The strawberry poison-dart frog *(Oophaga pumilio)* density in relation to environmental variables

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Preface

This study on the density of the strawberry poison-dart frog In relation to environmental factors has been achieved in collaboration with COTERC and its staff, without whom this project would not have been possible. Thanks to the HAS university who provided the opportunity for this study. In particular I would like to thank Tamarah Lohman, Helen Pheasey, Elias Bader, Osama Almalik, Tom Boonen and Emily Khazan for their feedback and support. Thanks to my parents who gave me financial support. Thanks to Remco Quijs for his assistance on literature search queries. Special thanks to Sofia Papakonstantinou, Lieve Hurkens, Jeffrey Willems, Megan Garniers and Phillip Mercier for assisting with fieldwork. And thanks to Charlotte Foale, station manager, for accepting me as an intern and providing logistical support.

Table of Contents

Abstract

It is known that amphibians globally suffer from climatic changes and deforestation. Long-term population studies are required to monitor the decline of species. Using repeated counts an abundance estimate of the strawberry poison-dart frog (*Oophaga pumilio*) could be established for the Caño Palma Biological Station grounds. A total of 36 randomly selected ~36m² (M = 42.10m², SD = 6.51m²) plots were surveyed. These plots were marked with flagging tape. Each location was selected to be 36m apart from another plot to insure independence. The plots were surveyed in 4 transects to ensure the entire area was observed. Timed surveys of 5-10 minutes were conducted. Every location was visited 5 times. Surveys took place between 07:00 and 16:00. An interval of at least four days was left to ensure disturbance within the plot was kept to a minimum between samples. Environmental variables that were measured were; bromeliads, cloud cover, inundated area, leaf litter, temperature and canopy cover. Two plots were removed from the analysis due their deviation in size. Abundance was estimated at 88.55 frogs. Density was calculated on 7 frogs per 100m². The combination of the following variables had the most explanatory value; bromeliads, cloud cover, rain, canopy. However with only 10 bromeliads counted over all the 34 plots suggests bromeliads had very low explanatory value. Environmental factors that reduce risk of desiccation such as: canopy cover, cloud cover and rain seemed to have the most influence on the abundance estimate or detectability. Because calling male calling behaviour does not influence the detectability, no standardising for survey periods is required because frogs counted before and after 10:00 were equally distributed.

1. Introduction

It is known that globally amphibians suffer from climatic changes and deforestation (Araújo et al., 2006;Pounds et al., 2006; FOA 2009). This decline has resulted in an increased interest in knowledge about amphibians (Wilbur, Blaustein, & Wake 1990). Long-term population studies are key to determining the significance of this decline. Due to the physiological constraints of amphibians, species typically have small ranges and they generally maintain high site fidelity. This can prevent fast repopulation of areas after local extinction (Blaustein, Wake and Sousa, 1994). One of the species in decline is the Strawberry poison-dart frog (*Oophaga pumilio)* (Solís et al., 2010). Despite its decreasing numbers, this species is currently declared least concern by the IUCN, mostly due its wide ranging habitat (Solís et al., 2010). As of yet, there is little research on the density of *O. pumilio* which makes for an interesting opportunity to study this species.

1.1 Oophaga. pumilio

O. pumilio is a small frog of the family Dendrobatidae with a mean snout-vent length ranging from 17-24 mm (Savage, 2002). It exhibits numerous colour variations, many of which many can be found in Bocas del Toro archipelago off the east coast of Panama (Sandmeier, 2001). At Caño Palma Biological Station in Northeast Costa Rica, the majority of *O. pumilio* individuals are red, dark red, or orange with few exhibiting completely blue legs. This terrestrial species inhabits lowland wet and pre-montane rainforest ranging from southern Nicaragua to western Panama along the coastal forest regions.

