

A note on amphibian decline in a central Amazonian lowland forest

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Abstract The massive reductions in amphibian populations taking place across the globe are unprecedented in modern times. Within the Neotropics, the enigmatic decline of amphibians has been considered predominantly a montane phenomenon; however, recent evidence suggests amphibian and reptile populations in lowland forests in Central America are waning as well. Unfortunately, very little baseline data are available for conducting large scale time series studies in order to further investigate and confirm declines in the lowland forests of tropical America. Here we compare leaf litter herpetofauna abundance at sites in the Central Amazon, sampled first in 1984–1985 and again in 2007. We find no evidence for a decline in abundance or biomass of amphibians over a period of 22 years at this site. This conclusion differs markedly from the decline of 75% in amphibian populations over 35 years at a lowland site in Costa Rica. To explore potential declines in lowland Neotropical amphibian populations in detail, we suggest that existing baseline data be comprehensively compiled and analyzed for previously sampled sites and that these sites be re-sampled using comparable methodologies.

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Introduction

Amphibian decline is a global phenomenon occurring at an alarming rate (Stuart et al. 2004) and is therefore a high-priority conservation issue. With over one-third of the world's amphibian species threatened with extinction and with data lacking for another 20% (IUCN 2008), researchers struggle to determine causes of the declines and to develop sound conservation strategies for maintaining the world's still extant amphibian biodiversity. These endeavors are confounded by “enigmatic decline”, or reductions in populations within seemingly pristine habitat. While habitat loss is clearly the most important driver of overall amphibian decline (IUCN 2008), enigmatic decline has been attributed to a number of proximal causes including climate change (Pounds 2001; Pounds et al. 2006), fungal disease (Lips et al. 2006; Rohr et al. 2008), and UV radiation and pollution (Blaustein et al. 2003), although more than one mechanism may be responsible (Collins and Storer 2003; Alford et al. 2007; Di Rosa et al. 2007). Much attention has been given recently to predicting what characteristics of amphibian species make them most susceptible to decline (Bielby et al. 2008; Cooper et al. 2008; Sodhi et al. 2008). Enigmatic decline in tropical America has resulted in rapid reductions or extinctions primarily in populations of stream-breeding species with ranges at mid to high elevations (Lips et al. 2003; 2005; Bielby et al. 2008) whereas amphibian populations within protected lowland Neotropical wet forests were initially judged to be stable (Stuart et al. 2004).

Recently, Whitfield et al. (2007) used data sets of leaf litter herpetofauna density, collected via quadrat sampling over a 35 year period at La Selva Biological Station in Costa Rica, to reveal a steady decline in populations of leaf litter frogs in primary forest. The authors found a parallel decline in lizards and suggested that these lowland declines in herpetofauna may be widespread. The decline at La Selva was gradual, uncharacteristic of the enigmatic decline of montane areas that typically transpires over a much shorter period of time (Whitfield et al. 2007). Without drastic differences in populations from one year to the next, long-term baseline data are needed to recognize trends of decline at lowland sites.

The proposition that both amphibian and reptile populations are declining in lowland forests has major implications for conservation. Amphibian species in lowland forests are not typically considered to be most vulnerable to the causes of enigmatic decline. Furthermore, lizards were not previously regarded as declining. In fact, the existing evidence for Neotropical lowland decline is based on a single site, La Selva, albeit an extensively sampled one. Still, generalizing from the La Selva conclusions is hampered by the lack of other quantitative baseline data sets. Although some studies have investigated effects of forest fragmentation on species richness and composition over time, generally with little change in either variable (e.g., Tocher et al. 1997; Vigle 2008), to our knowledge, only the La Selva study has looked at changes in density of individuals over time, unhampered by on-going fragmentation effects. Here, we present a comparison of a rare, quantitative time-step dataset from continuous forest in the Central Amazon Basin, sampled initially in 1984–1985 and again in 2007.

