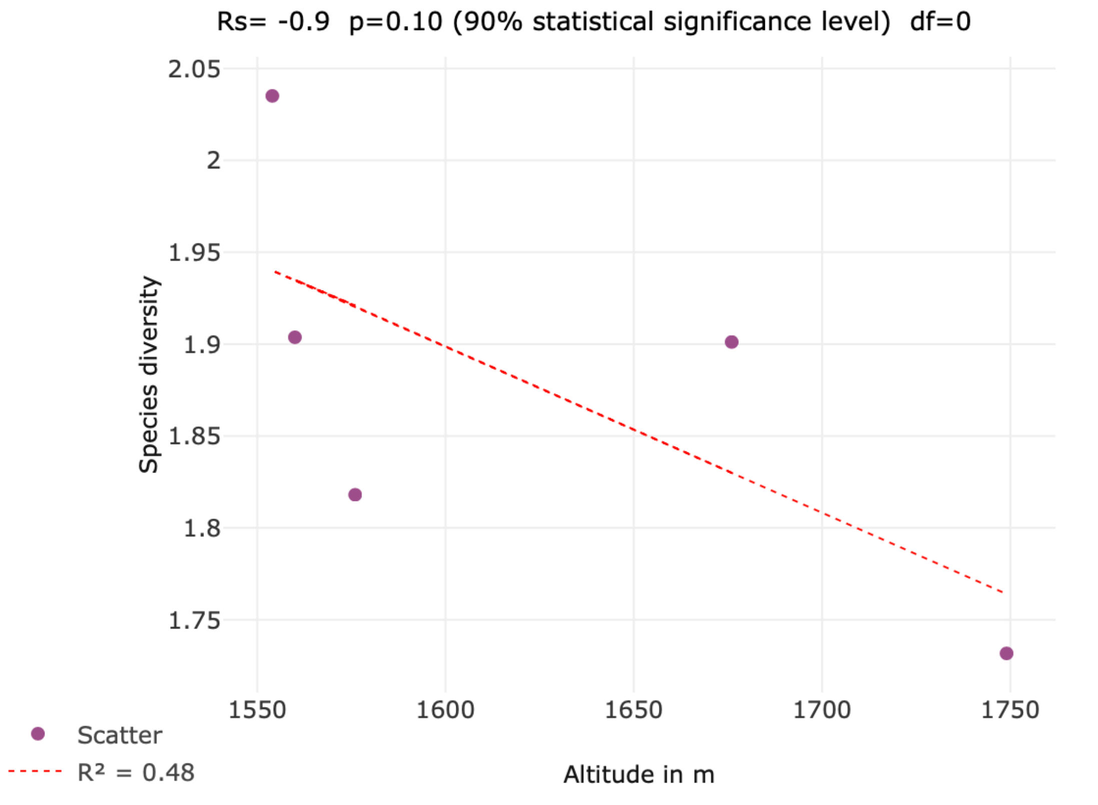

Figure 6: Number of different species at different Altitude at the sites.

There appears to be a very strong negative correlation Rs value (-0.9). There is a 10% probability that the null hypothesis is correct p=0.10 (90% statistical significance level). The null hypothesis must be accepted, that there is no correlation. A general decrease of species occurrence with altitude was observed although it was not a significant difference. The results show that the altitude did not have a significant effect on the species diversity of herpetofauna at the transects seen in Figure 6 (r^2=0.48, p=0.10).

H_0: There is no correlation in altitude related to species abundance.

H_1: There is a correlation between altitude and species abundance at least between two different sites.

