Diet Comparison of Free-Ranging and Cave-Associated Puerto Rican Boas, *Chilabothrus inornatus* (Reinhardt, 1843) (Reptilia: Boidae), Using Stable Carbon and Nitrogen Isotopes[1]

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Abstract: The study of prey consumed by different species has been useful for the understanding of the relationships among species. The use of stables isotopes in studies of diet offers advantages over other methods. The objective of this study was to determine, using stable isotopes, whether *Chilabothrus inornatus* that actively forage in caves have a different prey spectrum than snakes that forage in the forest. Tissue samples from the tail of free-ranging and cave-associated snakes were collected. Mean isotope values were not statistically different between the free-ranging and cave-associated *C. inornatus*. Free-ranging snakes showed more isotopic variance in $\delta\ ^{13}C$ suggesting different types of prey being consumed at different localities. Free-ranging and cave-associated *C. inornatus* acquired most of their energy from rodents (rat and mice). These explorations of diet using stable isotopes have provided an initial baseline for the development of new research incorporating this technique. Future research might focus on the seasonality of prey and the response of *C. inornatus* to it.

Keywords: *Chilabothrus inornatus*, boa, bats, caves, snakes, conservation, Puerto Rico

The study of prey consumed by different predatory reptile species has been useful for the understanding of the relationships among species and has allowed development of food webs that help understand energy flow, nutrient cycling and the dynamics of ecosystems (Reagan and Waide 1996). Another contribution of studies of food and feeding relationships in reptiles is an understanding of physiological and evolutionary processes (Losos and Greene 1988, Pough et al. 1998, Rodríguez-Robles 2002). Also, studying food habits generate important information about foraging behavior and ecology of individuals (Rodríguez-Robles 2002). This information is important when dealing with endangered species, given that the understanding of how animals

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use their resources is critical for population management and can be used for identifying important habitats for protection.

Fecal analysis and analysis of the gut contents of dead animals found at the study sites or of specimens in collections are two ways to obtain the data required for these studies. However, these studies can be biased due to the difficulty of measuring relative abundance of prey taxa or failure to identify all prey items because of differences in the digestibility and assimilation rates that may result in either over-representation or under-representation of certain food items (Bearhop et al.1999, 2004; Votier et al. 2003).

Recently, the use of stable isotopes on diet studies has offered advantages over other methods (Layman et al. 2012). These advantages consist of the isotopic composition of carbon and nitrogen in the consumer's tissues as the function of: ^{15}N and ^{13}C of each prey species; the relative proportions of each prey species assimilated; the isotopic fractionation associated with converting prey tissue into consumer tissue; and in certain instances, the location where foraging took place. Also, isotope signatures of tissues generally reflect the diet over the period during which the tissue was synthesized (Hobson and Clark 1992a, Bearhop et al. 2002). Overall, species that have a wide range of prey will exhibit wider variations in their isotopic signature than will species that consume a narrow range of prey (DeNiro and Epstein 1978, 1981, Hobson and Clark 1992a).

Within reptiles, stable isotope analysis has been use primarily on sea turtles (Godley et al. 1998, Hatase et al. 2002, Biasatti 2004, Wallace et al. 2006), and to a lesser extent on lizards (Magnusson et al. 2001, Struck et al. 2002). Recently, this technique has been used to study snakes because it does not require sacrificing animals and small quantities of skin or other tissues are sufficient for analysis (Wilson et al. 2010, Brischoux et al. 2011). However, there are no studies applying this technique on snakes in the West Indies.

One group of snakes vulnerable to extirpation and extinction is the boid genus *Chilabothrus* (Tolson and Henderson 2006). Therefore, gathering baseline information on the life history of these snakes is fundamental for solving questions dealing with their conservation and management (Burry 2006). The Puerto Rican Boa, *Chilabothrus inornatus* (J. T. Reinhardt, 1843) is one of the 12 large and robust species of snakes found on the Bahamas and the Greater Antilles (Tolson and Henderson 1993). This species was declared endangered in 1970 by the U.S. Fish and Wildlife Service (Endangered Species Act, 1973), and a recovery plan was completed in 1986. In 2004, the Puerto Rico Department of Natural and Environmental Resources classified this species as vulnerable, but still it was considered as endangered by the U. S. Fish and Wildlife Service. In terms of its diet, studies on the stomach content of dead individuals revealed that 73% of their prey items were Black rats, *Rattus rattus* (Linnaeus, 1758). However, the species has been reported feeding frequently on different species of bats (Rodriguez and Reagan 1984, Rodríguez-Durán 1996,

Puente-Rolón and Bird-Picó 2004, see Figures 1-3, 7, the latter located on p. 99).