Methods

The Biological Dynamics of Forest Fragments Project (BDFFP), initiated in 1979 as the Minimum Critical Size of Ecosystems Project, is jointly run by Brazil's Institute for Amazonian Research (INPA) and the Smithsonian Tropical Research Institute (STRI). The BDFFP (2°30'S, 60°W; 90–160 m asl) is located in Amazonas state, Brazil, 80 km north of Manaus, within an area of approximately 500,000 ha of relatively undisturbed, terra firme lowland rainforest (Lovejoy and Bierregaard 1990). The BDFFP is composed of three main areas, or fazendas (Fig. 1). Each fazenda, Dimona, Esteio and Porto Alegre, contains a number of control reserves in nearby continuous forest, as well as the isolated forest fragments on the fazendas.

Initial sampling of leaf litter herpetofauna was done in 1984–1985 using 5×5 m quadrats (Allmon 1991). Of the continuous forest reserves, one of us (WDA) sampled seven of them, two near Dimona, one near Porto Alegre and four near Esteio. The lead author (JLD) sampled the BDFFP again in 2007, also using 5×5 m quadrats. The 2007 plots were located within continuous forest at Dimona (but outside the established reserve), one reserve near Porto Alegre and one reserve near Esteio. For both sampling protocols, all frogs were captured and snout-vent length (SVL) was measured (0.1 mm). For the 2007 samples, individuals were also weighed (0.01 g). Changes in leaf litter herpetofauna abundance and biomass were compared using data collected only within continuous forest at the BDFFP. Also, in order to avoid seasonal bias in the analyses, we made comparisons using only data collected during the wet season (November–May). In total, data from 188 plots (4,700 m²) sampled in 1984–1985 and 265 plots (6,625 m²) sampled in 2007 were included in the analyses.

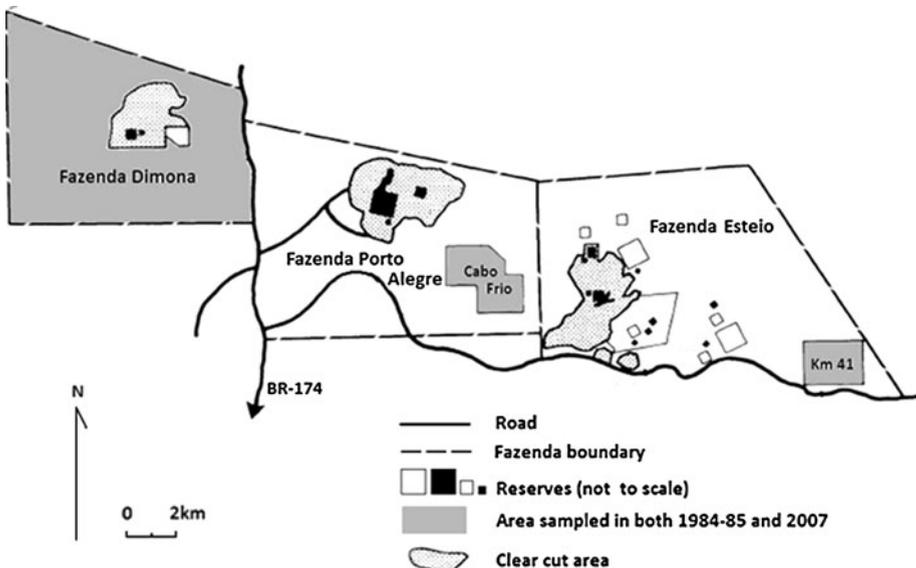


Fig. 1 A map of the Biological Dynamics of Forest Fragments Project in 1986 (Modified from Allmon 1991). *Black and white squares* represent different size forest reserves and the *solid gray areas* are the continuous forest sites from which data were analyzed in the present study

For the 2007 samples, total biomass was calculated by summing the mass of all individuals found in each plot. Although mass was not recorded in the 1984–1985 survey, SVL was measured. Therefore, individual biomass was estimated using species-specific SVL/mass regressions (Deichmann et al. 2008), and they were then summed for each plot. For individuals that were identified, but escaped capture, mass was recorded as the average mass of all individuals of the species found at that site.

