Comparing herpetofauna diversity in a tropical terra firme rainforest and nearby grassland

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Introduction

The destruction or modification of ecological systems is a primary cause of species decline (Vitousek *et al*. 1997; Sala *et al*., 2000). Since habitat loss is the main cause of amphibian and reptile extinctions (Lips *et al*., 2005; Blaustein *et al*., 2011; Böhm *et al*., 2013; Doherty *et al*., 2019), it is important to compare herpetofauna diversity between disturbed and undisturbed habitats. One review estimated that Latin American amphibians may be at serious risk of extinction (Lips *et al*., 2005). Habitat loss, a pathogenic fungus, climate change, introduced exotic species and over-exploitation have all been associated with amphibian declines (Young *et al*., 2001; Daszak *et al*., 2003; Lips *et al*., 2005; Von May *et al*., 2008). Furthermore, these factors and others act synergistically at both population and species levels (Blaustein *et al*., 2010). Reptiles are declining for much of the same reasons as amphibians (Gibbons *et al*., 2000; Todd *et al*., 2010), i.e., primarily due to habitat loss and modification (Böhm *et al*., 2013), but also unsustainable removal, pollution, climate change, invasive species, disease and parasitism, and trophic cascades (Todd *et al*., 2010). The exact proportion of reptiles and amphibians that are declining globally are unknown but Böhm *et al*., (2013) has made a useful estimate by assuming that data deficient species are declining in the same proportion as non-data deficient species. Therein, applying this assumption to Stuart *et al*., (2004), it was estimated that about 42% of the world's amphibians are threatened, compared to 20% of the world's reptiles (Böhm *et al*., 2013). Amphibian habitat loss is caused by factors such as old mining, logging, slash and burn agriculture, and climate (McMenamin *et al*., 2008; Von May *et al*., 2008; DeFries and Rosenzweig, 2010; Davidson *et al*., 2012), while reptile habitat loss is caused by mining, logging, agriculture, infrastructure development, golf course construction, and lake dredging for recreation activities (Todd *et al*., 2010; Doherty *et al*., 2019). Due to the continuing destruction of tropical rainforests (Seymour and Harris, 2019), a large proportion of amphibians and reptiles are threatened (Gibbons *et al*., 2000; Stuart *et al*., 2004; Lips *et al*., 2005; Bohm *et al*., 2013). This study will compare estimates of herpetofauna alpha diversity between a terra firme rainforest and a clear-cut grassland to estimate the local impact of deforestation on a tropical herpetofauna community.

Methods

Study site

The Finca Las Piedras Research Station, hereafter Finca, is the field site of the Alliance for a Sustainable Amazon, located in the Madre de Dios department of Peru (S 12°13.570'; W 069°06.850'). Finca contains terra firme rainforest, grassland, and palm swamp (aguajal). The terra firme rainforest was selectively logged over the last 30-40 years for spanish cedar (*Cedrea odorata*), big-leaf mahagony (*Swietenia macrophylla*), and ironwood (*Dipteryx micrantha*). Data collection took place between 11th Nov 2022 and 4th Dec 2022.

Pitfall trap arrays

The pitfall traps were setup in Y-shaped arrays according to Corn and Bury, (1990). Two forest pitfall trap arrays were constructed in 2017, and two grassland pitfall trap arrays were constructed this year. Data was collected from all four traps between 11th November 2022 and the 4th December 2022. Traps were checked at sunrise and sunset. For each specimen, the time of day (sunrise/sunset), the weather, habitat type (forest/grassland), family, genus, species, and the number of individuals were recorded.

