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DIETS OF THREE SPECIES OF BUFONIDS (AMPHIBIA, ANURA) FROM NORTHERN MEXICO

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ABSTRACT.—We examined the diets of 3 species of bufonids from northern Mexico (*Anaxyrus debilis, Anaxyrus punctatus,* and *Incilius mazatlanensis*) with the objective of better understanding the diets of amphibians in this region of Mexico, which is currently undergoing environmental change. The diet of *A. debilis* was numerically and volumetrically dominated by termites, followed by ants. In *A. debilis,* some aspects of prey size were correlated with toad head width but were not related to head length or body size (i.e., snout–vent length [SVL]). Ants were numerically the most important prey item in the diet of *A. punctatus,* but beetles were volumetrically the most important prey item. Prey size was not related to toad head size or body size in *A. punctatus.* The diet of *I. mazatlanensis* numerically consisted of ants, beetles, and bugs; however, volumetrically, its diet was dominated by beetles. In *I. mazatlanensis,* only prey length was correlated with toad head width and SVL. The diets of these 3 species generally fit our previous understanding of the diets of bufonids.

RESUMEN.—Examinamos la dieta de 3 especies de bufónidos del norte de México (*Anaxyrus debilis, Anaxyrus punctatus* e *Incilius mazatlanensis*) con el objetivo de entender mejor la dieta de los anfibios en esta región de México que actualmente experimenta un cambio ambiental. La dieta de *A. debilis* fue dominada numérica y volumétricamente por las termitas, seguidas por las hormigas. En *A. debilis,* algunos aspectos del tamaño de sus presas estuvieron correlacionados con el ancho de la cabeza pero no estuvieron relacionados con el largo de la cabeza ni con el tamaño del cuerpo. Numéricamente, las hormigas fueron la presa más importante en la dieta de *A. punctatus,* pero los escarabajos fueron la presa más importante de acuerdo al volumen. El tamaño de la presa no estuvo relacionado con el tamaño de la cabeza o el cuerpo de los sapos en la dieta de *A. punctatus.* Numéricamente, la dieta de *I. mazatlanensis* consistió principalmente de hormigas, escarabajos e insectos; sin embargo, su dieta fue dominada volumétricamente por escarabajos. En *I. mazatlanensis,* solo el largo de la presa estuvo correlacionado con el ancho de la cabeza de los sapos y con su LHC (longitud hocico-cloaca). Las dietas de estas 3 especies corroboran en general nuestro entendimiento previo de las dietas de los bufónidos.

Analysis of diet breadth may provide some indication of how a species might be able to respond to changes in the prey community that might be associated with environmental change. For example, conversion of natural ecosystems to agricultural ecosystems or the invasion of areas by alien plants or animals can alter the insect community and thus affect the diets of insectivores, such as amphibians or reptiles (e.g., Dunn 2004, Rand and Louda 2006, Davis et al. 2008, Tallamy et al. 2010). Therefore, a basic understanding of a species' diet may be useful in considering the conservation or management of that species (Solé and Rödder 2010).

Some species of bufonids have been described as dietary generalists (e.g., de Carvalho Batista et al. 2011) and others as specialists on ants or termites (e.g., Isacch and Barg 2002, Santana and Juncá 2007). While we know the diets of several bufonids in the genus *Anaxyrus,* particularly species from the northern parts of the range in the United States and Canada, gaps still remain in our knowledge of the diets of *Anaxyrus* from Mexico (Table 1). In addition, we know far less about diets in the bufonid genus *Incilius* (Table 1). Here, we examine the diets of 3 species of bufonids (*Anaxyrus debilis, Anaxyrus punctatus,* and *Incilius mazatlanensis*) from northern Mexico, an area that has undergone and that continues to undergo environmental changes associated with overgrazing (Bryant et al. 1990, Mata-González et al. 2007, Sánchez Flores and Yool 2007), conversion to agriculture (Doolittle 2006, Macías-Duarte et al. 2009, Franklin and Molina-Freaner 2010), and climatic changes (e.g., decrease in precipitation; Villers-Ruiz and Trejo-Vázquez 1998, Serrat-Capdevila et al. 2007, Kimball et al. 2010). To our knowledge, the diets of these 3 species have not been previously described.