O. pumilio males have a distinct call that consists of short chirps lasting between 5 and 30 seconds. They use this call to announce sexual availability and to defend their territory. Males are very territorial and can be found calling from elevations of up to 1m above the ground (Savage, 2002). There are four known calls. The most common can be heard between 8:00 and 10:00 and is used to defend their territory (Walls, 1994; Sandmeier, 2001). Graves (1999) found that *O. pumilio* was highly active in the morning and this level of activity gradually declined towards mid-day. This would suggest that more frogs are visible before 10:00.

The female home-range (~36m²) is much larger than their territory (~2m²) and overlaps with male territories (~15m²) (Meuche, et al 2013).

The species' breeding strategy is well documented and breeding occurs year-round (Weygoldt, P., 1980; Pröhl, H., Hödl, W. 1999; Savage, 2002). The female lays between 3-17 eggs in the leaf litter. The male protects the eggs and keeps them moist with urine. When the eggs hatch, the female moves the individual tadpoles on her back to an elevated tadpole rearing site, usually a bromeliad filled with water. She visits the bromeliads daily to lay an egg as a food source for the tadpoles. Only one tadpole is typically deposited per bromeliad, however when more than one tadpole is reared in the same site, only one survives (Duellman, 1986).

O. pumilio adults and juveniles feed on a wide variety of prey, using their tongues to catch it. Formicine ants are an important part of their diet because they provide the toxins that *O. pumilio* excretes from their skin (Donnelly, 1991). In captivity *O. pumilio* can live for 7.5 years ("AnAge entry for *Oophaga pumilio*", 2014). However there are no clear data on how long *O.pumilio* live in situ.

1.2 Density

Density is the number of individuals per given area. In order to determine the relationship between the density of *O. pumilio* and environmental factors of a given site, the density itself must be measured. The density of a population is dependent on numerous factors including birth rate, death rate, immigration, and emigration. Behaviour and feeding strategy also play an important role in the dispersion of species (Donnelly, 1989a). Therefore the environmental factors measured were chosen based on their expected influence on *O. pumilio* behaviour (Donnely 1989). Cloud cover, rainfall, temperature and canopy cover are all expected to influence the risk of desiccation of *O. pumilio.* Areas inundated with water are expected to influence breeding behaviour e.g. they facilitate keeping eggs moist. Availability of leaf litter is expected to influence flight and/or travel behaviour. Assuming that one leaf is enough to hide from predators, leaf litter depth is not measured. Since *O. pumilio* is assumed to adjust its diet based on the availability of food this has not been taken into account (Donnelly, 1991).

The goals of this study are to (1) determine the density of *O. pumilio*, (2) how this correlates with species-specific environmental variables at the Caño Palma Biological Research Station and (3) if the time surveys take place could influence detectability. Monitoring the species over several years will help determine the extent of decline or increase among *O. pumilio* in this population.

2. Materials and method

2.1 Location

The study took place South of Barra del Colorado Wildlife Refuge near Tortuguero National Park, Costa Rica. The research site was located adjacent to the Caño Palma Biological Station (022 3420 N, 117 2150 E).

2.2 Plot selection

Starting 50m from the Caño Palma base a tree on the left side of the path was selected. From this point forward every 42m a tree on the opposite side of the path was selected. All selected trees were labelled with a number. When there was no more space to label a tree 42m from the next, due a limited trail length, random number generation was used to select 36 out of the X amount of trees to become plots. Every plot was approximately 6x6m but due to the lack of trees exactly 6m from each other, some plots are smaller or bigger than others. Plots that turned out to be too big (60m²>) were removed from the analysis. All plots had their surface area calculated and this was used as a variable to determine the explanatory value of surface area on the detection of frogs within a plot. The 42m between plots ensured that all plots were independent based on female home range size, even when a corner of one plot is 6m closer to the following plot there was still 36m in between.