We conducted a comparison of overall abundance and biomass of amphibians found in plots at the BDFFP in 1984–1985 and 2007 with the main effect of year and an effect of site nested in year, using PROC MIXED in SAS (Version 9.1.3, Cary, NC). Because the BDFFP encompasses 1,000 km², we also examined abundance and biomass specifically at reserves that were sampled in both 1984–1985 and 2007: Km 41 in Fazenda Esteio and Cabo Frio in Fazenda Porto Alegre. Although at Fazenda Dimona, WDA sampled two continuous forest reserves which were later isolated as fragments, we also included Dimona in this comparison because of the proximity (1 km) of those sites to the areas of continuous forest sampled at Dimona in 2007. We compared the mean abundance and biomass at sites between years using post-hoc Tukey multiple comparisons. Among the six most abundant species in both samples, five were common to both the 1984–1985 and 2007 samples. We used a Wilcoxon rank-sum test in R (Version 2.10.0) to compare the abundance and biomass of these five species.

Results

There were no differences in either overall abundance ($F_{1,444} = 0.95$, $P = 0.331$) or biomass ($F_{1,444} = 0.05$, $P = 0.817$) of leaf litter amphibians between 1984–1985 and 2007 at the BDFFP (Fig. 2). For the reserves within the BDFFP that were sampled in both years (Fig. 3), post-hoc tests also indicated no difference in either frog abundance (Cabo Frio, $t = 2.83$, $df = 444$, Tukey Adj. $P = 0.109$; Dimona, $t = 0.14$, $df = 444$, Tukey Adj. $P = 0.999$; Km 41, $t = 0.68$, $df = 444$, Tukey Adj. $P = 0.999$) or biomass (Cabo Frio, $t = 1.37$, $df = 444$, Tukey Adj. $P = 0.910$; Dimona, $t = 0.47$, $df = 444$, Tukey Adj. $P = 0.999$; Km 41, $t = 0.40$, $df = 444$, Tukey Adj. $P = 0.999$). Because the distributions for these data were skewed from normal in the direction of the Poisson, non-parametric Wilcoxon rank-sum tests were also performed for the data. These tests yielded results parallel to the ANOVAs, so only the latter are shown here.

Nine species and 118 individuals were encountered in quadrats in the 1984–1985 samples while seven species and 226 individuals were found in 2007. By far, the most abundant species in both samples was *Leptodactylus andreae*, which did not differ significantly in abundance or biomass in 1984–1985 and 2007 (Table 1). *Allobates marchesianus* was significantly more abundant in 1984–1985 while *Anomaloglossus stepheni* was more abundant in the 2007 samples. The same patterns held for biomass of these species. Abundance and biomass did not differ significantly between samplings for the other two species of the five most abundant (Table 1).

Discussion

There has been no significant change in leaf litter frog abundance and biomass at the BDFFP over the last 22 years. Although community composition appears to have changed slightly, with *A. marchesianus* decreasing in abundance and the ecologically similar

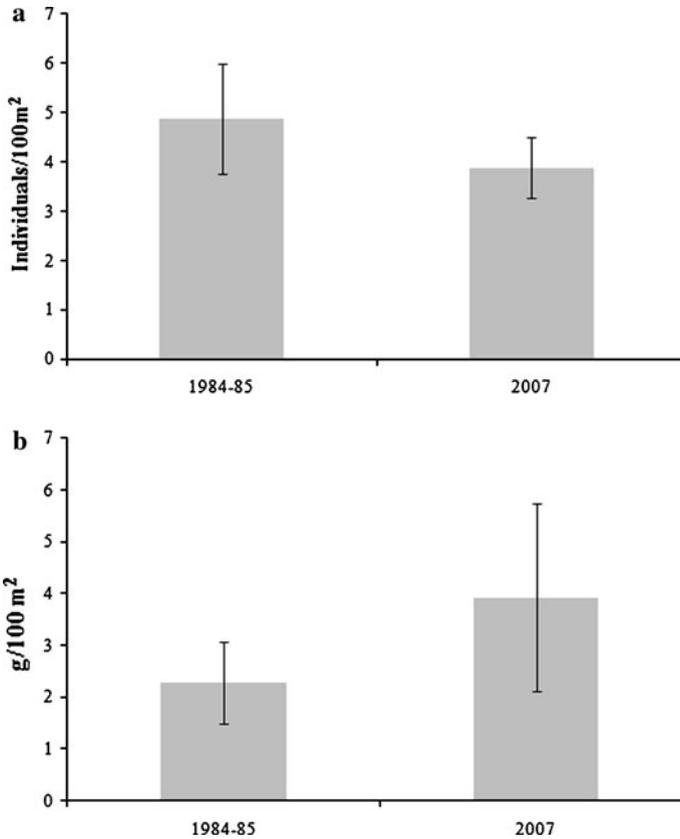


Fig. 2 Overall **a** abundance and **b** biomass of amphibians at the BDFFP sampled in 1984–1985 and again in 2007. Error bars represent 95% confidence intervals