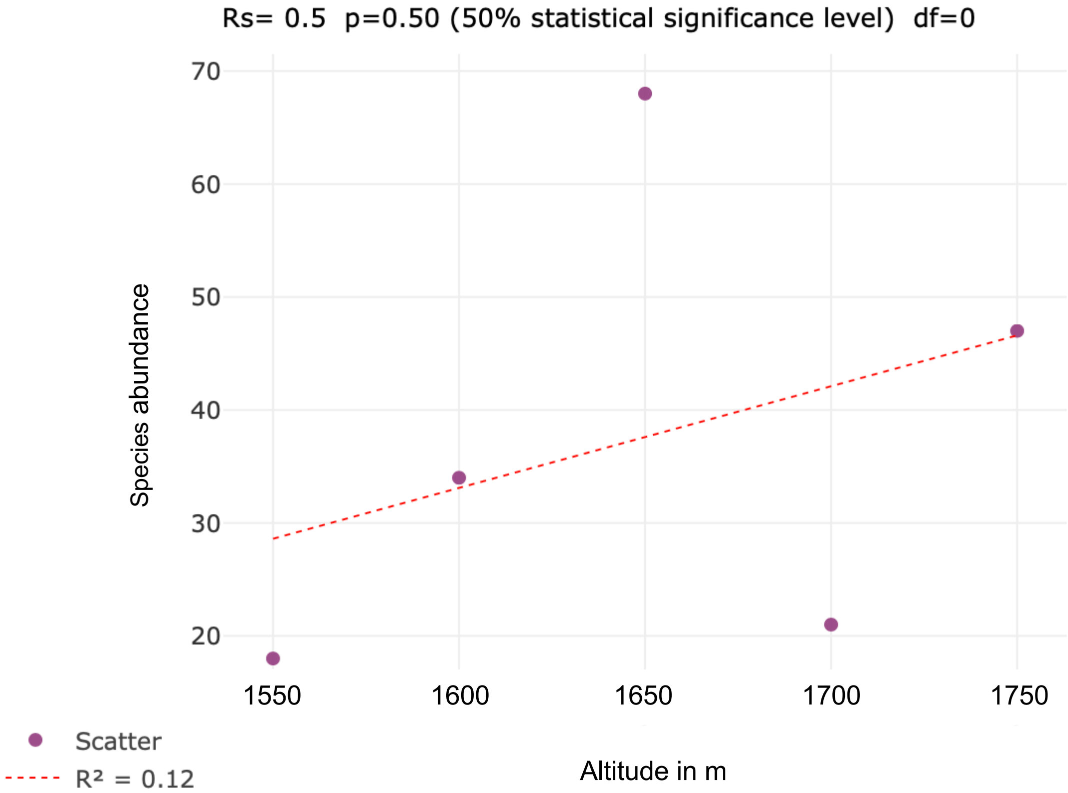

Figure 7: Species abundance in different Altitude at the sites.

There appears to be a moderate positive correlation Rs value (+0.5). There is a 50% probability that the null hypothesis is correct p=0.50 (50% statistical significance level). A decrease of species abundance in higher elevation was ascertained although it was not a significant difference. The null hypothesis must be accepted, that there is no correlation.

Hypothesis H_0: There is no correlation in forest types related to abundance of herpetofauna.
Hypothesis H_a: There is a correlation between forest types and abundance of herpetofauna.