2.3 Counting

Frogs were counted within the plots and on the roots of trees that are part of the boundary. Counting took place between 07:00 and 16:00. Counting was undertaken by walking up and down the plot in 4 small transects. The first transect was from the 1st labelled tree to the 2nd labelled tree along the path. Then the counter would step approximately 2m away from the path and walk back through the plot parallel to the path followed before. When just outside the plot boundary the counter would step another 2m away from the path and walk parallel to the path. The 4th transect is walked on the outer border between the 2 plot markers that are furthest away from the path (figure 1).

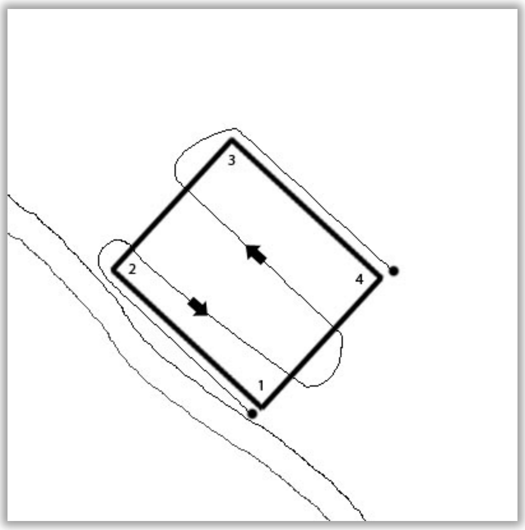

Figure 1, counting method

The transect starts at the 1st tree labeled along the path. There is a distance of approximately 2m between each of the 4 transects. Out of the 4 transects 2 are at the boundary of the plot (the first and last).

2.4 Co-variables

Co-variables were collected alongside counting the frogs. These data were collected prior to the counting due the disturbing effect of a surveyor walking through the plot. Co-variables included time, date, surveyor, cloud cover, rainfall, inundated area and, leaf litter cover.

Time and date of counting was noted for several reasons. Graves (1999) suggested that most *O. pumilio* activity occurred before 10:00. To investigate if this could influence detectability, and therefore the abundance estimate, count data from before and after 10:00 was compared. Secondly the time and date can be used to correlate against temperature data recorded at the station. The temperature data is recorded once every hour with a logger owned by COTERC. Sampling time was rounded down to 5 minutes so temperature data closest to the sampling time was used. In cases where sampling time was in the middle of two temperature data points, the average was calculated.

The cloud cover is assessed in percentages. It was noted as 0, 25, 50, 75 or 100%. Cloud cover can influence local temperature and might therefore be more accurate than the hourly temperature data collected by the logger. When standing at the 1st corner post of a plot the counter would look straight up and based on the amount of blue sky the cloud cover was determined (e.g. a full blue sky would be 0% cloud cover).

Rainfall was based on a scale from 0-2. Where 0 would define no rain at all, 1 would be drizzle or rain and 2 would be heavy rain.

Inundated area is assessed in a percentage based scale. Similar to the cloud cover scale the inundated area is 0, 1-25, 26-50, 51-75, or 76-100% recorded simply as 0, 25, 50, 75, and 100 respectively. Because it is sometimes hard to assess the inundated area from the corner post this data is sometimes collected after the counting

Leaf litter cover is estimated in a percentage of the ground covered. To reduce the chance of being biased across years due to different surveyors the scale is in 0, 25, 50, 75 or 100%. In case of an inundated area only the dry ground was part of the leaf litter cover assessment. Due the terrestrial nature of *O. pumilio* it was not expected to hide underneath leaves that were under water.

2.5 Bromeliad counting

Bromeliads were counted on trees that were either inside the plot or part of the boundary (e.g. corner posts). Binoculars were used to spot bromeliads at higher elevations. Because not all bromeliads hold water in their leaf axils and are therefore useless as tadpole rearing sites, solely the bromeliads expected to hold water were noted. Bromeliads expected to hold water are defined by bromeliads where the leaves axils form a closed chalice (e.g. *Vriesea sp.*). Only bromeliads above 2m were counted.

