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Data *in* South American Journal of Herpetology · December 2011
DOI: 10.2994/057.006.0311

South American Journal of Herpetology, 6(3), 2011, 234-238

LAKE PROXIMITY AS A DETERMINANT OF ANURAN ABUNDANCE AT LAGO SACHAVACAYOC, AMAZONIAN PERU

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Abstract. Because anurans are highly dependent on water for hydroregulation and respiration, they may use microhabitats that are in proximity to standing water preferentially to other microhabitats, especially during dry periods. We examined the anuran assemblage of Sachavacayoc, Peru during the dry season to test if lake proximity, distance to trees, temperature, and humidity influenced anuran abundance and diversity in the leaf litter of a rainforest habitat. We conducted quadrat searches of paired plots at the shore of a lake and 25 m distant from the lake's shore. Both overall abundance of anurans and abundance of the most common species, *Leptodactylus andreae,* a terrestrial breeding species, were significantly higher in the lakeshore quadrats. Temperatures at capture sites in the shore quadrats were significantly higher; frogs were significantly closer to trees in the away-from-water quadrats. Humidities at points of capture did not differ significantly with quadrat position. For eight of the 14 species captured, more individuals were found in shore quadrats than inland quadrats, which supports our hypothesis. Likewise, *L. andreae* was more abundant at the lake's shore, even though previous studies have not recorded this species utilizing lakeshore habitats. The extreme lack of rain experienced immediately preceding and during the study may have caused the frogs, including *L. andreae,* to shift their microhabitats to a more humid area to prevent dehydration. Additional studies that examine the fine scale spacing in relation to large water bodies will shed more light on this phenomenon.

Key-Words. Anura, hydroregulation, *Leptodactylus andreae,* microhabitat, Peru, water proximity.

Introduction

Anurans are highly dependent on water for metabolism, respiration, and reproduction (Duellman and Trueb, 1994). The water balance of amphibians constantly fluctuates with changes in climate, humidity, and weather (Claussen, 1969; Shoemaker *et al.,* 1992). Because of their permeable skin, amphibians can lose 10% of their body mass due to water loss in a matter of hours, even in high humidity conditions (Feder, 1983). However, for frogs in tropical rainforests, water conservation is less problematic. High air humidity allows amphibian species to exist most of the year independently of standing water, only seeking out standing water for reproduction (Stebbins and Cohen, 1995). Moreover, many species have evolved to reproduce in completely terrestrial microhabitats (Duellman and Trueb, 1994), thus breaking the link with standing water entirely.

While the entirety of an anuran's skin is permeable and contributes to water loss and acquisition, many species have developed areas of thin skin around the groin and lower abdominal surfaces to allow for more rapid water uptake (Tracy, 1976; Duellman and Trueb, 1994; Stebbins and Cohen, 1995). Anurans can also alter rates of water intake and loss behaviorally through different postures as well as microhabitat selection (Pough *et al.,* 1983). Unlike larger animals such as mammals and birds, most rainforest frogs tend to have relatively small home ranges, where they feed, grow, reproduce, and seek refuge from predators in a confined area (Hodgkison and Hero, 2001; Doan and Arizábal Arriaga, 2000). However, water stress may cause anurans to migrate to areas of higher humidity (Pough *et al.,* 1983).

The Tambopata region is located in the southwestern Amazon Basin of Peru and is home to diverse assemblages of herpetofauna (Doan and Arizábal Arriaga, 2002). At Sachavacayoc Centre, a site in the Tambopata Province, a previous study identified 105 species of herpetofauna, including 55 anurans (Doan and Arizábal Arriaga, 2002). The rainy season in the Tambopata region occurs from October to March and is characterized by annual rainfall extremes of 1836-3418 mm (Duellman, 2005). The dry season peak occurs from June to August; high moisture levels persist in the dry season due to the evaporation and evapotranspiration that occur as a result of direct solar radiation (Duellman, 2005). Doan and Arizábal Arriaga (2002) reported that the most common frog species found at Sachavacayoc Centre and the entire Tambopata region was *Leptodactylus andreae* (taxonomy according to Frost *et al.,* 2006). This species was captured in quadrat and visual encounter survey plots that were distant from standing water (Doan and Arizábal Arriaga, 2002). *Leptodactylus andreae,* a terrestrial frog that inhabits terra firme forest, is a generalist arthropod predator, and is primarily nocturnal, but may vocalize during daylight hours (Toft, 1980; Zimmerman and Simberloff, 1996; Duellman, 2005).