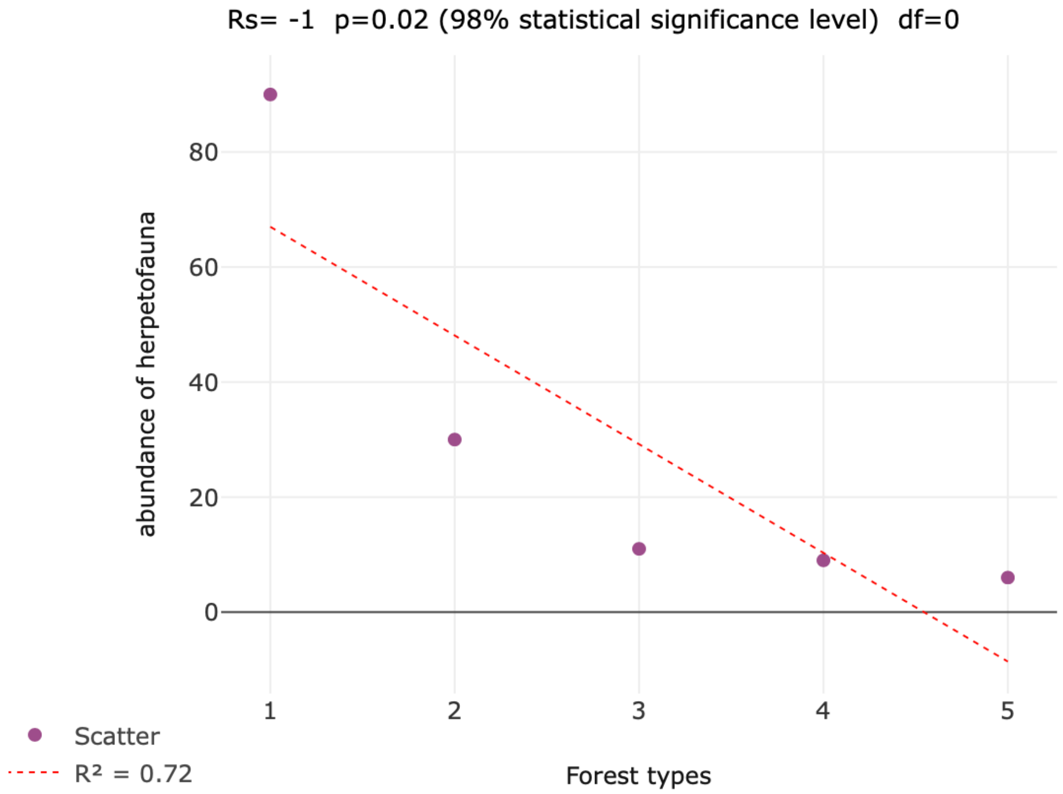

Figure 8: Abundance of herpetofauna in different forest types. Forest types are as follows: 1 = Human Area, 2 = Planted Area, 3 = Natural regrowth, 4 = Secondary Forest, 5 = Old growth.

There is a 2% probability that the null hypothesis is correct p=0.02 (98% statistical significance level). So, the alternative hypothesis must be accepted and reject the null hypothesis as there is a correlation between the forest types and the abundance of herpetofauna (r^2=0,72, p=0.02).

H_0: There is no correlation in Herpetofauna present during Rain or no Rain.

H_1: There is a correlation between Herpetofauna present during Rain or no Rain.