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TABLE 1. Review of the diets of bufonids in the genera *Anaxyrus* and *Incilius.* Order of diet items in column 2 reflects the items' order of importance as reported in the original study.

Species	Prey of importance	Reference
A. americanus	Ants, beetles	Smith and Bragg 1949
	Diptera, mites, ants, beetles	Hamilton 1930
A. boreas	Ants, beetles	Schonberger 1945, Campbell 1970
A. cognatus	Beetles, ants, Lepidoptera	Smith and Bragg 1949
A. compactilis	Beetles, ants, Lepidoptera	Smith and Bragg 1949
A. fowleri	Ants, beetles	Brown 1974, Clarke 1974
	Beetles, ants	Bush and Menhinich 1962, Klimstra and Myers 1965
A. hemiophrys	Beetles, ants	Moore and Strickland 1954
A. quercicus	Ants, beetles	Hamilton 1955
	Ants, spiders, termites, beetles	Punzo 1995
A. terrestris	Ants, beetles	Meshaka and Mayer 2005
	Beetles, ants, termites, spiders	Punzo 1992
A. woodhousei	Beetles, Lepidoptera, ants	Smith and Bragg 1949
I. alvarius	Beetles	Bogert and Oliver 1945
I. coccifer	Beetles, ants	Greding and Hellebuyck 1980
I. nebulifer	Termites, ants (numerically), Orthoptera (volumetrically)	Santana and Juncá 2007

We provide information on the composition of the diets, as well as the relationships between measures of toad size and prey size, with the objective of better understanding the diets of amphibians in this region of Mexico.

We examined specimens of *A. debilis* (n = 32), *A. punctatus* (n = 23), and *I. mazatlanensis* (n = 21) from the collection of the Laboratorio de Ecología, UBIPRO-FES-Iztacala, UNAM (see Lemos-Espinal et al. 2004 and Smith et al. 2005 for details of collection). The *A. debilis* specimens were collected in summer and fall 2004 from a locality in Coahuila at an elevation of 114 m, with one specimen coming from Chihuahua at an elevation of 1427 m (Appendix). The *A. punctatus* specimens were pooled from collections made in the summer of 2003 and the summer and fall of 2004 from several localities in Sonora, Chihuahua, and Coahuila, ranging in elevation from 435 m to 1545 m (Appendix). The *I. mazatlanensis* specimens were collected in summer 2003 and in summer and fall 2004 from 3 localities in Sonora and 2 localities in Chihuahua, ranging in elevation from 435 m to 1545 m (Appendix). Specimens were preserved in formalin within 30 minutes of collection; thus, the effects of digestion on observed stomach contents were likely minimal.

We measured snout–vent length (SVL) of each specimen using a clear plastic ruler (to nearest mm). We measured head width (HW; at corner of mouth) and head length (HL; from corner of mouth to tip of nose) using a digital caliper (to nearest 0.01 mm). We dissected specimens to remove the stomach. Stomach contents were identified to the lowest taxonomic level possible and counted. We measured the length and width of each prey item using a digital caliper (to nearest 0.01 mm) and calculated prey volume using the volume of a prolate spheroid. We used BugRun software to calculate niche breadth based on prey number and prey volume (Vitt and Zani 2005). We calculated importance values for each prey category using the sum of the percent prey volume, percent prey number, and percent of stomachs that contained the prey item (Powell et al. 1990). We used linear regression to examine the relationships among morphological variables (SVL, HW, HL) and prey size (width, length, volume), stomach volume, and number of prey consumed.

Anaxyrus debilis

Of the 32 stomachs examined, 30 contained identifiable prey items, and 2 contained unidentifiable prey items. Mean SVL was 4.20 cm (SE = 0.11, n = 32). The diet of *A. debilis* was numerically and volumetrically dominated by termites, followed by ants (Table 2). The remaining prey items were also insects. Isopterans had a high importance value compared to all other prey items (Table 2). Niche breadth based on number of prey was 1.74, and niche breadth based on volume of prey was 1.25.