The objective of this study is to determine, using stable isotopes, whether *Chilabothrus inornatus* that forage in caves, and presumably feeding on bats, have a different spectrum of prey than do free-ranging snakes (snakes that don't forage in caves). We predict that snakes that forage at caves will show less variation in stable isotope signatures of their tissues than do free-ranging animals owing to a diet restricted to bats, as opposed to the generalist diet of free-ranging animals.

Figures 1-3. *Chilabothrus inornatus* (J. T. Reinhardt, 1843) snakes in its habitat. 1. - 2. Two different adults, approximately 1.5 m long in a cave filled with bats in Arecibo, Puerto Rico. 3. Adults (arrows) hunting at same cave's entrance (arrow). Sex of the snakes is unavailable as they were not captured.

Methods

Ten free-ranging snakes or forest foragers (n = 10, five ♂, five ♀) were obtained from the northern karst area of Puerto Rico, specifically from Frontón Ward in Ciales, "El Tallonal" Private Reserve in Arecibo and fresh road kills. Snakes were considered freely ranging if the capture site was more than 1 kilometer from any cave with documented bat populations. We used this criterion due to the fact that Puente-Rolón and Bird-Picó (2004) relocated snakes from forested areas to caves and snakes have not stayed in the cave area. Another 11 samples were obtained from the inside of "Cueva Agrodel" located in Hatillo municipality, also within the northern karst region, and were considered as associated with caves. For each captured snake, we determined the snout vent length (SVL) and tail length (TL) in cm. We determined sex by cloacal probing. All live snakes were released at the site of capture after the data had been collected. For each animal, we collected a tissue sample from the tail. Muscle samples from various recently dead bats from "Cueva Agrodel" were collected. For rodents such as rats and mice, muscle samples were collected from forested areas, using victor traps.

All tissue samples were transported to the laboratory, rinsed with distilled water, and dried for 72 hours in a Shel Lab Oven at 60ºC. Samples were finely ground using a Retsch M200 frequency grinder. Samples of 0.9 to 1.3 mg were placed individually in 5 x 8 mm tin cups (Elementar, Hanau, Germany), compressed to a small sphere and analyzed for carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopes at the Laboratory of Stable Isotope Ecology in Tropical Ecosystems (University of Miami).

Tin spheres containing samples were placed in an automated elemental analyzer (Eurovector, Milan, Italy) and pyrolized. The gases from the pyrolysis were led into a mass spectrometer (Isoprime, Elementar, Hanau, Germany) and analyzed for abundances of ^{13}C and ^{15}N. Carbon and nitrogen isotope ratios are expressed as $\delta 13C = ([R_{sample}/R_{standard}]-1)\ (1000)$, $\delta 15N = ([R_{sample}/R_{standard}]-1)(1000)$, where R_{sample} and $R_{standard}$ are the corresponding ratios of heavy to light isotopes: (13C/12C and 15N/14N) in the sample and standard, respectively. The standards are the Belemnite from the PeeDee formation in South Carolina and atmospheric nitrogen for carbon and nitrogen isotope ratios respectively.

All data were reported as means and its standard error and was examined prior to each analysis to determine if statistical assumptions were met. We tested differences in mean isotope values using test for comparisons at $P = 0.05$ level of significance. We used a Levene's test for homogeneity of variance. Also, we assessed variations on isotope signal among groups using ANOVA. All analyses were performed using the software Sigma Stat® (version 3.5, Systat Software Inc. 2006) and JMP® (version 4.0.4, SAS Institute 2001). We applied the Ben-Davis and Schell (2001) linear mixing model to estimate *Chilabothrus inornatus'* use of bats and rodents (mice and rats) as a source of energy. For these, we used the two following equations:

$$\% \text{ Bat} = [(\delta\ ^{13}C_{predator} - \delta\ ^{13}C_{rodent})/ \delta\ ^{13}C_{bat} - \delta\ ^{13}C_{rodent})] \times 100$$

$$\% \text{ Rodent} = [(\delta\ ^{13}C_{predator} - \delta\ ^{13}C_{bat})/ \delta\ ^{13}C_{bat} - \delta\ ^{13}C_{rodent})] \times 100$$

Where $\delta\ ^{13}C_{predator}$ was the mean value for *Chilabothrus inornatus*, $\delta\ ^{13}C_{rodent}$ was the pooled rodent (mice and rodents) samples and $\delta\ ^{13}C_{bat}$ was the mean of all bats' samples from Agrodel Cave. This model assumed that fractionation was constant for all food sources and those predators were similar in their physiologic states (Gannes et. al. 1997). Due to the fact that the model did not include all the prey identified to species, the results must be interpreted as an approximation.