During August 2007 very little rain fell in Tambopata, Peru (World Meteorological Organization, 2007), including the complete absence of rain for at least eight days before and during our study period. This lack of rain may have created water stress for the local amphibians. Therefore, it was likely that anurans would relocate near a large lake, which would presumably have higher local humidity. We hypothesized that we would find a greater abundance and diversity of anurans in quadrats located closer to standing water (Lago Sachavacayoc) due to their need for hydroregulation, with the exception of *Leptodactylus andreae,* which we hypothesized would be more abundant distant from the lake, because this was found in previous studies (Doan and Arizábal Arriaga, 2002). We also hypothesized that anurans would be found near tree trunks as leaf litter may accumulate more deeply there (Voris, 1977; Whitfield and Pierce, 2005) and herpetofaunal density and species richness have been positively correlated with leaf litter depth in other studies (Fauth *et al.,* 1989; Blair and Doan, 2009).

Material and Methods

Data were collected in the Tambopata region at Sachavacayoc Centre (SC), Madre de Dios, Peru, 8-19 August 2007, during the dry season. This research station is situated at an altitude of 220 m, 35 km SSW (river distance) from the town of Puerto Maldonado, the capital of the Madre de Dios Department. The rainforest area surrounding SC includes multiple forest types and various stages of succession (Erwin, 1984; Phillips, 1993; Doan and Arizábal Arriaga, 2002). The zone of focus in this study is the area surrounding the 45 ha Lago Sachavacayoc, an oxbow lake, which is located approximately 5 km from the SC station (12.89274°S; 69.36090°W). The zone immediately surrounding the lake is filled with dense vegetation and an understory of woody vines, leafy plants, fallen trees, and regions of dense leaf litter. The area is predominantly terra firma clay forest (Doan and Arizábal Arriaga, 2002; *pers. observ.*).

We sampled quadrats of leaf litter because previous studies in the region have shown quadrats to be a superior method of sampling terrestrial anurans (Doan, 2003). We sampled our quadrats at night because that is when leaf litter frog activity is at its highest (Rocha *et al.,* 2000; Doan, 2003). Pairs of 8 × 8 m quadrats were established 0 m ("shore" quadrats) and 25 m ("inland" quadrats) from the water's edge of Lago Sachavacayoc. The term 'paired plot' was implemented to designate a set of quadrats, one directly adjacent to the lake's edge and one parallel to the first, such that the edge nearest the lake shore of the second quadrat was located 17 m from the far edge of the first quadrat of the pair. Ten sets of paired plots were surveyed; to ensure data independence, sets of paired plots were separated by a distance of at least 20 m along the lake's shore, which was far enough away not to disturb the leaf litter anurans in subsequent quadrats. Within each paired plot, the quadrat plotted adjacent to the water was set up and surveyed first, which prevented the surveying team from walking through quadrats before they were sampled. Each night two sets of paired plots were surveyed (i. e., four quadrats total per night); each quadrat was sampled only once.

The collection method was based on that of Heyer *et al.* (1994) and Doan (2003). To sample each of the quadrats, a five-person team was assembled. Four people located and captured anurans within the quadrat, while one individual measured the environmental parameters and identified and recorded the anurans that had been captured. Beginning with one person at each corner of the quadrat, individuals worked in a clockwise direction toward the center of the quadrat. This technique was implemented to assist in the capture of all anurans and prevented escape from the quadrat prior to capture. Because we were most interested in examining terrestrial anurans, each quadrat was intensively searched for frogs by moving leaf litter and vegetation up to 1 m in height. Anurans were identified to species (without regard to age or sex) and the environmental parameters of proximity to nearest tree trunk (diameter greater than or equal to 5 cm), relative air humidity, and substrate temperature were recorded at the site of each capture. A tape measure was used to record proximity to nearest tree. A digital hygrometer/thermometer was placed on the ground at the site of capture in order to measure the local ambient temperature and relative humidity. Upon completion of quadrat sampling, all specimens were returned to their original locations.

