NORTH-WESTERN JOURNAL OF ZOOLOGY 13 (1): 154-158 ©NwjZ, Oradea, Romania, 2017
Article No.: e162503 http://biozoojournals.ro/nwjz/index.html

Population Assessment Strategy for *Atelopus elegans* (Bufonidae) in the Gorgona National Natural Park, Colombia

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Received: 25. August 2015 / Accepted: 14. February 2016 / Available online: 30. March 2016 / Printed: June 2017

Abstract. *Atelopus* species are among the most endangered anurans, and have recently suffered enigmatic declines. However, several species for which preventive actions have been proposed continue to be recorded in Colombia. As an initial step for preventive actions, we assessed the baseline population status for *Atelopus elegans* at the Parque Nacional Natural Gorgona. We conducted distance sampling based on perpendicular measures to estimate population density, and compared six models based on three functions (uniform, half normal, and hazard rate) in combination with three expansion series (cosine, simple polynomial, and hermite polynomial) by using the Akaike Information Criterion. A total of 123 individuals were observed. The *Hazard rate* function with *Cosine* and *Simple polynomial* expansion series were the models with the lowest AIC values. Estimated population density for *A. elegans* was 0.01 individuals/m^2 with a 55% detection probability. Furthermore, a power analysis, with the current sampling design, showed that three annual surveys in a five-year program would detect a 12% change in population density. Since amphibian populations can quickly decline, we recommend a sampling design that enhances sample size, in order to increase the sensitivity to detecting population fluctuations.

Key words: *Atelopus,* distance sampling, monitoring, population density, power analysis.

Amphibians represent one of the most endangered group of vertebrates with at least a third of the species being threatened (Stuart et al. 2004, Stuart et al. 2008). Amphibians have experienced population declines and even local and regional extinctions because of threats like habitat transformation and loss, emergent diseases, pollution, invasive species, and overexploitation (Sodhi et al. 2008, Bielby et al. 2008). Each one of these threats can act independently or in synergy, and the effects could be exacerbated by global climate change (Sodhi et al. 2008, Hof et al. 2011). Furthermore, intrinsical traits of many species, such as their rarity (reduced population size, small geographic range, and habitat specialization; Rabinowitz 1986), contribute to increasing their extinction risk (Sodhi et al. 2008).

Particularly, anurans of the genus *Atelopus* or harlequin frogs have experienced fast and enigmatic declines (La Marca et al. 2005, Pounds et al. 2006, Stuart et al. 2008), including inside protected areas. Many species of harlequin frogs have become difficult to observe or they are no longer found, therefore it is feared that many species in the genus have disappeared (Lötters et al. 2004, Lötters 2007). In Colombia, about 80% of the *Atelopus* species are threatened with extinction (Gómez-Hoyos et al. 2014). But populations of critically endangered species have been recently recorded, such as *Atelopus nahumae*, *A. laetissimus* and *A. carrikeri* in the Parque Nacional Natural (PNN) Sierra Nevada de Santa Marta (Carvajalino-Fernández et al. 2008, Rueda Solano 2008, 2012), *A. spurrelli* in the PNN Utría (Gómez-Hoyos et al. 2014), *A.* aff. *limosus* in Capurganá municipality (Flechas et al. 2012b), and *Atelopus elegans* in PNN Gorgona (Flechas et al. 2012a, 2012b). Persisting populations offer an opportunity to conserve and manage these threatened species.

The Elegant Stubfoot Toad (*Atelopus elegans*) has been considered Critically Endangered (IUCN 2015) because of a drastic population decline possibly due to chytridiomycosis (Coloma et al. 2010). Despite its vulnerability to extinction, few population studies have been performed for the species, and there are no population monitoring strategies. Proposed mitigation actions include extensive fieldwork to assess population status through monitoring programs (La Marca et al. 2005, Lötters 2007, Lampo et al. 2012). These programs should be implemented using robust sampling methods (Crossland et al. 2005, Dénes et al. 2015), that include population parameter estimates based on models. Information on population trends is needed to take appropriate actions in management and conservation (Gómez-Hoyos et al. 2014). Hereby, we present the baseline population assessment for *A. elegans* from the PNN Gorgona performed with distance sampling methods, and analyze the statistical power of detecting population density changes with these methods.

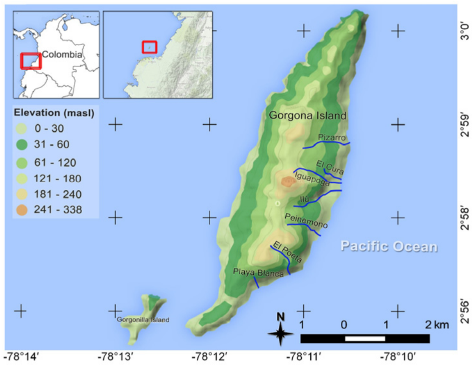

Figure 1. Geographic location of the study area, Parque Nacional Natural Gorgona, Colombia.