Results

For snakes associated with caves, mean SVL was 138.74 ± 15.40 cm and mean tail length was 24.69 ± 1.96 cm. On the other hand, free-ranging snakes had a mean SVL of 133.17 ± 14.28 cm and a mean tail length of 23.08 ± 2.28 cm (Table 1).

Table 1. Location, sex, snout to vent length, tail length, $\delta\ ^{13}C$, and $\delta\ ^{15}N$ of the 21 *Chilabothrus inornatus* examined for this study.

Group	**Sex**	**Snout-Vent Length (cm)**	**Tail (cm)**	**$\delta\ ^{13}C$**	**$\delta\ ^{15}N$**
Cave	Female	142	24.5	-21.64	9.39
Cave	Female	150.1	25.4	-22.39	7.97
Cave	Female	133.5	24.9	-21.82	8.79
Cave	Female	145.5	23.5	-21.11	9.95
Cave	Female	132.3	23.5	-23.13	8.02
Cave	Male	141.3	25.0	-22.26	8.37
Cave	Male	139.5	27.0	-22.27	7.68
Cave	Male	134.6	24	-22.39	8.00
Cave	Male	172.4	29	-21.74	9.30
Cave	Male	123	22.5	-23.24	7.73
Cave	Male	112	22.3	-22.51	7.54

Free ranging	Female	115.5	21.5	-24.56	7.32
Free ranging	Female	156.5	24.2	-23.30	7.50
Free ranging	Female	127	22	-22.32	10.34
Free ranging	Female	112	24	-20.27	9.95
Free ranging	Female	137.4	26	-23.00	7.30
Free ranging	Male	147	26.6	-22.74	8.70
Free ranging	Male	121	19.2	-22.07	9.15
Free ranging	Male	141	23	-21.79	8.99
Free ranging	Male	145.3	20.8	-24.20	6.83
Free ranging	Male	129	23.5	-20.02	8.91

Mean isotope signal was -22.23 ‰ $\delta^{13}C$ (range: -23.25 to -21.11 ‰) and 8.43 ‰ $\delta^{15}N$ (range: 7.52 to 9.954) for *C. inornatus* at Cave Agrodel. Free-ranging *C. inornatus* isotope signal was -22.42 ‰ $\delta^{13}C$ (range: -24.565 to -20.02 ‰) and 8.50 ‰ $\delta^{15}N$ (range: 6.83 to 10.34 ‰) (Figure 4). Mean isotope values were not statistically different between the free-ranging and cave-associated *C. inornatus*. (*t* test: $\delta^{15}N$, $t = 0.160$, $n = 19$, $p = 0.874$; $\delta^{13}C$, $t = -0.404$, $n = 19$, $p = 0.691$). Although, mean $\delta^{15}N$ and $\delta^{13}C$ isotopes were not different, free-ranging snakes showed more isotopic variance in its $\delta^{13}C$ (Levene's test for homogeneity of variances: $\delta^{13}C$, F-= 5.05, $n = 19$, $p = 0.0366$). No difference in isotopic variance of $\delta^{15}N$ between free-ranging and cave *C. inornatus* was detected (Levene's test for homogeneity of variances: $F = 2.55$, $n = 19$, $P = 0.126$).