2.6 Canopy cover

Canopy cover is measured as defined by Jennings and Zhu et al. (2003), "canopy cover is understood to be the vertical projection of the forest floor that is obscured by forest canopy". Due the lack of a hemispherical lens, all photos in the plots are taken in a similar way. Ropes were tied between corner posts to form a cross in the middle of the plot. A picture will be taken from 1m high facing upwards with the bottom of the camera body facing towards the path. Fiala et al. (2006) suggested not taking photos on a sunny day. Photos taken on a sunny day are harder to process due to lens flare. To preserve equipment rainy days were avoided as well. Images were processed with image-J.

2.7 Statistics

The Royle count method was used for the processing of the data sets collected on the frogs counted and the environmental factors. The data was processed with the PRESENCE software. PRESENCE will analyse which environmental factor, or which combination of environmental factors has the highest probability of explaining the frog abundance. The Royle count method in conjunction with PRESENCE assigns Akaike information criterion (AIC) scores to each model. The model with the most explanatory value (the model with the highest likelihood of being true) and lowest AIC score will be listed at the top of all tested models. This gives a relative value of what models are likely to be true and conclusions can be drawn based upon this. Models that differ less than 2 in AIC score are not significantly different.

A Student's t-test was used to compare frogs counted before and after 10:00.

3. Results

Plot #4 and plot #37 were adjacent to each other and turned out to be less than 36m apart. Therefore the plot which differed the most in size from the 36m² was removed from the analysis. Plot #4 had a 26.10m² surface area where as plot #37 had a 39.86m² surface area. Thus plot #4 was removed from the analysis.

Because plot #18 (surface area 91.32m²) turned out to have a big influence in determining the likelihood of the model, it was removed from the analysis as well. This resulted in a mean plot size of 42.10m² (*SD* = 6.51m²).

The AIC score of the repeated count alone (i.e. without any of the measured abiotic variables) was compared to the AIC of the several other models that use variables to explain the abundance estimate (Table 1). Since the AIC score difference is <2, the top two models are not significantly different from one another. Running the models without plot #18 (the largest plot) (91.32m²) did not result in differential model selection based on AIC scores. When using surveyor ID to explain the frog abundance estimate, the AIC difference is >2, implying that surveyor is a non-significant variable and does not affect detection

Tabel 1 AIC comparison between repeated count model and the model that uses surface area or surveyor to explain the model without plot #18.

Model name	AIC score
Repeated Count Data (Royle Biometrics)	308.15
Repeated Count Data (Royle Biometrics) surface area	309.05
Repeated Count Data (Royle Biometrics) Surveyor	312.29

3.1 Abundance

The abundance estimate given by PRESENCE of *O. pumilio* counted in 34 plots is estimated to be 88.55, 95% CI [47.44, 165.28] (*SD* = 28.20). Total surface area of the plots was 1431.51 m². Using this information density can be calculated. Density is 6.19 (7) frogs per 100m².

3.2 Interesting covariates

Table 2 the most likely models to explain the abundance estimate.

Covariate combinations.	AIC score	Delta AIC
Bromeliad + cloud + rain + canopy	304.83	0.00
Cloud + rain + canopy	305.14	0.31
Cloud + rain + inundated + canopy	306.33	1.50
Bromeliad + cloud + rain + temp	306.38	1.55
Bromeliad + cloud + rain + leaf	306.47	1.64
Bromeliad + cloud + rain + leaf + canopy	306.47	1.64
Bromeliad + cloud + rain + inundated + canopy	306.60	1.77
Cloud + rain + leaf + canopy	306.60	1.77
Cloud + rain + temp	306.63	1.80
Cloud + rain + leaf	306.72	1.89
Bromeliad + cloud + rain + temp + canopy	306.79	1.96

As shown in table 2 models that use cloud + rain have high relative explanatory values for abundance and detection of the frogs. Bromeliads have high explanatory value as well however the model that uses bromeliads to explain the abundance had very low explanatory value (AIC = 323.29, Delta AIC = 15.34). Very few bromeliads were counted, 10 in total among 34 plots. All other models that were tested can be found in Appendix A.