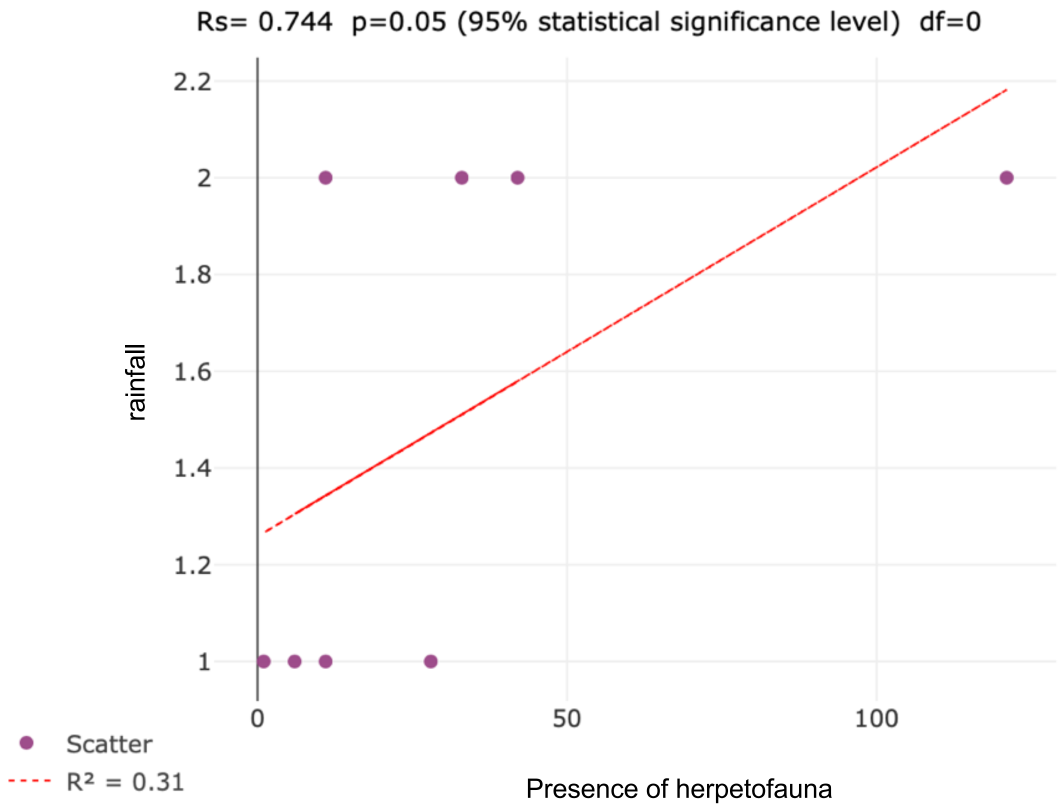

Figure 9: Number of herpetofauna seen in relation to rainfall during the survey. The rainfall is measured as 1 for present or 2 for not present.

A decrease in abundance of herpetofauna with present rain during the surveys was observed and proved that there is a strong positive correlation (Rs=0.744) between rainfall during the survey and the sightings of herpetofauna at the sites (r^2= 0.31, p=0.05). Therefore, it is assumed that rainfall influences the abundance of herpetofauna at the different sites and the H_0-Hypothesis that there is no correlation between rainfall and sightings at the different sites must be rejected.

4. Discussion

A: Species abundance and diversity

The trails were selected according to different habitats, forest types and elevational differences. Although the abundance of individuals was much higher at the Classroom site, with 164 individuals from 12 species the Shannon-Wiener Index, that reveals the species diversity, was slightly less than at the Rio site with only 43 individuals from 10 species and Catarata with 59 individuals observed from 9 species (Table 2). The result shows that the abundance at the Classroom site is higher but the evenness compared with the species richness is lower in contrast to the other sites. Despite the varying habitat structures and forest types, the observed difference was not significant enough to draw conclusions about the underlying reasons. Less abundance at those sites could be associated with higher abundance of predators occurring and poorer observation due to more hiding places. Another influencing factor could be the difference in elevation; it is well known that the abundance of herpetofauna decreases with higher elevation (Duellman 1970). A general decrease of species occurrence with altitude was observed although it was not a significant difference (r^2=0.12, p=0.5).

It was found that only 5 out of 20 observed species were present at each site and 10 out of 22 species could only be found in one of the sites by comparing the similarity of species richness. The results support the idea of different species in different elevation and habitat types. The observation of increased individuals in certain areas of the transects at the Catarata and Rio trail, with a higher density of lower vegetation may show that the vegetation composition influences the abundance. Although the different species were found on many types of lower vegetation which suggests that there is not a specific favorite plant species. The selected trails are located at different elevation, habitats and forest types (Table 1). The result shows that there is a significant difference between forest type and abundance of herpetofauna (r^2=0,72, p=0.02). Therefore, it is assumed that herpetofauna species do have a preferred forest type. The data shows that the average of the abundance was much higher at the human and planted areas compared to the natural regrowth, secondary forest and old growth area (see Figure 3). It is assumed that different valuables like elevation, predator presence and habitat structures influenced the presence of herpetofauna. The degree of disturbance is different at each trail. The Classroom and Rio trail have the most frequently disturbed transects. One transect at the Catarata trail is in comparison less frequently disturbed because it is not accessible for tourists and only volunteers and researchers have access to the trail. It is assumed that the disturbance influences the abundance of herpetofauna, since these species are very sensitive to changes in their surroundings. Less human disturbance might increase the abundance of predators. It is assumed that beside the fact that the Classroom transects have more sun exposure,the presence of predators is less compared to the other trails, because of the human disturbances. Another factor of abundance and diversity present at the transects are that different forest types with more ecological niches enable various species to inhabit bigger places and therefore the abundance and species diversity increases.

B: Species composition relative to considered valuables

Only one species, the *Oedipina savagei,* was observed, which is listed as "Vulnerable" according to the IUCN list, all other species observed are listed as "Least Concern" in the IUCN list (IUCN n.d.).