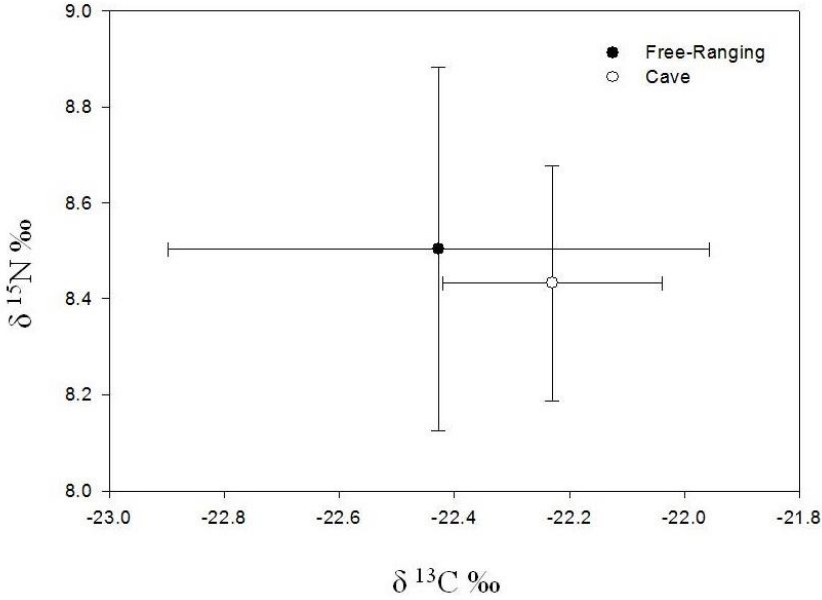

Figure 4. Average δ13C and δ15N values (± SE) of free ranging (n =10) and cave associated (n = 11) *Chilabothrus inornatus*.

Comparison of δ ^{13}C and δ ^{15}N signals for males and females at Agrodel cave showed no statistical difference (δ ^{13}C: t = - 1.579, n = 9, p = 0.149, δ ^{15}N: t = 1.012, n = 9, p = 0.338). Also, free-ranging males and females showed no differences in their isotopic signals (δ ^{13}C: t = 0.534, n =8, p = 0.608, δ ^{15}N: t = 0.043, n = 8, p = 0.967). No difference was detected among groups (ANOVA: δ ^{13}C: F= 0.323, p = 0.809, δ ^{15}N: F = 0.456, p = 0.716) (Figure 5). Potential prey samples average δ ^{15}N and δ ^{13}C isotope signals were 9.48 ± 0.95 and -25.39 ± 0.92 for bats, 8.25 ± 0.99 and -22.02 ± 2.14 for rodents (mice and rats) (Figure 6). The linear mixing model showed that free-ranging and cave-associated *C. inornatus* acquired most of their energy (88.0 % and 86.0%, respectively) from rodents (rat and mice), whereas bats were only 12 % and 14 % respectively.

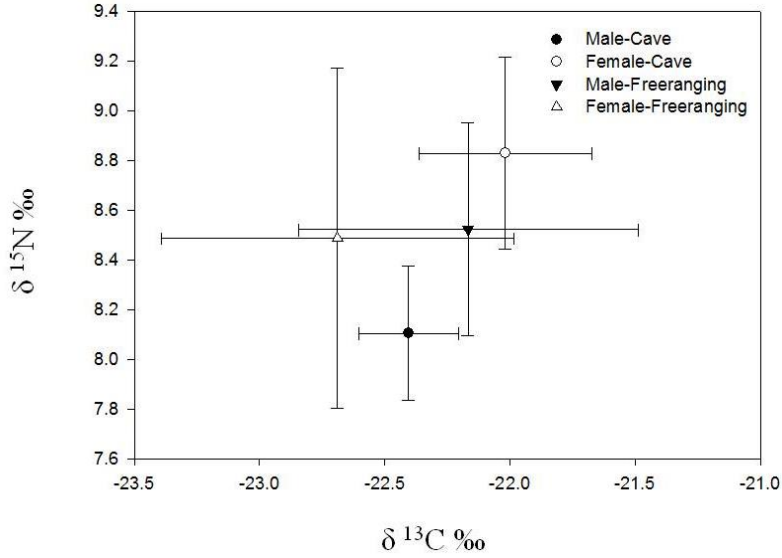

Figure 5. Average δ13C and δ15N values (± SE) of free-ranging male (n = 5) and female (n = 5) snakes and cave-associated male (n = 5) and female snakes (n = 6) of *Chilabothrus inornatus.*