A. stephensi exhibiting a concomitant rise in both number and biomass in the 2007 sample, these changes likely reflect temporal variation (i.e. normal population fluctuations that occur throughout the year) exhibited by many tropical anuran species (Duellman 1995) and the density differences generally fall within the range of variation exhibited by the same species on a yearly basis at a nearby site (Menin et al. 2008). The higher number of species found in the 1984–1985 samples appears to reflect random variation, either natural or a result of quadrat sampling. Three species were found in quadrats in 1984–1985 that were not found in quadrats in 2007; however, each of those three species was observed in 2007, but outside of sampled quadrats. Conversely, one species was found in the 2007 samples that was not found in the 1984–1985 wet season, but it was found in quadrats in the dry season that year. Although possible, it is unlikely that any amphibian decline occurred before the initial sampling in 1984–1985, because at this time, the sampled reserves had not yet been isolated and remained intact rainforest.

This conclusion of no change in leaf litter anuran abundance in the Central Amazon differs strikingly from La Selva Biological Station in Costa Rica where Whitfield et al. (2007) found that populations of both frog and lizard species declined by an average of 75% over a 35 year period. The discrepancy in the two sites over the time interval of several decades begs for interpretation.

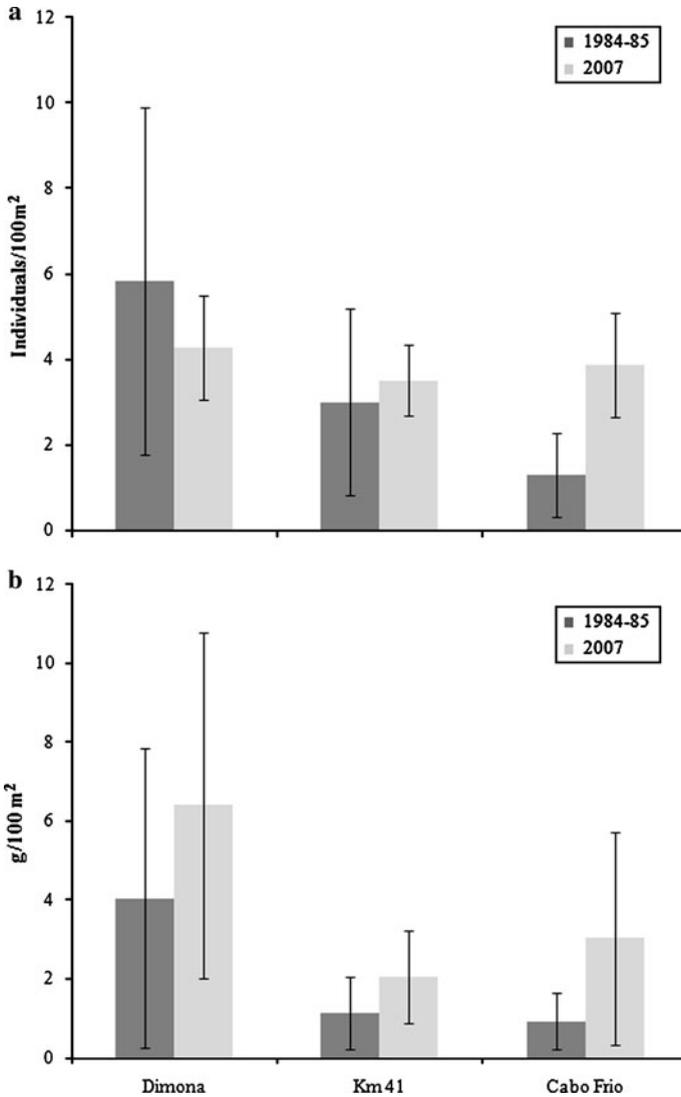


Fig. 3 Average **a** abundance and **b** biomass of amphibians at three sites within the BDFFP. Error bars represent 95% confidence intervals