Wilcoxon Matched Pair Signed Rank Tests compared the abundance of all anurans combined and the abundance of *Leptodactylus andreae* of the quadrats plotted adjacent to the lake's edge versus the inland quadrats. In order to test the differences between shore and inland quadrats in proximity to trees, humidity, and temperature, Mann-Whitney U tests were implemented. Because total quadrat numbers were relatively low, nonparametric statistics were used. The Shannon Diversity Index assessed the diversity of anurans observed in quadrats plotted on the lake's edge, inland, and the overall diversity of anurans found in this study. Data were evaluated using JMP-IN (SAS Institute, 2002).

Results

Surveys of 20 quadrats resulted in the capture of 158 individuals of 14 species of anurans with four species unique to the shore quadrats and four species unique to the inland quadrats (Table 1). The Shannon diversity index for the shore quadrats was 1.416 and for the inland quadrats was 1.424. Overall the diversity was 1.503.

Leptodactylus andreae was the most commonly encountered species, and was significantly more abundant in the shore quadrats (Wilcoxon = 16.000, df = 9, P = 0.031). Overall abundance of anurans was significantly higher near the lake (Table 1), both when including all species (Wilcoxon = 20, df = 9, P = 0.021), and when excluding *L. andreae* (Wilcoxon = 81, df = 9, P = 0.019).

Frogs in the inland quadrats were captured significantly closer to trees than the frogs in the shore quadrats (mean = 54.43 cm ± 45.67 and mean = 80.23 cm ± 56.56, respectively; U = 6.8327; df = 1; P = 0.009). Frogs caught in the shore quadrats were found in microhabitats of significantly higher temperatures than the inland quadrats (mean = 26.00°C ± 0 and mean = 25.44°C ± 1.45, respectively; U = 4.0548; df = 1; P = 0.044). Relative humidity at point of capture differed slightly between the captures in the shore quadrats (mean = 83.77% ± 9.01) and inland quadrats (mean = 81.06% ± 8.59), but not significantly (U = 2.6505; df = 1; P = 0.104).

Table 1. Species abundance by shore or inland quadrat type in August 2007 at Sachavacayoc Centre, Peru, by order of abundance.

Species	Shore	Inland	Total
Leptodactylus andreae	69	29	98
Chiasmocleis ventrimaculata	9	5	14
Hamptophryne boliviana	9	2	11
Leptodactylus wagneri	8	0	8
Dendrophryniscus minutus	4	2	6
Elachistocleis bicolor	2	4	6
Leptodactylus bolivianus	4	0	4
Ctenophryne geayi	3	0	3
Allobates trilineatus	1	1	2
Leptodactylus lineatus	2	0	2
Ameerega trivittata	0	1	1
Leptodactylus didymus	0	1	1
Pristimantis toftae	0	1	1
Scinax ictericus	0	1	1
Total Abundance	111	47	158
Total Richness	10	10	14

Discussion

As we hypothesized, we found a significant difference in abundance of frogs between areas close to Lago Sachavacayoc and areas farther away; but contrary to our hypothesis, species diversity between the two areas was nearly identical. The overall Shannon diversity index for this study of 20 quadrats was 1.503 compared to the 2.275 anuran diversity index documented in the 2-y study of Doan and Arizábal Arriaga (2002), demonstrating that our short study conducted during the dry season was not able to record all species present.

For eight of the 14 species, more individuals were found in shore quadrats than in inland quadrats, providing support for our hypothesis. These include four microhylids, a bufonid, and two leptodactylids (Table 1); therefore, the trend seems robust for frog family. The most surprising result of this study was that *Leptodactylus andreae* was more abundant at the lake's edge. No previous studies have recorded this species as using a lakeshore microhabitat (Duellman, 1989, 2005; Doan and Arizábal Arriaga, 2002). One possible reason this species was found in high proximity to the lake was that the area had not had rainfall for at least three days prior to the study and not at all during the study period, so perhaps *L. andreae* sought out higher humidity near the lake. However, the slight difference in average humidity between shore and inland quadrats was not significant. As no past studies have examined hydroregulation abilities of *L. andreae,* it is unknown if the small difference in average humidity was enough to cause these frogs to migrate to the lake's edge.