The *Espadarana prosoblepon* was observed several times at the Rio and Catarata sites and was only observed once at the Classroom site. This result is suggested to be correlated with the availability of water access on both Rio and Catarata sites, and the missing access at the Classroom site. The weather conditions were noted right before every survey, to see if there is a change in the number of observations with different weather conditions. Herpetofauna are particularly sensitive to temperature and moisture conditions and change. The average precipitation was 18,83mm in October (Meteorológica 2024). The high precipitation is correlated with the rainy season from October to December and influenced the abundance of herpetofauna seen during the surveys. A strong correlation between rainfall and the occurrence of herpetofauna at the different sites were observed. The number of sightings decreased with rainfall during the surveys (r^2=0.31, p=0.05) and increased with rainfall right before the surveys. It is assumed that there is a higher abundance of herpetofauna during the wet season compared to the dry season because of the habitat preference in wet and moisture areas of herpetofauna, especially Anurans.

The observed strong correlation between rainfall and the occurrence of herpetofauna at various sites indicates a significant relationship between these environmental factors and the presence of reptiles and amphibians. The study found that the number of herpetofauna sightings decreased significantly during periods of rainfall (p=0.05) when surveys were conducted, suggesting a decrease in visibility or activity of these species under wet conditions. Conversely, there was an increase in sightings when rainfall occurred right before the surveys, potentially indicating heightened activity or emergence of herpetofauna following rain events. These findings highlight the importance of considering weather patterns in ecological studies of herpetofauna and underscore the dynamic nature of their behavior in response to environmental cues such as rainfall. Understanding these relationships is crucial for effective conservation and management strategies aimed at preserving biodiversity in changing environments.

C: Similarity of species at different sites

Surveying for 68 hours resulted in 334 individuals and 20 species of herpetofauna identified. When compared to similar studies in the region, this was a successful rate of encounter. Of the 334 observed species in total, 120 of the individuals are in the *Anolis* genus, 96 of the species are in the *Craugastor* genus and 78 individuals in the *Pristimantis* genus. Frogs were the group most often observed, followed by lizards and snakes. The surveys took place during the day and night. Many of the frog species are nocturnal, meaning that the activity is much higher during the night resulting in a higher observation rate. In comparison the lizards were observed more often during the day in sun exposed places, especially at the Classroom transects. Most of the species were found on leaf vegetation slightly above the ground and in leaf litter on the ground. Across the observation it was interesting that the snakes were mostly observed on the ground, on walls covered with moss and in vegetation about 0.5m above the ground. There were only a few observations in vegetation about 1-1.5m above the ground although snakes are primarily arboreal (Hankin 2022). The fact leads to the assumption that the snakes were hunting prey. The variations in light, canopy coverage, and forest density result in significant differences in vegetation across each site. Despite slight elevation differences among trails (less than 100m at most sites, except for the Catarata and Rio Trail with a 107m difference), these differences are unlikely to heavily influence species abundance and diversity. Vegetation type may influence the presence of herpetofauna, as observed trends suggest certain species are primarily spotted on broad leaves or branches at specific heights above the ground.

The similarity of species decreases with bigger altitude gaps (Table 3). It is assumed that the similarity of species in different sites decreases because of different habitat requirements of the found species as well as other valuables such as weather, vegetation and ecological niches present at each transect. The specific species found at the sites offer insights into the influence of elevation and habitat on species abundance and diversity. The abundance and diversity at the different transects varied. The two transects at the Classroom site were relatively even compared to the difference in abundance at the Catarata and Rio transects. Especially the results from the Rio transects show that the transect right next to a once built pond showed a low abundance of herpetofauna compared with other transects. The pond is not intact anymore and according to the study not inhabited by herpetofauna.

Species in the *Ranidae* and partly the *Centrolenidae* family rely on water for reproduction, unlike the species of the *Craugastoridae* family (Duellman & Trueb 1986). The species of the *Craugastoridae* family are direct developers (Duelman & Trueb 1986). The species of the *Ranidae* family was only found at the garden trail near a pond and the *Centrolenidae* was with one exception only found near water bodies like ponds or streams, potentially due to their dependence on a water source.

