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Shifted Baselines, Forensic Taxonomy, and Rabbs' Fringe-limbed Treefrog: The Changing Role of Biologists in an Era of Amphibian Declines and Extinctions

My initial foray in tropical herpetology yielded less than spectacular results. In 1989, I was a new graduate student at the University of Texas at Arlington, where my mentors, J. A. Campbell and E. D. Brodie Jr., arranged for me to spend a field season in Guatemala. My task was to make collections on the wet northern slope of the Sierra de las Minas, based out of Finca Pueblo Viejo, a coffee/cardamom/rubber plantation at the edge of the Polochic Valley in Alta Verapaz (Mendelson 1990). This region of the sierra had never been surveyed herpetologically, so I was very excited to conduct an expedition.

As this was to be my first experience in the tropics, I "did my homework" in terms of relevant literature, available field notes, and especially reviewing the collections at UT Arlington. Consequently, when I arrived at the site and despite my inexperience, I was fairly knowledgeable of the animals I might encounter. I knew to look on the underside of leaves for centrolenid frogs, and to dig in piles of rotting coffee-bean husks for caecilians. I knew to look for species of frogs in the *Craugastor rugulosus* group on the ground and rocks along montane streams. That summer, I assembled a good collection of reptiles from Pueblo Viejo, but a poor collection of amphibians.

Late summer and fall, I sorted and identified my specimens. I was pleased to realize that I had, for the first time in my career, discovered a species new to science: *Incilius campbelli* (Mendelson 1994), a toad previously confused with the ubiquitous *Incilius valliceps*. One day, while I had some frogs out in a tray, Jon Campbell pointed to a specimen of the *Craugastor rugulosus* group (later described as *C. sabrinus* by Campbell and Savage 2000) and asked why I had collected only one of those. I responded "*Because that's the only one I found.*" It seemed clear to all concerned that Mendelson's inexperience explained the paucity in the collection of these typically common streamside frogs. Meanwhile, down the hall in his lab, Campbell was frustrated in his attempts to describe the tadpole of a new species of *Ptychohyla* from Guatemala (Campbell and Smith 1992) because—for some reason—none of the specimens collected by Eric Smith (then an undergraduate in Guatemala) had complete mouthparts.

That same month, September, hallway conversations at the First World Congress of Herpetology, held in Canterbury, UK, were considering that amphibians might possibly be in decline (Wake 1991). It would be several years yet until Joyce Longcore and colleagues described the insidious chytrid fungus that destroys the mouthparts of tadpoles as it proceeds to decimate amphibian populations (Longcore et al. 1999). But it would be a long time before I realized that the paucity of specimens of *C. sabrinus* in my collection was not the result of my tropical inexperience.

In 1992, my friend Adrian Nieto-Montes de Oca and I spent the summer in southern Mexico, looking for anoles and toads for our dissertations at the University of Kansas. I took along photocopies of field notes by Bill Duellman, Jan Caldwell, John Lynch, and others made in the 1960s and 1970s to help guide our efforts at certain sites. That trip was frustrating because, despite our best attempts, Adrian and I could not come close to duplicating the successes of the earlier collectors. For example, field notes indicated that salamanders of the genus *Thorius* could easily be found by the dozens or even hundreds in Oaxaca. We found one *Thorius* that summer, and it was a new species (*T. smithi* Hanken and Wake, 1994).

Around this time I became friends with Karen Lips, a graduate student from a "competing lab" (Jay Savage's group at the University of Miami), who had interests similar to mine but with field sites that were further south, mostly in Costa Rica. She and I often discussed our experiences and compared notes from our respective field adventures. She told me of working cloudforest streams at night and finding dozens and dozens of frogs, whereas I was hard-pressed to find dozens of upland frogs in Mexico during an entire season, much less a single night. We didn't think much of the disparity at the time, but I will be honest in admitting that I was worried that my life-long southern California field skills were not serving me well in the tropics. In the mid-90s I travelled extensively with Jonathan Campbell and Eric Smith, mostly in Guatemala, and it became obvious that they too could not find appreciable numbers of amphibians including the "common" species of the *Craugastor rugulosus* group or upland hylid frogs. I clearly remember a day in 1996, when I stood with Campbell at the type locality for *Plectrohyla cyanomma* (Caldwell, 1974) in the Sierra de Juárez, Oaxaca, and he pointed to a particular rock in the stream and commented that he inevitably found individuals basking on that rock, and the stream was always replete with their large tadpoles. There were none.