<u>Study area.</u> The Parque Nacional Natural Gorgona is located from 02°47'-03°06' N and 078°06'-078°18' W in the Colombian Pacific, Cauca department, Guapi municipality (BirdLife International 2012; Fig. 1). The national park occupies an area of 60.357 ha, of which 1.600 ha represent island territory (Vásquez & Serrano 2009), and spans an altitudinal gradient from sea level to 338 m. Gorgona island lies in the Intertropical convergence zone, which determines a bi-seasonal pattern and annual unimodal precipitation pattern (Zapata et al. 2010), with an annual average temperature of 26 °C, relative humidity of 90% and precipitation of 6.700 mm. High precipitation maintains 25 permanent creeks (Gómez-Aguirre et al. 2009).

<u>Sampling design.</u> From March 6-15, 2012, three observers surveyed 12 transects of variable length (length measured with GPS, maximum error 6 m) in 7 creeks in search of *A. elegans* individuals between 8:00-11:00 in the morning and 14:00-17:00 in the afternoons (Table 1). Transects consisted of frog counts along linear trails. Captured toads were placed individually in plastic bags to measure snout vent length (SVL) with a caliper (±0.1 mm). Low sexual dimorphism prevented sex identification, although it was assumed that individuals with SVL > 29 mm were females. The age categories correspond to those proposed by Atuesta (2003): metamorph (SVL: 5-8 mm), juveniles (8.1-15 mm), sub-adults (15.1-22 mm), and adults (22.1-32 mm). Perpendicular distance to the creek was measured from the edge of the creek to the exact place where the toad was first sighted.

<u>Distance sampling.</u> We choose this technique to survey populations of *A. elegans* because distance sampling estimates population density (Buckland et al. 1993, Thomas et al. 2010, Buckland et al. 2016) with models that minimize detection bias and that offer greater inferential power than estimations based on indices in which detectability is assumed to be perfect (Barry & Welsh 2001).

The distribution of measured distances obtained from transects was analyzed using the software

Table 1. Creeks inspected in the PNN Gorgona, transect length and applied sampling effort.

Creek	Transect	Length	Sampling effort (hours/person)
Ilu	1	123	3.1
	2	137	2.5
	3	176	4.8
El Poeta	4	78	1.8
Iguapoga	5	141	4.8
El Cura	6	136	3.0
	7	128	4.2
Pizarro	8	149	4.3
	9	153	3.6
Peinemono	10	152	3.2
	11	153	3.6
Playa Blanca	12	111	4.9
	Average	136.41	3.6
	SD	24.95	0.98

DISTANCE 6.0 Release 2 (Thomas et al. 2010). We generated six models based on three functions (Half normal, Uniform, and Hazard rate) in combination with three expansion series (Cosine, Hermite polynomial, and Simple polynomial), according to the recommendations made by Buckland *et al*. (2001). The model that better adjusted to the perpendicular distance distribution was selected under Akaike's information criterion (AIC), where the lower AIC values indicate the most plausible model (Burnham & Anderson 2002). The model with the best fit was used to estimate *A. elegans* density and detection probability.

<u>Power analysis.</u> We performed power analysis with the software MONITOR 11.0 (Gibbs & Ene 2010) to estimate the statistical power of detecting fluctuations in population density using distance sampling. Specifically, we determined the method sensitivity to detect population changes with power of at least 80% during a 3 to 5 year monitoring program with annual to trimestral sampling regimes, as proposed by Gómez-Hoyos et al. (2014) for *A. spurrelli* in the PNN Utría. Statistical

Table 2. Models generated and density estimation for *Atelopus elegans* in the Parque Nacional Natural Gorgona, Colombia.

Function	Expansion series	AIC	ΔAIC	Parameters	Density (CI 95%)
Hazard rate	Simple polynomial	356.3	0	2	0.013 (0.008 – 0.021)
	Cosine	358.3	0	2	0.013 (0.008 – 0.021)
Uniform	Simple polynomial	359.88	3.59	2	0.013 (0.008 – 0.021)
	Cosine	360.14	3.85	1	0.013 (0.008 – 0.021)
Half normal	Hermite polynomial	362.04	5.74	1	0.013 (0.008 – 0.022)
	Cosine	362.04	5.74	1	0.013 (0.008 – 0.022)

Table 3. Power statistic estimations and annual exponential changes in *Atelopus. elegans* population from the PNN Gorgona.