Although the abundance of herpetofauna varied between the transects at the Catarata trail the species diversity was relatively high. It is assumed that the level of diversity is related to the heterogeneity of the habitat. The abundance at the C 3+4 transect was low but the species found were valuable and could only be found there, for example the *Imantodes cenchoa* was only observed at that transect. Snakes select habitats that provide suitable conditions for finding and capturing their preferred prey. For *Imantodes cenchoa*, this often means habitats with dense vegetation and diverse microhabitats where lizards and frogs thrive. These snakes are adapted to arboreal life, utilizing trees and foliage to hunt for their prey (Leenders 2019). The presence of snakes can have significant impacts on prey populations, influencing the abundance and behavior of lizards and frogs in their habitat (Greene 1997). Predation pressure from snakes may affect the distribution and activity patterns of prey species, leading to localized fluctuations in their populations. Snakes play a crucial role in maintaining ecological balance by controlling populations of their prey species (Greene 1997). By regulating the numbers of lizards and frogs, snakes like *Imantodes cenchoa* or *Bothriechis lateralis* can help prevent overpopulation of certain prey species and contribute to the overall diversity and stability of the ecosystem (Savage 2002).

Bothriechis lateralis and *Bothriechis nubestris* thrive in humid environments, such as cloud forests (Savage 2002). Those species were found at the Catarata and the Rio Trail on the ground or in the tree. They are commonly encountered near streams, rivers, or other water sources within their habitat (Savage 2002). The presence of tall trees, epiphytes, and dense undergrowth is important for these snakes, as it offers shelter, camouflage, and access to their preferred prey, which includes small mammals, birds, and lizards. While *Bothriechis lateralis* and *Bothriechis nubestris* can be found at various elevations, they are often observed in montane forests at higher altitudes, where cooler temperatures and misty conditions prevail.

Pristimantis cruentus, a species of terrestrial frog, prefers montane forests characterized by dense vegetation and high humidity (Savage 2002). These frogs were found on the forest floor among leaf litter and fallen logs, where they seek shelter and forage for small invertebrates. They thrive in cooler, moist environments, often inhabiting cloud forests and areas close to streams within their montane habitat (Savage 2002). *Pristimantis ridens* is typically found at elevations between 1,200 to 3,000 meters above sea level (Savage 2002). The presence of *Pristimantis cruentus* and *Pristimantis ridens* at every site indicates that the environmental conditions across all sites were suitable for these species to inhabit.

Craugastor crassidigitus is typically found in moist and humid environments within tropical rainforests or cloud forests. They inhabit areas with dense vegetation, including leaf litter, fallen logs, and mossy rocks (Savage 2002). *Craugastor crassidigitus* prefers cooler temperatures and is often found at higher elevations, typically between 500 to 1,500 meters above sea level (Savage 2002). Although the species was found in higher elevations as well, it was especially on the forest floor among leaf litter and on plant leaves. The species was also found near streams and other water bodies within their forest habitat. Conserving the habitat of *Craugastor crassidigitus* is crucial for its survival, as threats such as habitat loss, deforestation, and climate change can negatively impact its population.

Anolis polylepis, also known as the many-scaled anole, as well as *Anolis marsupialis* are species of lizards found in Central and South America. These arboreal lizards prefer habitats with dense vegetation, including tropical rainforests, cloud forests, and montane forests (Savage 2002). They have been found at the Catarata, Classroom and Garden site during the study. They are commonly found in the upper canopy layers of trees, where they can bask in sunlight and hunt for prey although they have only been found in lower vegetation at the sites. *Anolis polylepis* thrives in humid environments and was also found near streams and water sources. Conservation efforts should prioritize protecting their forested habitats to ensure the survival of *Anolis polylepis* and its associated biodiversity.

Threats such as deforestation, habitat fragmentation, and climate change can negatively impact the populations of these species by reducing suitable habitat and disrupting ecological processes. Therefore, conservation efforts for those species should prioritize protecting their forested habitats, the montane cloud forest, to ensure the long-term survival of those species and its associated biodiversity.