During those times in the late 80s and the 90s, it never occurred to me that I found few amphibians on my trips because they simply were no longer there. It is clear now that I began my career in tropical herpetology in a geographic arena (Mexico

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FIG. 1. JRM in Sierra de Juárez, Oaxaca, Mexico, July 1992. Photo by A. Nieto-Montes de Oca.

and Guatemala) that had experienced a dramatic baseline shift in amphibian diversity and abundance before I ever arrived. As we were to discover, Karen Lips began her career in a geographic arena (Costa Rica and Panama) that was just on the verge of having its baseline shifted. When it did so, I am glad at least that she and her collaborators were able to describe that shift in great detail. They were there to document one of the great stories unfolding in natural history during our times (e.g., Lips 1999; Lips et al. 2006; see also Collins and Crump 2009). As for me, I got but a single glimpse at an intact Mesoamerican amphibian community in central Panama in 2005, just months before it crashed. All told, I personally feel like I was cheated of a natural history experience that I deserved and I am angry about it. I also am sad that current and future cohorts of graduate students and naturalists will share this loss. There no longer exists a natural upland ecosystem in Mesoamerica.

Nobody noticed the declines taking place in Mexico and Guatemala. In 2000 Karen Lips and I led resurveys of historical collecting sites in southern Mexico that had not been visited in years, and concluded that a subset of the amphibian fauna was simply missing and what species did remain in the higher elevations were far less abundant than they had been historically (Lips et al. 2004). Our reasonable estimate was that the declines there took place in the mid-1980s. That summer we found exactly one individual representing the entire *Craugastor rugulosus* group. Similarly, in Guatemala, the remnant amphibian fauna of a cloudforest reserve, Biotopo Mario Dary in the Sierra de las Minas, Baja Verapaz, bears little resemblance to its historical assemblage and abundance, based on Campbell's field work there ca. 1980 (Mendelson et al. 2005). If you wish to know the details of how a decline like these comes about, then do read the important paper by Ryan et al. (2008) wherein they describe the final days of a population of *Craugastor* cf. *punctariolus*. We now believe that species to be extinct in the wild (Griffiths, Ross, and Mendelson, unpublished data), but taxonomists are not entirely sure as to what species it was.

It is reasonable to conclude that the chytrid fungal pathogen *Batrachochytrium dendrobatidis* Longcore, Pessier, and Nichols, 1999, played a major role in eliminating amphibian species and reducing their populations in Mexico and Guatemala (Lips et al. 2004; Mendelson et al. 2005) in the 1980s, but of course this is difficult to demonstrate directly in retrospect. Although histological examination of museum specimens (where sufficient series of specimens exist, which is unusual) might identify synchronous appearance of the fungus and subsequent population declines, correlation is not causation. Quite frankly, such studies are psychologically depressing, and I have noticed that few students delve into them. It is not very rewarding to study a population or species so recently vanished.

Herpetologists spent the better part of the 1990s aggressively debating the reality of amphibian declines and potential causes (reviewed by Collins and Crump 2009) and, meanwhile, the situation became worse. The baseline shift that I missed means that, despite my 20 years of field work and research in northern Mesoamerica, I have never experienced a natural amphibian community there. The baseline shift that Karen Lips and colleagues are documenting in southern Mesoamerica means that no herpetologist visiting the area in the future can ever possibly know the historical reality of those ecosystems.

When an epidemic of chytridiomycosis decimates a regional amphibian assemblage, the ecosystem there is fundamentally changed (Lips et al. 2006; Smith et al. 2009; Crawford et al. 2010) and those changes have ecosystem-level effects (Whiles et al. 2006; Connelly et al. 2008). A national park near El Copé, Panama, lost at least 30 species of amphibians (41% of the assemblage; Crawford et al. 2010). The fully-protected Biotopo Mario Dary in Guatemala appears to have lost about 70% of its amphibian fauna (J. A. Campbell, pers. comm.). When you consider losses of this magnitude together with the phenomenal biomass that amphibians may attain (Burton and Likens 1975), it is impossible to assume that the affected ecosystem will function in any manner similar to pre-epidemic conditions. The implications of these faunal upheavals are considerable, and they are generally ignored outside the research community that is directly related to amphibian declines. Biologists of all sorts should acknowledge if their research is taking place in the context of an intact, or an altered, amphibian community. Would not a cardiologist also consider the fact that their patient has emphysema? The reality of amphibian declines and extinctions has shifted the ecological baseline in so many ecosystems, that an entire generation of biologists is conducting their research in a framework that has been very recently remodeled. And I feel like we—herpetologists, ecologists, biogeographers,

systematists, and more—are not really talking about it; this reality compromises our research, and this is a problem.

I am a taxonomist and I have seen my career vacillate between the thrill of discovering new species and the chill of tracking extinction events—including species that I described. Taxonomists are not the warmest lot of people, but I will opine that one feels a personal connection with a species that you yourself have named. In a recent species description (Mendelson and Mulcahy 2010) we put forward the term "Forensic Taxonomy" to try to communicate the frustrating reality of what it means to be an amphibian taxonomist in this era. In the last 20 years, I have contributed to naming (or resurrecting) 32 amphibian species. Of these, I believe at least four of them are extinct, and several others are hanging on in very low numbers. I have never seen several of them in life, having described them based on specimens on the shelves of museums. I sought a career in herpetology because I enjoy working with animals. I did not anticipate that it would come to resemble paleontology. I am not alone in this cutting-edge new field of Forensic Taxonomy, as I note that my friend Luis Coloma (Coloma et al. 2007, and especially Coloma et al. 2010) has independently discovered the field as he works his way taxonomically through the ashes of what once was the wonderful radiation of *Atelopus* (LaMarca et al. 2005). I focus most of my attentions on frogs, but the salamanders are in no better shape (Parra-Olea et al. 1999; Rovito et al. 2009), and the poor caecilians perpetually languish in the cloud of our ignorance of their fascinating habits.