Visual Transects

Visual transects were conducted at night for one-hour transect walks in each habitat. Only time spent actively looking for individuals was counted towards survey time. Forest transects were conducted along forest trails, documenting all amphibians and reptiles seen. Photos were taken of each individual in situ. Then the individual was placed in a transparent container for photographing of all sides of the animal. All snakes were considered potentially venomous and therefore were not captured, only photographed, as per the advice of Eekhout, (2010). Habitat was checked 0.5m either side of the trail. Due to ground invisibility in the grassland, transects were conducted along grass verges, roads, paths and bare ground criss-crossing the habitat. Decomposed logs and piles of slash were checked infrequently in both forest and grassland habitats and no individuals were found using this method. Repeated identical transects on consecutive days were avoided to prevent counting the same individual twice (sensu; Rodel and Ernst, 2003). Individuals heard but not seen were excluded. For each specimen, the time, weather, habitat type (Forest/Grassland), family, genus, species, and the number of individuals were recorded.

Statistical analysis

Using the R statistics program (v 4.2.2 for intel macs), a test for normality was conducted. Since the data from the grassland habitat was non-normal ($P<<0.05$), the Mann-Whitney U test was used to compare habitats. The Mann-Whitney U test was conducted on the Shannon Entropy values for each day for each habitat to see if there was a difference in alpha diversity between habitats. Shannon's Entropy was calculated using the formula:

$$e^{H_1}$$

where $H_1 = -1\sum pi\text{Ln}pi$,

and pi = proportion of sample made up by species i. The calculation is then summed across all species.

The two main drawbacks of using simple species counts are that they ignore the abundances of individual species, and they are highly dependent on sample size (MacArthur, 1965). Species richness is simply the number of different species in a sample but it can be very laborious to determine accurately, even when focusing on a single taxonomic group or guild. For example, it took Vojtech Novotny five "scientist years" to catalogue all the leaf-chewing insect species in just 1-hectare of rainforest (Novotny *et al.*, 2004). The relative abundances of species within a sample can vary spectacularly. In fact, most communities have a few highly abundant species and many that are rare (Eichhorn, 2016). For example, across Amazonia there are an estimated 16,000 tree species but just 227 make up more than half of all individuals (ter Steege *et al.*, 2013). Clearly, species richness is unsuitable and insufficient and when dealing with a very large number of individuals. Unlike species richness, diversity takes into account the relative proportion of each species (Hill, 1973; Tuomisto, 2010). In addition, diversity requires much less data to estimate accurately (Eichhorn, 2016). There are three main diversity indices which differ in their inclusion or exclusion of rare species: Species richness, Shannon's entropy, and Simpson's index. Shannon's entropy is the uncertainty in the identity of a randomly chosen individual from a sample. One unfortunate caveat of the study is that the basic form of shannon's entropy formula used above only provides a value for sample diversity but not population diversity. Since the sample size was very small in both habitats, the community diversity of either habitat cannot be reliable inferred from the results.

Results

The Mann-Whitney U test was conducted on the shannon entropy values for each day of non-zero sampling in each habitat. Days in which zero individuals were found, were excluded for this purpose because it is impossible to determine the diversity of a sample with zero individuals. The Mann-Whitney U test returned ($W = 55.5$, p-value <0.05), thus the null hypothesis was rejected in favour of the alternative. There is a difference in diversity of the samples between the grassland and forest habitats. A boxplot of the Shannon entropy values shows a visual difference between habitats (Fig. 1).