Years of monitoring	Samplings per year	Significance (α)	Desired power	Power (1-β)	Annual exponential change (%)
3	1	0.05	0.8	0.165	20
		0.1	0.9	0.271	20
	2	0.05	0.8	0.400	20
		0.1	0.9	0.608	20
	3	0.05	0.8	0.643	20
		0.1	0.9	0.779	20
	4	0.05	0.8	0.779	20
		0.1	0.9	0.811	18
5	1	0.05	0.8	0.563	20
		0.1	0.9	0.723	20
	2	0.05	0.8	0.800	16
		0.1	0.9	0.822	14
	3	0.05	0.8	0.786	12
		0.1	0.9	0.875	12
	4	0.05	0.8	0.877	12
		0.1	0.9	0.847	10

significance was α = 0.05 for a desired power to detect a change of 0.8, and α = 0.1 for a 0.9 power (Schwarz 2013).

We observed 123 *A. elegans* metamorphs, juveniles, sub-adults, and adults, two of which were females (Fig. 2). We did not find amplectant couples, eggs or tadpoles (the last two were not part of the systematic survey).

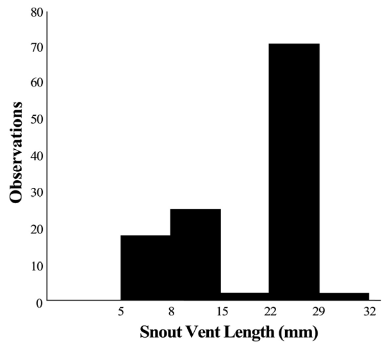

Figure 2. Frequency distribution of the snout to vent length in *Atelopus elegans* individuals observed in the PNN Gorgona.

Distance sampling. The models with *Hazard rate* function and both expansion series (*Cosine* and *Simple polynomial*) best fitted the distributions of observed perpendicular distances (Table 2). These models estimated a population density of 0.01 individuals/m^2 (95% CI: 0.01 – 0.02; CV = 24.27 %) with a 0.55 detection probability (95% CI: 0.47 – 0.66; CV = 8.71%). The component that most contributed to variance in density (87% contribution) was the encounter rate.

Power analysis. The statistical power to detect changes in *A. elegans* population density is affected by the survey duration and by the frequency of sampling events (Table 3). We found that the highest power was obtained with a sampling program over five years with four samplings per year; a reduction from trimestral sampling to quarterly sampling reduced power to 78% of detecting annual changes of 12% in population density (Table 3). Such sampling regime could detect adult aggregation near creeks during reproduction or population recruitment when metamorphs emerge from the creek.

The distribution of SVL and age categories for *A. elegans* is similar with that for *A. spurrelli* in the PNN Utría (Gómez-Hoyos et al. 2014). In both species, sexually immature individuals are very close to the creek, whereas presumed females move towards the creek when they are ready to reproduce (Lötters 1996, Lötters 2007, Fig. 2). Otherwise, the low sub-adult frequency close to the sampled creeks in *A. elegans* (Fig. 2) could be related to the strong seasonality in the distribution patterns of the species in the island (Atuesta 2003), or with low recruitment rates. To dismiss the latter and understand its contribution to population dynamics, additional sampling effort is necessary.

The density of *Atelopus elegans* at Gorgona was lower than the density of *A. spurrelli* in the PNN Utría (0.03 individuals/m^2; 95% CI: 0.022 – 0.038; Gómez-Hoyos et al. 2014) estimated with similar sampling effort and design, but higher than the density obtained by Atuesta (2003) for the same Gorgona population during the dry season (0.004 individuals/m^2; CV: 17.82 %) and wet season (0.004 individuals/m^2; CV: 21.27 %) in 2002. While distance sampling methods were implemented in all studies, we cannot conclude that there is a current increase in population density because we only surveyed creeks, whereas Atuesta (2003) surveyed the forest interior of the Gorgona island. Alternatively, our findings would support the hypothesis by Flechas et al. (2012a) of a population recovery in recent years, following putative declines caused by the chytrid fungus *Batrachochytrium dendrobatidis*.

Our estimated population density was less accurate than those obtained by Atuesta (2003) for the same species and by Gómez-Hoyos et al. (2014) for *A. spurrelli*. Implications for planning a monitoring strategy include a reduced capability to detect population fluctuations. Amphibian populations have declined sharply over short periods of time (Lips 1999, Young et al. 2001), thus an ideal population monitoring strategy must be able to promptly detect declines and to inform proper management actions (Gómez-Hoyos et al. 2014). We recommend maximizing sample size to increase the estimation precision (Buckland et al. 2001) and the sensitivity to detect population fluctuations because the encounter rate most contributed to variance in the estimated population density.

Acknowledgments. This project was funded by Parques Nacionales Naturales de Colombia (research fund "Mono Hernández" code 225). We thank the staff of PNN Gorgona for field support, and the WCS Colombia program for advice during study development, Idea Wild for providing equipment, and anonymous reviewers and Margarita Gil Fernández for their contributions to enhance the manuscript.

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