Temperature was expected to have a higher explanatory value, however when comparing temperature with frog counts it can be seen that temperature does not correlate with frog counts. (Figure 2). NB No frogs were counted during surveys conducted on the 5th and the 7th of November.

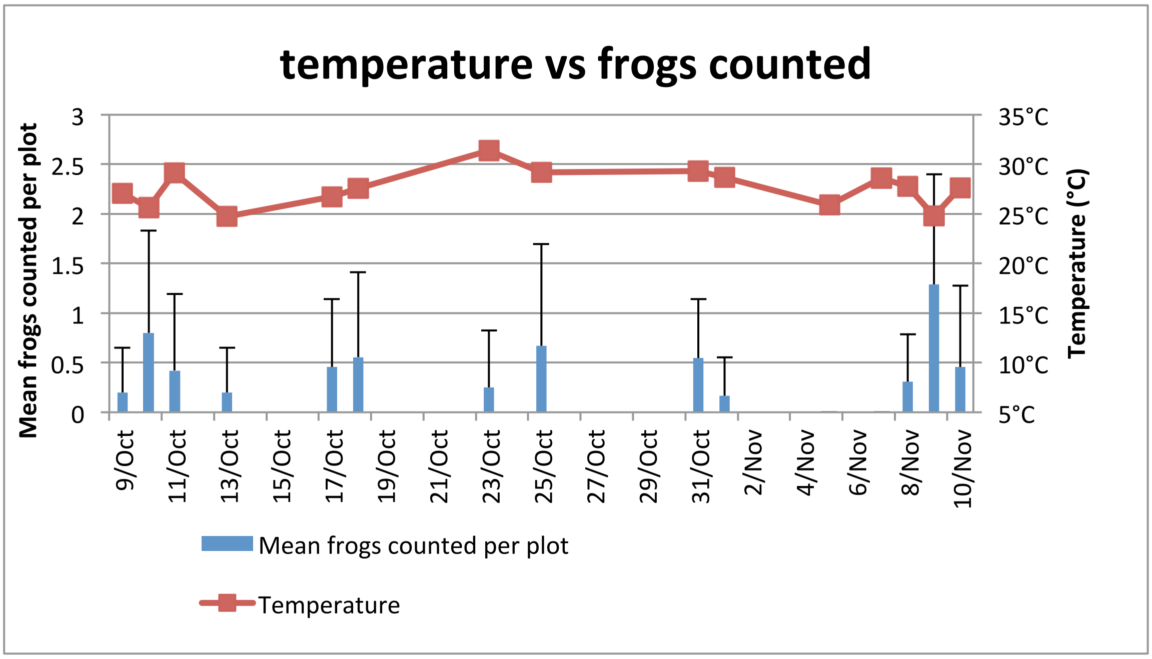

Figure 2. Mean frogs counted per plot versus mean temperature per day respectively

3.3 Detectability before and after 10:00

A Student t-Test (dependent samples *t*-tests) was used for comparing frogs counted before and after 10:00. The number of frogs counted before 10:00 ($\bar{x}$ = 1.21, *SD* = 1.80) did not significantly differ from the number frogs counted after 10:00 ($\bar{x}$ = 1.17, *SD* = 2.39), $t(33) = 0.11$, $p = 0.92$).

4. Discussion

Surveys were undertaken twice a week to cover all plots. However during the 5th week of surveying the jungle was flooded and plots were surveyed as soon as they became accessible, resulting in multiple counts over the week. It is not believed to influence the results due to the short time-span of 5 weeks in which all the frog counting data has been collected.

4.1 Abundance

When we compare the density of 7 frogs per 100m²with other studies. Pröhl and Hödl (1999) found densities of 2-3 adults per 100m² at Hitoy Cerere biological station on the Atlantic side of Costa Rica, whereas Donnelly (1989a,b) found 13 adults per 100m² at La Selva Biological Station. This suggests that the density of O. pumilio at Cano Palma is average.