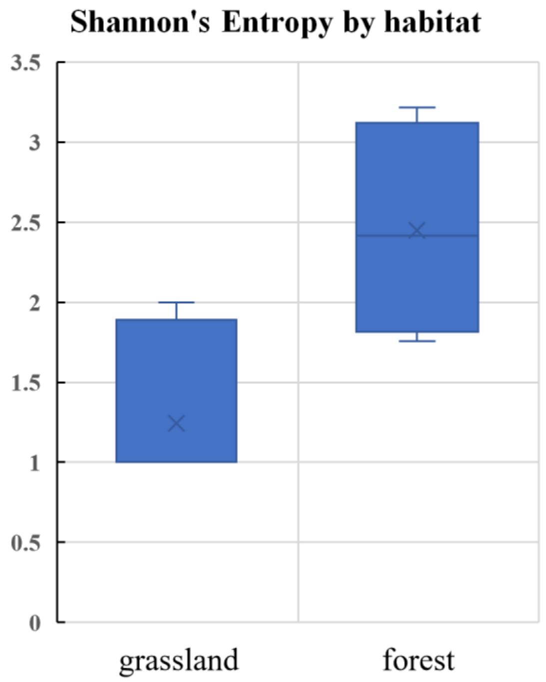

Fig. 1. Compares the shannon entropy values for grassland and forest habitats. The forest habitat has a higher mean ($\bar{\mu} = 1.25$) than the grassland habitat ($\bar{\mu} = 2.49$).

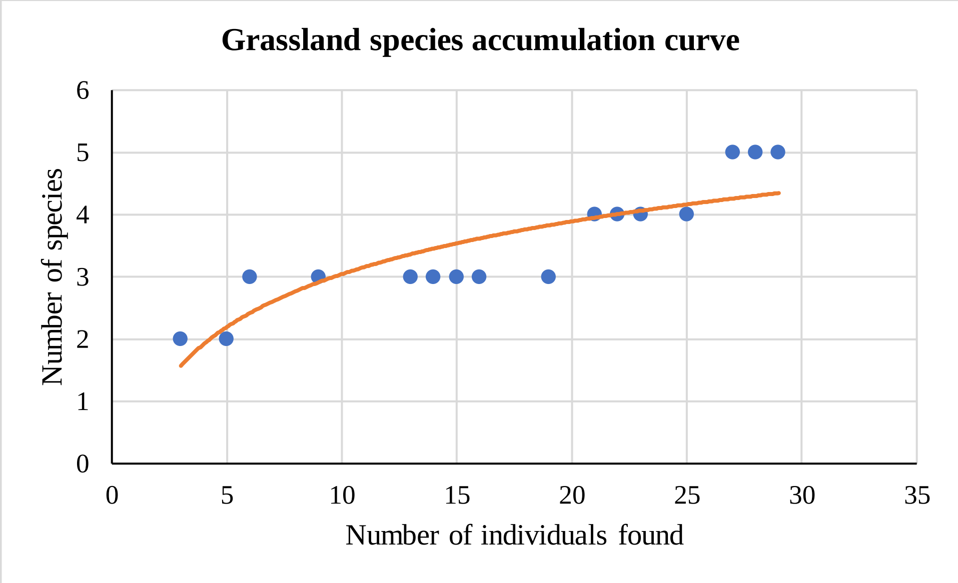

Fig. 2. Shows the relationship between survey effort and species richness, i.e., the number of individuals found (x-axis) versus the number of new species encountered (y-axis), in the grassland habitat. Here the first nineteen individuals sampled equated to just three different species.