Mean prey width, length, and volume were not not significantly related to HL or SVL. However, mean prey width, length, and volume did have significant positive relationships with HW. Number of prey per stomach was not related to SVL, and prey volume per stomach was not

TABLE 2. Diet of 30 *Anaxyrus debilis* from northern Mexico. IV = importance value.

Prey taxon	Number	% Number	Volume (cm^3)	% Volume	Stomachs	% Stomachs	IV
Coleoptera							
Adult	10	0.68	0.16	0.68	6	20	21.36
Larvae	13	0.88	0.03	0.13	1	3.33	4.34
Diptera	55	3.74	1.5	6.4	10	33.3	43.44
Hymenoptera							
Formicidae	323	21.94	0.61	2.6	18	60	84.54
Apidae	2	0.14	0.1	0.43	1	3.33	3.9
Other	4	0.27	0.1	0.43	1	3.33	4.03
Isoptera	1065	72.35	20.93	89.33	25	83.3	244.98

TABLE 3. Relationships of prey attributes with head length (HL), head width (HW), and snout–vent length for 3 bufonid species. Sample size, coefficient of determination, and probability values are given for each linear regression model; $\alpha = 0.05$.

Species and model	n	r^2	P	Regression equation
Anaxyrus debilis				
prey width vs. HL	30	0.107	0.078	
prey length vs. HL	30	0.057	0.20	
prey volume vs. HL	30	0.089	0.11	
prey width vs. HW	30	0.149	0.035	Prey width = –0.043 + 0.152HW
prey length vs. HW	30	0.13	0.05	Prey length = 0.030 + 0.401HW
prey volume vs. HW	30	0.20	0.013	Prey volume = –0.034 + 0.033HW
prey width vs. SVL	30	0.001	0.90	
prey length vs. SVL	30	0.029	0.37	
prey volume vs. SVL	30	0.017	0.50	
prey per stomach vs. SVL	30	0.007	0.67	
prey volume per stomach vs. SVL	30	0.044	0.26	
Anaxyrus punctatus				
prey width vs. HL	20	0.006	0.76	
prey length vs. HL	20	0.058	0.30	
prey volume vs. HL	20	0.029	0.47	
prey width vs. HW	20	0.029	0.48	
prey length vs. HW	20	0.018	0.58	
prey volume vs. HW	20	0.007	0.72	
prey width vs. SVL	20	0.10	0.16	
prey length vs. SVL	20	0.003	0.83	
prey volume vs. SVL	20	0.084	0.21	
prey per stomach vs. SVL	20	0.084	0.21	
prey volume per stomach vs. SVL	20	0.248	0.025	Stomach volume = –0.13 + 0.065SVL
Incilius mazatlanensis				
prey width vs. HL	20	0.002	0.86	
prey length vs. HL	20	0.008	0.72	
prey volume vs. HL	20	0.032	0.45	
prey width vs. HW	20	0.127	0.123	
prey length vs. HW	20	0.233	0.031	Prey length = 0.077 + 0.321HW
prey volume vs. HW	20	0.126	0.12	
prey width vs. SVL	20	0.133	0.11	
prey length vs. SVL	20	0.328	0.0083	Prey length = –0.005 + 0.129SVL
prey volume vs. SVL	20	0.125	0.13	
prey per stomach vs. SVL	20	0.088	0.205	
prey volume per stomach vs. SVL	20	0.007	0.73	

related to SVL. Results for all models are given in Table 3.

Anaxyrus punctatus

Three of the 23 examined stomachs were empty. Mean SVL was 4.24 cm (SE = 0.28, n = 23). Ants were numerically the most important prey item in the diet of *A. punctatus,* followed distantly by termites and beetles (Table 4). Volumetrically, beetles were the most important prey item, followed by ants (Table 4). Ants had the highest importance value followed relatively

TABLE 4. Diet of 20 *Anaxyrus punctatus* from northern Mexico. IV = importance value.