Although we did discover significantly higher temperatures at the capture sites of frogs in shore quadrats, these data do not necessarily imply that anurans selected quadrats of higher temperature. Pairs of quadrats were surveyed in the order of shore quadrat first and inland quadrat second for all pairs of this study (to get accurate measurements of distance from the lake without disturbing shore quadrats before sampling them). Therefore, as temperature decreases and humidity rises as the night progresses in the rainforest habitat (Duellman, 2005), the difference in temperature and humidity between quadrats could be biased toward higher temperatures and lower humidity in the shore quadrats. Humidity may have been higher nearer water at any one point in time, even if our research design could not detect it. Hydroregulation is known to be an important aspect of amphibian biology and it is likely to be one of the factors influencing microhabitat for the anurans that were found during our study.

Although we did not directly test differences in leaf litter depth, many studies have shown that deeper leaf litter accumulates at the base of trees (Voris, 1977; Whitfield and Pierce, 2005). It is likely that this increased depth in leaf litter could hold more moisture and this is probably one of the reasons that frogs found inland were more likely to be found nearer to tree trunks than the frogs captured on the lakeshore. The frogs on the lakeshore had an abundance of wet soil from which to absorb water and did not need to find the deepest leaf litter for that resource. Deep leaf litter could also be favored by anurans because it gives some refuge from predators and may support more numerous and diverse prey populations (Fauth *et al.,* 1989). It has been shown in rainforest habitats that arthropods move closer to water during the dry season (Janzen, 1973), which may prompt the frogs to migrate to areas near water because prey may be limited in the dry season (Toft, 1980). Further studies of this trend would be beneficial to the understanding of the microhabitats of anurans. In addition, comparing our dry season quadrats with ones conducted at the same sites during the wet season would help to test if the patterns found in this study hold when water is more abundant. Finally, although not analyzed in this study, it was observed that the majority of frogs found in the shore quadrats were directly on the water's edge as opposed to dispersed throughout the quadrat. An examination of fine scale spacing within quadrats, or along transects perpendicular to the lakeshore, would add another interesting component to our knowledge of microhabitat in relation to water proximity and along gradients of moisture.

Resumen

A causa de los anuros son dependientes en agua por hidroregulación y respiración, pueden usar microhábitats en proximidad a un cuerpo de agua prefieramente a los otros microhábitats, especialmente durante épocas de poca lluvia. Examinamos la comunidad de anuros de Sachavacayoc, Perú para examiner si proximidad al lago, distancia de árboles, temperatura y humedad influyeron el abundancia y la diversidad de anuros en la hojarasca de un hábitat selvático. Realizamos búsquedas de quadratos de parcelas apareadas en la ribera de un lago y 25 m de distancia de la ribera. El abundancia de anuros en total y de la especie más común, *Leptodactylus andreae,* una espécie con reproducción terrestre, fueron más grandes en los quadratos de ribera del lago. Las temperaturas en sitios de captura en los quadratos de ribera fueron más altas; las ranas fueron más cerca de árboles en los quadratos lejos del lago. Las humedades en puntos de captura no fueron diferentes entre quadratos de ribera y lejos del lago. Para ocho de las 14 especies capturadas, más individuos fueron encontrados en quadratos de ribera que los quadratos lejos del lago, que apoya nuestro hipótesis. Además, *L. andreae,* fue más abundante en la ribera del lago, aunque estudios anteriores no habían registrado el uso de riberas del lagos por esta especie. La falta de lluvia durante y antes del estudio podría efectuar un cambio de microhábitat de las ranas, incluyendo *L. andreae,* a una zona más humeda para prevenir deshidratación. Estudios adicionales que examinan la posición en una escala fina en relación a cuerpos de agua explicarán más sobre este fenómeno.

Acknowledgments

We would like to thank W. Arizábal A. of Oicos Habitare for facilitating the field work. N. M. Koffman, L. Nachtigal, J. I. Watling, R. Carson, and L. Gamble contributed helpful comments on the manuscript.

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Submitted: 09 September 2011
Accepted: 29 October 2011