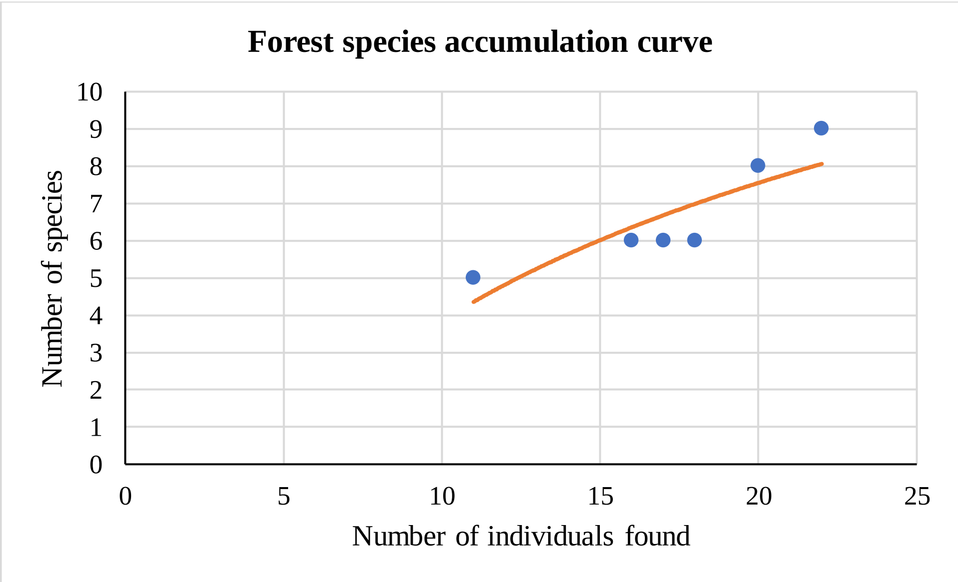

Fig. 3. The same as Fig. 2 but for the forest habitat. Shows the relationship between survey effort and species richness, i.e., the number of individuals found (x-axis) versus the number of new species encountered (y-axis). Here five species were found in the first 11 individuals sampled. Note that the forest curve is much steeper than the grassland curve in Fig. 2, suggesting that more sampling would find many more species in this habitat.

Discussion

There are over 114 species of amphibians in Madre de Dios, Peru (Von May *et al*., 2008). Amphibians are useful for comparing species richness and composition between sites (Von May *et al*., 2008). Alpha diversity refers to species diversity within a community and does not account for space or time (Ochoa-Ochoa *et al*., 2012), i.e., it is the number of species in a community at a particular time. In practice, calculating species richness is exceedingly difficult because as sample size increases, so too does the number of species. This is called the species-area relationship (MacArthur and Wilson, 1967). The rainforest habitat had a greater estimate of alpha diversity compared to the grassland. This finding meets expectations for several reasons. Tropical forests are one of the most biodiverse habitat types, and so it is no wonder that the terra firme habitat harboured more herpetofauna species than a nearby open grassland. Despite covering just 10% of the Earth's land area, tropical forests house between a half and two-thirds of the world's species (Lewis, 2006). Furthermore, 49% of the world's tropical forests are in tropical America (Lewis, 2006).

Laurence and Cochrane, (2001) state that "habitat loss and fragmentation are probably the most important threats to global biodiversity". Habitat modification, fragmentation or destruction causes species decline (Vitousek *et al.* 1997; Sala *et al*., 2000). Habitat modification is a primary cause of reptile decline (Doherty *et al*., 2019). Species survival is predicted to be inversely proportional to habitat fragmentation, i.e., patch area and distance between patches (MacArthur and Wilson, 1963; Kindvall and Ahlen, 1992). One potential drawback of the current study is that the grassland habitat was much smaller and more isolated from similar habitat compared to the rainforest habitat. This may have reduced the effective number of species in this habitat, exaggerating apparent differences in herpetofauna diversity between the grassland and forest. Indeed, in a book entitled "The theory of island biogeography", MacArthur and Wilson, (1967) describe that both area and isolation can influence the population dynamics of habitat fragments. Conversion of tropical forests to grasslands extirpates most plant species and those animals which depend on them for habitat (Sala *et al*., 2000). Empirical field studies of fragmented habitats can yield important insights into the responses of taxa to fragmentation; however, care must be taken to take consideration of anthropogenic effects (Laurence and Cochrane, 2001). Fragments should be viewed not just in the classical perspective of MacArthur and Wilson, (1967), which mainly focuses on fragment area and isolation, but also with consideration to anthropogenic influences such as increased hunting, pollution, and extreme weather. Such factors can act synergistically with area and isolation (Laurence and Cochrane, 2001). The current study did not take potential anthropogenic effects into account.

Structural complexity may partly explain why tropical forests have a high number of animal species (Eichhorn, 2016). Indeed, tropical forests are much more diverse than boreal forests despite growing on much poorer soils (Eichhorn, 2016). The much lower structural diversity of grasslands might partly explain why this habitat had a lower species diversity compared to the rainforest habitat. Habitat heterogeneity may influence amphibian species richness and composition at the local and regional scale (Von May *et al*., 2008).