4.2 Covariates

Interestingly, bromeliads in no way seem to explain the abundance estimate. Donnelly (1989a) found that by increasing potential tadpole rearing sites the density increased. It was expected, then, that bromeliads would be present in areas with more frogs. This suggests that *O. pumilio* uses different tadpole rearing sites in this region, not exclusively bromeliads. For example, frogs have been spotted carrying tadpoles to the top of palm trees. Being limited to the ground prevented searching for bromeliads or other tadpole-rearing sites in the canopy. Few papers describe specific tadpole rearing sites other than water-filled bromeliad leaf axils (Savage, 1968). This would make for an interesting research opportunity.

While models with high explanatory value (table 2) contained bromeliads counted as a covariate, considering the low amount of bromeliads counted, it appears unlikely that bromeliads are truly influencing *O. pumilio* densities. This seems to be the contradicting Donnely's (1989a) findings that increasing the amount of bromeliads increases *O. pumilio* densities.

Cloud cover and rain fall seem to be covariates that best explain the abundance estimate. A possible explanation is that due to a decreased risk of desiccation the frogs are more prone to expose themselves in the open. Newman (1990) suggested that frogs try to avoid risk of dehydration.

Leaf-litter coverage was expected to have a higher explanatory value due its influence on detectability as demonstrated by Koch et al. (2007) with the giant barred-frog (*Mixophyes iterates*). Difference might be that the giant barred-frog is nocturnal. Difference in results might be found when using leaf litter depth instead of or with percentage leaf litter cover.

Temperature was expected to have a higher explanatory value especially since the combination of cloud cover and rain seemed to have high explanatory value. Newman (1990) found that Hamilton's frog (*Leiopelma hamiltoni*), from the family Leiopelmatidae, activity correlated positively with atmospheric temperature. Similar studies related to the family Dendrobatidae were not found. Becker et al. (2012) found that canopy density had a bigger influence on ground water temperature than the ambient air temperature. It is unclear if ambient air temperature or canopy cover has a bigger influence on water temperature in bromeliads. If tadpole rearing-site quality affects *O. pumilio* density, such as found with the foothill yellow-legged frog (*Rana boylii*), from the Ranidae family, by Catanazzi et al. (2013) perhaps water temperature in bromeliads is an important factor. Temperature requirements for most species are poorly known (Pough, 2007).It is expected that ground temperature at the plots differed too much from the ambient air temperature, taken at the weather station. It is suggested to measure ground temperature at plots and if possible in tadpole rearing-sites in follow-up research.

The variable canopy cover, was represented in seven of 11 models as having the highest AIC score (Table 2). Canopy cover can, besides affecting water temperature, provide shade and reduce risk of desiccation.

Inundated area seemed to have little explanatory value on the abundance estimate of *O. pumilio*. Perhaps the floods, that caused the plots to become inundated, triggered flight behaviour in the frogs causing them to move upwards reducing the chance of detection. Due to the lack of literature describing *O. pumilio*, or frog behaviour in general as a response to inundation, only speculations can be made. Aichinger (1987) found that some species of frogs in the Amazon stop their calling behaviour after inundation but made no comments on what other behaviour they exhibited.

4.3 Detectability before and after 10:00

Graves (1999) suggested *O. pumilio* is more active in the morning. However the amount of frogs counted before and after 10:00 did not differ. This would suggest that time does not influence detectability and therefore the surveys do not have to be limited to the morning for follow-up research.

5. Conclusion

Environmental factors that reduce risk of desiccation (e.g. rain, cloud cover, canopy cover) are the most likely environmental factors to influence the abundance estimate. Frogs in this region are suspected to use different tadpole rearing sites than only bromeliads. The density is expected to be 7 frogs per $100m^2$. Surveys do not have to be limited to the mornings in follow-up research.

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