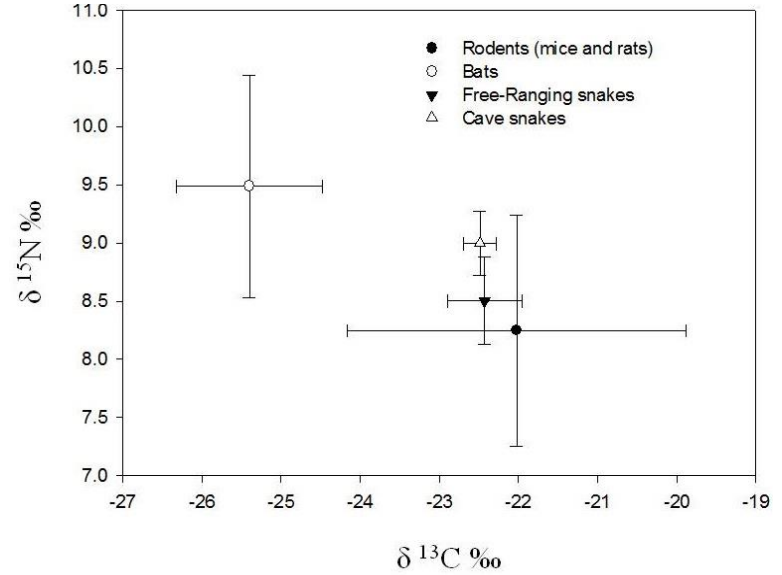

Figure 6. Average δ13C and δ15N values (± SE) for free ranging (n = 10) and cave associated (n = 11) *Chilabothrus inornatus* and prey items such as bats (n = 7) and rodents (n = 5).

Discussion

Isotope ratios in consumers reflect those of their prey; thus, species carry in their tissues a record of what they have eaten. Also, the resident time of these isotopic records can varies from days to years according to the sampled tissue (Hobson and Clarke 1992a, b, Hobson 1999a). The findings of this study do not support the prediction that *C. inornatus* that forage at caves will show less variation in the stable isotope signatures of their tissues than do free-ranging animals. Stable isotope signals of $\delta\ ^{13}C$ and $\delta\ ^{15}N$ were not different between the two groups. This suggests that even though snakes forage at caves and are consuming bats as prey; their diet is not limited to bats. The lack of statistical difference in *C. inornatus* $\delta^{15}N$ suggests that the two groups of snakes are feeding on similar prey. Puente-Rolón and Bird-Picó (2004), reported that snakes foraging at "Cueva de los Culebrones" over a period of 10 months moved away from the cave and returned an average of four times. If this behavior is exhibited by the snakes using the Agrodel Cave, animals there are likely foraging in the forest (for rodents) as well and hence the tissue signature for $\delta\ ^{13}C$ and $\delta\ ^{15}N$ will be similar for both study groups. Three questions that arise from this study are, as follows. (1) Is there any seasonality in the use of caves by *C. inornatus*? (2) Are the same group of snakes visiting the cave every year? (3) How frequently rodents use caves?

Recently, we began implanting passive integrated transponders in snakes at Agrodel Cave in order to identify the individuals using the cave. Preliminary data from three yearly visits showed that for 25 snakes already marked, only four of them were recaptured. This means that the number of snakes visiting the cave must be high and probably, there is a particular size of *C. inornatus* using this habitat (Puente-Rolón and Vega-Castillo, unpublished data). Also, this supports the observed lack of difference among isotope signals of the two groups of *C. inornatus*.

The isotopic $\delta\ ^{13}C$ variance observed for free-ranging snakes may result from the opportunistic sampling of snakes' tissues in a wider study area. Carbon isotope ratios change little from prey to predator, but vary among primary producers, thereby allowing tracing of the carbon source (Vander Zanden and Rasmussen 2001). For that reason, the observed difference may be an artifact of different types of prey being consumed by free-ranging *C. inornatus* at different localities.

The linear mixing model showed that for both groups of snakes studied, rodents, *Rattus rattus* and *Mus musculus* Linnaeus, 1758, were the most important prey. This coincides with the stomach contents observed by Wiley (2003), who examined 49 specimens of *C. inornatus* collected from different localities and found that *Rattus rattus* was the most common prey, with a 73.1% occurrence. Even though rodents are an important prey for *C inornatus*, no studies on population size or seasonality have been conducted in the northern karst area. Zwank and Laycon (1989) conducted a study on *Rattus rattus* at the

Caribbean National Forest and found that there the species has a single spring breeding season that produces a peak population during the fall. This coincides with the period of the year when female *C. inornatus* are giving birth and in need of prey to recover their body mass. Zwank and Laycon (1989) also observed a decline in numbers through the remainder of the year. If the northern karst populations of *Rattus rattus* have the same pattern, studies focusing on population dynamics of the prey of *C. inornatus* may help explain why snakes visits caves at different periods of the year.

In conclusion, these initial explorations of diet using stable isotopes have provided a baseline for the development of new research incorporating this technique. Further research may focus on seasonality of prey and on the response of *C. inornatus* to it. Such studies would provide tools for conserving this endangered species.

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Figure 7. Close up of *Chilabothrus inornatus* (Reinhardt, 1843).