Coexistence occurs when there are multiple limiting resources and each species has the largest effect on the resource it is most limited by (Dybzinski and Tilman, 2007; Eichhorn, 2016). If there is just one limiting resource or constraint, and all other resources are excessively abundant with no constraints, species are not expected to coexist at equilibrium, unless there is habitat heterogeneity in space or time (the storage effect) (Eichhorn, 2016). Rainforests have significant habitat heterogeneity across space and time (Eichhorn, 2016). This might help explain why rainforests are so diverse and why the current study found more herpetofauna species in the rainforest (n=8) compared to the grassland (n=4).

Eichhorn, (2016) states that "the starting point of any study of species richness should be to draw a species accumulation curve which reflects the number of species caught per unit effort". Curves for the grassland and forest habitats are illustrated in figures 2 and 3, respectively. The forest curve of Fig. 3 is much steeper than the grassland curve of Fig. 2, suggesting that many species are yet to be found in the forest habitat. Indeed, this is likely since lowland rainforest of the Madre de Dios region holds more than 114 species of amphibians (Von may *et al*., 2008). Species accumulation curves approach the asymptote of species richness (the actual number of species in a community). Fig. 3 shows no sign of reaching an asymptote but Fig. 2 appears to be flattening. Although there is not enough data to make a confident estimate, it appears that the five species sampled in the grassland habitat (Fig. 2) is much closer to the actual number of species of this habitat, compared to the nine species sampled in the forest habitat (Fig. 3). Indeed, the species accumulation curve of the forest habitat shows no sign of approaching its asymptote for species richness (Fig. 3). Thus, the species accumulation curves support the finding that the forest habitat has a much higher diversity of species.

Conclusion

The forest herpetofauna community of the Finca Las Piedras research station, Peru is probably much more diverse than the grassland herpetofauna community of the same. This provides evidence that deforestation has negative consequences for herpetofauna communities at the local scale. Due to their limited dispersal ability, habitat modification has a large impact on amphibians, especially since many species are highly philopatric, i.e., they prefer to stay in the same area (Gardner, 2001). Furthermore, herpetofauna are important for ecosystem functioning and trophic relationships. For example, amphibians often represent the highest fraction of vertebrate community biomass, and amphibians and reptiles occupy primary, mid-level and top trophic levels in neotropical ecosystems (Gardner, 2001; Beirne *et al*., 2013). Therefore, due to the ecological importance of amphibians and reptiles, humans should work to reduce deforestation, especially in areas with high diversities of herpetofauna.

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Appendix.1.

The table shows the identity of species found in each habitat. Only one species occurred in both habitats: *Leptodactylus unknown*. Since this species was not identified to species level it is possible that the individuals found in the forest were in fact separate species, just with a very similar appearance to the grassland individuals.

Habitat	***Family***	***Genus***	***species***	**number of individuals**
grassland	*Teiidae*	*Ameiva*	*ameiva*	6
grassland	*Leptodactylidae*	*Leptodactylus*	*Unknown*	21
grassland	*Gymnophthalmidae*	*Cercosaura*	*eigenmanni*	1
grassland	*"Species X2"*	*Unknown*	*Unknown*	1
forest	*Microhylidae*	*Ctenophryne*	*geayi*	4
forest	*Microhylidae*	*Hamptophryne*	*boliviana*	8
forest	*Bufonidae*	*Rhinella*	*roquena*	1
forest	*"Species X1"*	*Unknown*	*Unknown*	1
forest	*Polychrotidae*	*Anolis*	*nitens*	1
forest	*Dendrobatidae*	*Unknown*	*Unknown*	1
forest	*Leptodactylidae*	*Leptodactylus*	*rhodomystax*	1
forest	*Leptodactylidae*	*Leptodactylus*	*Unknown*	3
Total				49