Whitfield et al. (2007) claim that a decrease in the number of dry days over the 35 year period may have decreased the amount of standing leaf litter through increased decomposition rates. However, Manaus, which lies just 80 km south of the BDFFP, has shown a trend of increased rainfall over the last eight decades (Satyamurty et al. 2010), although much of the Amazon may have experienced decreased precipitation (Marengo 2004). Therefore, our sites may also have experienced a decrease in standing leaf litter due to increased moisture, but this trend is not reflected in leaf litter herpetofauna at the BDFFP. Alternatively, perhaps the continuous forest at the BDFFP is more stable than that of La Selva, which over the last 30 years has gone from continuous forest to a 1,600 ha forest

Table 1 Abundance and biomass of the most abundant anuran species in 1984–1985 and 2007 samples, along with results of Wilcoxon rank-sum tests

Species	Abundance (ind./100 m ²)				Biomass (g/100 m ²)			
	1984–1985	2007	% change	<i>P</i>	1984–1985	2007	% change	<i>P</i>
<i>Allobates</i> (<i>Colostethus</i>) <i>marchesianus</i>	0.72	0.06	−91.7	<0.001	0.35	0.03	−92.8	<0.001
<i>Anomaloglossus stepheni</i> (<i>Colostethus</i> new sp.)	0.38	1.00	61.6	<0.001	0.17	0.36	53.3	<0.001
<i>Rhinella proboscidea</i> (<i>Bufo dapsilis</i>)	0.57	0.11	−81.6	0.215	0.26	1.05	75.6	0.249
<i>Leptodactylus</i> (<i>Adenomera</i>) <i>andreae</i>	2.51	2.04	−18.9	0.577	0.81	0.65	−20.5	0.622
<i>Pristimantis</i> (<i>Eleutherodactylus</i>) <i>fenestratus</i>	0.11	0.05	−57.4	0.400	0.06	0.07	20.0	0.403

Species names in *bold* are current taxonomy, while those in *parentheses* are names used in Allmon (1991)

fragment surrounded on three sides by a matrix of agricultural lands, although connected by a corridor to a larger national park. The difference in spatial scale between the Caribbean lowland forests of Costa Rica and the Amazonian rainforests of Central Brazil is enormous, and could explain the relative stabilities of their amphibian populations.

One potential source of error is sampling bias from different researchers through time. In the earlier study, Allmon (1991) sampled what he termed three different ‘subhabitats’ within sites at the BDFFP—slopes, stream valleys, and plateaus—while the 2007 data come primarily from flat plateaus. We were not able to distinguish among the subhabitats in the 1984–1985 data set; thus, data from all three microhabitats were combined in the analysis. Previous studies in the area suggest that topography on a local scale does not affect frog abundance and that most terrestrial species are habitat generalists (Allmon 1991; Menin et al. 2007). However, because the Brazilian data were collected using similar plot methodology, the data sets used here may contain less inter-researcher bias than those from La Selva, which were collected by numerous researchers, using a variety of different sampling regimes and different quadrat sizes—factors previously shown to influence density estimates (Rocha et al. 2001). Still, the trends recorded by Whitfield et al. (2007) attest to the size and strength of the numerous datasets over a 35 year period, in contrast to our Brazilian datasets which compare only the endpoints of the 22 year interval.

Perhaps more important is that La Selva and the BDFFP represent only two sites in Neotropical lowland forests, and further research is needed to determine why these two herpetofauna community patterns are contradictory. The lack of quantitative data sets is problematic, and priority should be given to re-sampling sites that have been sampled for leaf litter herpetofauna in the past. Additionally, researchers conducting re-sampling should communicate deliberately with those who first collected the data in order to duplicate methods used in the initial collection. In this way, we can standardize data collection and make more accurate comparisons of data sets, allowing a more exact assessment of the scope and consequences of amphibian decline globally.

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