D: Limitations

The surveys only took part on specific times during the day with different people, different knowledge and skills. Furthermore, the survey was heavily influenced by weather conditions as discussed before. Additional research that integrates Visual Encounter Surveys (VES) with calling surveys could be beneficial in herpetology, particularly for identifying individuals that predominantly inhabit the canopy throughout their lives. Furthermore, it would be interesting to focus on abundance change in the wet and dry season whether the abundance fluctuates with different temperatures. It would also be interesting to continue the study long-term to see if there is going to be an increase in species abundance in higher elevations with time.

5. Conclusion

In conclusion, the main question (H I) whether elevation and habitat like forest types influence the herpetofauna diversity and abundance was rejected. The data shows that there was a slight decrease towards higher elevation. There was a significant difference between rainfall and herpetofauna present at the sites. The result shows that it is important to consider factors like weather or predators and competitors at higher elevation to the study valuables. This study provided insight into the abundance and diversity of herpetofauna species in different elevations of a tropical cloud forest. There are various valuables that can be considered in further studies to understand the reasons of fluctuation and species decline better. It is still little known about herpetofauna and how to protect the species in different habitats. Overall, most regional studies align with the results, indicating that protected areas will be crucial for safeguarding herpetofauna under the impacts of climate change (Mi et al. 2023). Therefore, studying the abundance and diversity of species to understand their habitat preferences in different locations is essential for effective conservation efforts. It is important to create and protect habitats in higher elevations regarding the forecast of increasing range shifts of habitats for herpetofauna. It is likely for herpetofauna species to extend their ranges into higher elevation due to rising temperatures or changes in vegetation composition. Conservation efforts need to adapt to those changes to ensure protected sites at various elevational gradients.

6. References

Cooperrider, A., Boyd, R. J., Stuart, H. R., & McCulloch, S. L. (1986). *Inventory and monitoring of wildlife habitat* (pp. 1–858). Denver, Co.: U.S. Dept. of the Interior, Bureau of Land Management. https://archive.org/details/inventorymonitor00coop/page/268/mode/2up.

Cox, N., Young, B. E., Bowles, P., Fernandez, M., Marin, J., Rapacciuolo, G., Böhm, M., Brooks, T. M., Hedges, S. B., Hilton-Taylor, C., Hoffmann, M., Jenkins, R. K. B., Tognelli, M. F., Alexander, G. J., Allison, A., Ananjeva, N. B., Auliya, M., Avila, L. J., Chapple, D. G., Xie, Y. (2022). A global reptile assessment highlights shared conservation needs of tetrapods. *Nature*, *605*(7909), 285–290. https://doi.org/10.1038/s41586-022-04664-7.

Doan, T. M. (2003). Which methods are most effective for surveying rain forest herpetofauna? *Journal of Herpetology*, *37*(1), 72–81. https://doi.org/10.1670/0022-1511(2003)037[0072: wmamef]2.0.co;2.

Duellman, W. E., & Trueb, L. (1986). Biology of Amphibians. McGraw-Hill.

Duellman, W. E. (1966). The Central American herpetofauna: An ecological perspective. *Copeia*, *1966*(4), 700. https://doi.org/10.2307/1441403.

Environment. (n.d.). Embajada de Costa Rica En DC. Retrieved December 3, 2023, from http://www.costarica-embassy.org/index.php?q=node/12.

Foster, P. (2001). The potential negative impacts of global climate change on tropical montane cloud forests. *Earth-Science Reviews*, *55*(1–2), 73–106. https://doi.org/10.1016/s0012-8252(01)00056-3.

Giddy, I. (n.d.). *The Cloud Forest/el bosque nuboso*. Retrieved December 3, 2023, from http://www.cloudbridge.org/wp-content/uploads/2011/10/NatureNotesNo1.pdf-.

Global amphibian assessment 2 – IUCN SSC Amphibian Specialist Group. (n.d.). IUCN SSC Amphibian Specialist Group About Working Group. Retrieved December 3, 2023, from https://www.iucn-amphibians.org/red-listing/global-amphibian-assessment-2/.

Grabherr, G., M. Gottfried, & H. Paull. (1994). Climate effects on mountain plants. Nature 369: 448.