Prey taxon	Number	% Number	Volume (cm^3)	% Volume	Stomachs	% Stomachs	IV
Aranae	1	0.24	0.01	0.23	1	5	5.47
Coleoptera							
Adult	34	8	2.28	52.41	13	65	125.41
Larvae	1	0.24	0.03	0.69	1	5	5.93
Diptera	1	0.24	0.02	0.46	1	5	5.7
Hemiptera	1	0.24	0.07	1.61	1	5	6.85
Homoptera	4	0.94	0.09	2.07	2	10	13.01
Hymenoptera							
Formicidae	329	77.41	1.41	32.41	16	80	189.82
Isoptera	51	12	0.37	8.51	1	5	25.51
Lepidoptera (larvae)	2	0.47	0.06	1.38	2	10	11.85
Mollusca (snail)	1	0.24	0.01	0.23	1	5	5.47

TABLE 5. Diet of 20 *Incilius mazatlanensis* from northern Mexico. IV = importance value.

Prey taxon	Number	% Number	Volume (cm^3)	% Volume	Stomachs	% Stomachs	IV
Coleoptera	78	33.62	11.84	81.82	17	85	200.44
Diptera	1	0.43	0.29	2	1	5	7.43
Hemiptera	64	27.59	1.58	10.92	3	15	53.51
Hymenoptera							
Formicidae	84	36.21	0.56	3.87	7	35	75.08
Apidae	2	0.86	0.13	0.9	2	10	11.76
Isoptera	3	1.29	0.07	0.48	7	35	36.77

closely by adult beetles (Table 4). Niche breadth based on prey number was 1.61, and niche breadth based on prey volume was 2.58.

Mean prey width, length, and volume were not significantly related to HL, HW, or SVL. The number of prey per stomach was not related to SVL. Stomach volume increased with SVL. Model results are given in Table 3.

Incilius mazatlanensis

Twenty of the examined stomachs contained identifiable prey items, and one stomach contained unidentifiable prey items. Mean SVL was 6.18 cm (SE = 0.31 cm, n = 21). The diet of *I. mazatlanensis* primarily consisted of ants, beetles, and bugs, at least numerically (Table 5). However, volumetrically, the diet was dominated by beetles (Table 5). Beetles also had the highest importance value, followed distantly by ants (Table 5). Niche breadth based on number of prey was 3.12, and niche breadth based on prey volume was 1.46.

Mean prey width, length, and volume were not significantly related to HL. Mean prey width and volume were not significantly related to HW, but mean prey length was positively related to HW. Mean prey width was not significantly related to SVL. Mean prey length was positively related to SVL. Mean prey volume and the number of prey per stomach were not related to SVL. Prey volume per stomach was not related to SVL. Model results are given in Table 3.

In general, niche breadths were relatively low in these 3 species of toads, although niche breadth varied somewhat depending on whether prey number or prey volume was used in the calculation. In any case, our results suggest that relatively few prey types were consumed by any single toad and the species as a whole. What is unclear is whether the low niche breadths are a consequence of prey selection on the part of the toads or a reflection of the availability of prey in the environment. For example, diet composition may reflect the relative availability of local prey (e.g., Hamilton 1955, Klimstra and Myers 1965, Boomsma and Arntzen 1985, de Carvalho Batista et al. 2011), although some species appear to select particular prey (Toft 1980, Teixeira et al. 1999, Isacch and Barg 2002, Santana and Juncá 2007). The low niche breadth suggests that environmental changes that could alter the prey community might have adverse effects on these toads; however, we need to know more about the relationship between diet and prey availability in these species to draw firmer conclusions.