Greene, Harry W. (1997). Snakes: The Evolution of Mystery in Nature. University of California Press.

Hankin, E. (2022). *From river to ridge: The influence of elevation and habitat on herpetofauna species abundance and diversity in the llanganates-sangay ecological corridor, ecuador*. SIT Digital Collections. https://digitalcollections.sit.edu/isp_collection/3475.

Hannah, L. (2011). Ecosystem change. In *Climate Change Biology* (pp. 101–130). Elsevier. http://dx.doi.org/10.1016/b978-0-12-374182-0.00005-4.

Jarvis, A., & Mulligan, M. (2010). The climate of cloud forests. *Hydrological Processes*, *25*(3), 327–343. https://doi.org/10.1002/hyp.7847.

Leenders, T. (2016). *Amphibians of Costa Rica: A field guide*. Comstock Publishing Associates.

Leenders, T. (2019). *Reptiles of costa rica: A field guide*. Comstock Publishing Associates.

Mi, C., Ma, L., Yang, M., Li, X., Meiri, S., Roll, U., Oskyrko, O., Pincheira-Donoso, D., Harvey, L. P., Jablonski, D., Safaei-Mahroo, B., Ghaffari, H., Smid, J., Jarvie, S., Kimani, R. M., Masroor, R., Kazemi, S. M., Nneji, L. M., Fokoua, A. M. T., … Du, W. (2023). Global Protected Areas as refuges for amphibians and reptiles under climate change. *Nature Communications*, *14*(1). https://doi.org/10.1038/s41467-023-36987-y.

Mifsud, D. A. (2014). A status assessment and review of the herpetofauna within the Saginaw Bay of Lake Huron. *Journal of Great Lakes Research*, *40*, 183–191. https://doi.org/10.1016/j.jglr.2013.09.017.

Mitchell, A., & Bergmann, P. J. (2015). Thermal and moisture habitat preferences do not maximize jumping performance in frogs. *Functional Ecology*, *30*(5), 733–742. https://doi.org/10.1111/1365-2435.12535.

Savage, J. M. (2002). *The amphibians and reptiles of Costa Rica: A herpetofauna between two continents, between two seas*. University of Chicago Press.

The IUCN red list of threatened species. (n.d.). IUCN Red List of Threatened Species. Retrieved April 12, 2024, from https://www.iucnredlist.org.

Urbina-Cardona, J. N. (2008). Conservation of neotropical herpetofauna: Research trends and challenges. *Tropical Conservation Science*, *1*(4), 359–375. https://doi.org/10.1177/194008290800100405.

Wake, D (2007). Climate change implicated in amphibian and lizard declines. *Proceedings of the National Academy of Science, 104*(20), 8201-8202. www.pnas.orgcgidoi10.1073pnas.0702506104.

Whitfield, S. M., Bell, K. E., Philippi, T., Sasa, M., Bolaños, F., Chaves, G., Savage, J. M., & Donnelly, M. A. (2007). Amphibian and reptile declines over 35 years at La Selva, Costa Rica. *Proceedings of the National Academy of Sciences*, *104*(20), 8352–8356. https://doi.org/10.1073/pnas.0611256104.

7. Appendix

Appendix A

Table 1: Species observed during the surveys.

	Rio	Catarata	Classroom	Sentinel	Garden
Toads					
Rhinella marina	1				
Frogs					
Craugastor crassidigitus	13	10	47	6	9
Craugastor melanostictus	1		4		
Craugastor podificerus	2			2	
Craugastor underwoodi			1		
Espadarana prosoblepon	8	14	1	2	9
Pristimantis cruentus	9	13	3	6	8
Pristimantis ridens	4	7	20	3	5
Rana warszewitschii					2
Salamander					
Oedipina savagei	1				
Lizards					
Anolis altae			1		
Anolis limifrons		2	13		2
Anolis marsupialis		8	39		
Anolis pachypus			2		
Anolis polylepis			32		7
Anolis woodi	3	1	1		3
Snakes					
Bothriechis lateralis	1	3			2
Bothriechis nubestris				1	
Geophis brachycephalus				1	
Imantodes cenchoa		1			
Total	43	59	164	21	47