Anaxyrus debilis ranges from Kansas south through the central plateau of Mexico (Lemos-Espinal and Smith 2007a, 2007b). *Anaxyrus punctatus* occurs from the southwestern U.S. south to the states of Jalisco and Hidalgo in Mexico (Lemos-Espinal and Smith 2007a, 2007b). *Incilius mazatlanensis* is relatively limited in its distribution, and only occurs in parts of Chihuahua, Colima, Jalisco, Nayarit, Sonora, and Sinaloa (Lemos-Espinal and Smith 2007a, Santos-Barrera et al. 2008). Given that *I. mazatlantensis* had the highest niche breadth based on prey numbers, *A. punctatus* had the highest niche breadth based on volume, and *A. debilis* had the lowest or near lowest niche breadths in both cases, there does not appear to be a relationship between geographic range and dietary breadth in these 3 species, at least in the pooled samples we examined.

Ants were an important prey item in all 3 species (*A. debilis, A. punctatus,* and *I. mazatlanensis*), at least from a numerical standpoint. However, termites were more important than ants in *A. debilis,* and volumetrically, beetles were more important than ants in *I. mazatlanensis* and *A. punctatus.* The importance values suggest that termites were the most important prey item in *A. debilis,* beetles were the most important prey item in *I. mazatlanensis,* and ants and beetles were both relatively important prey items in *A. punctatus.* Thus, while ants are numerically important in these species, it is misleading to consider them ant specialists since, from an energetic point of view, the taxa that were volumetrically more important were not ants. The diets we found in these species are similar to many other bufonid diets, and the variability among these 3 species reflects the variation within the family (Table 1). Duré et al. (2009) found that smaller species of bufonids appear to prefer ants, whereas larger species prefer beetles, suggesting prey choice may be related to body size. Indeed, our results tend to support this contention, at least in part: the largest species, *I. mazatlantensis,* consumed primarily beetles, whereas the 2 smaller species ate ants or termites relatively more than *I. mazatlanensis.*

We found that the relationships between prey size and toad head size or toad body size varied among the 3 species we studied. In *A. debilis,* prey size was correlated with head dimensions but was not related to body size. In *I. mazatlanensis,* only prey length was correlated with toad HW and toad SVL. Prey size was not related to toad head size or body size in *A. punctatus.* Our results, however, suggest that the relationship between prey size and toad body size in bufonids may not be generalizable and that other factors may drive diet composition in these species.

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APPENDIX.—Locality data for the specimens examined.

Specimen count	Location	Latitude, Longitude	Elevation
Anaxyrus debilis			
31	Charcos de Risa, Coahuila	26°12′32.7″N, 103°6′24.0″W	1114 m
1	Between Sierra de En Medio and Rancho Nogales, Chihuahua	31°9′51.1″N, 108°34′40.3″W	1427 m
Anaxyrus punctatus			
5	Yécora, Sonora	28°22′4.0″N, 108°55′32.6″W	1545 m
4	Valle de Tacupeto, Sonora	28°15′20.5″N, 109°18′1.9″W	435 m
4	53 km S, Químicas del Rey, Coahuila	26°38′44.5″N, 103°9′13.4″W	1084 m
3	Chínipas, Chihuahua	27°23′39.9″N, 108°32′36.0″W	469 m
3	Moris, Chihuahua	28°8′51.6″N, 108°31′21.8″W	772 m
2	Químicas del Rey, Coahuila	27°1′13.2″N, 103°21′49.8″W	1051 m
1	General Trias, Chihuahua	28°25′5.9″N, 106°25′55.4″W	1516 m
1	Las Borregas, Chínipas, Chihuahua	27°23′4.3″N, 108°32′27.5″W	470 m
Incilius mazatlanensis			
6	Valle de Tacupeto, Sonora	28°15′200.5″N, 109°18′1.9″W	435 m
5	Yécora, Sonora	28°22′4.0″N, 108°55′32.6″W	1545 m
4	Chínipas, Chihuahua	27°23′39.9″N, 108°32′36.0″W	469 m
3	Santa María, Moris, Chihuahua	28°12′20.9″N, 108°31′36.7″W	794 m
3	Between Fronteras and Esquela, 49 km S Agua Prieta, Sonora	30°59′40.7″N, 109°33′22.4″W	1136 m