The US National Science Foundation has an entire program devoted to Biotic Surveys, and I endorse that program entirely. However, I must pose the question "*What does it mean to conduct biotic surveys in an era of shifted, shifting, or soon-to-be shifted baselines of amphibian diversity*?" Crawford et al. (2010) discovered that even seven years of systematic collections of tissues, specimens, and ecological notes failed to discover a good proportion of the actual amphibian species-level diversity that existed near El Copé, Panama, prior to the epidemic of chytridiomycosis documented by Lips et al. (2006). Our discovery and description of *Incilius karenlipsae* Mendelson and Mulcahy, 2010, based on a single specimen found at that site in the wake of the disease, was an experience I can classify only as bittersweet because the effects of chytridiomycosis there suggest that it likely no longer exists. I hope I am wrong about that.

I can tell you what it feels like to conduct biotic surveys for amphibians in this era. In 2004, I joined Martín Bustamante to survey a site in southern Ecuador. That general region of the Amazonian slope of the Andes had never been surveyed herpetologically, so the project qualified as an expedition into an area undocumented by herpetologists—the kind of excursion that made H. M. Smith, E. H. Taylor, L. C. Stuart, and our other heroes legendary. We were on site for about a month, with a team of eager students, in what we thought was a pristine ecosystem along a cloudforest–paramo transition zone. In that month we found only seven species of amphibians—five *Pristimantis* spp., one *Gastrotheca* sp., and one dendrobatid; at least three of the *Pristimanis* spp. are new to science. Biannual surveys of the site in the last six years have not increased the numbers. Bustamante and I are working on describing these new species (e.g., Bustamante and Mendelson 2008), but it is apparent that our attempt to conduct a modern biotic survey came too late. Where were the hylids, the centrolenids, the bufonids, or the *Telmatobius*? What we surveyed was in no way a typical Andean amphibian fauna (see Duellman 1979), which should have harbored many more species. Local ranchers told us that the site used to include *jambatos* (= *Atelopus* spp.). They also provided perfect descriptions of a local *Telmatobius* sp. but they had not seen either frog in many years. The *Telmatobius* sp. likely was *T. cirrhacelis* Trueb, 1979, a species described as "possibly extinct" on the IUCN Red List (www.iucnredlist.org). We cannot hazard a guess as to the identity of the *Atelopus* spp. that had once existed at the site. Bustamante and I had gone into the area too late even to conduct a proper Forensic Taxonomy of the life that once existed there.

In late 2004, Karen Lips determined that the chytrid pathogen had finally arrived at her long-term study site near El Copé, Panama, and the expected massive die-off was in progress. This reality created a terrifying reality of predictiveness—we knew where it was going next, but we had no idea of what to do about it. In response to this important finding, an emergency meeting in Atlanta brought together a small group of key stakeholders to try to determine what, if anything, could be done about the situation there, as all precedents indicated that the amphibian fauna of the adjacent highlands of Panama were about to be

FIG. 2. JRM in Sierra de Huautla, Oaxca, Mexico, July 1992. No individuals of *Craugastor* nor *Plectrohyla* were found along this cloudforest stream. Photo by A. Nieto-Montes de Oca.

decimated by the disease (Collins and Crump 2009, provided more details about this meeting). Among the projects that resulted from that meeting was a pilot-study for the development of a rapid-response multi-species "extraction" of amphibians into captive safekeeping. This was to be launched near El Valle de Antón, just east of Lips' site at El Copé. This pilot project took place in 2005, and was described by Gagliardo et al. (2008).

Among the frogs collected at the El Valle site for safekeeping was a large fringe-limbed treefrog of the genus *Ecnomiohyla*. We assumed it to be *E. fimbrimembra* (Taylor, 1948), but our colleague Brian Kubicki (Costa Rican Amphibian Research Center) immediately recognized it as a new species. Eventually, we collaborated and described the species *Ecnomiohyla rabborum* Mendelson, Savage, Griffith, Ross, Kubicki, and Gagliardo, 2008. The name honors George and Mary Rabb, as lifelong stalwarts for conservation—especially for amphibians. It meant a lot to us to honor them with this spectacular new species. Edgardo Griffith and Heidi Ross (El Valle Amphibian Conservation Center [EVACC]) led the field work that discovered the frog and were able to document some of its amazing natural history (detailed in Mendelson et al. 2008). As is known in other species of *Ecnomiohyla*, the frog does leap from upper tree limbs and glide to the forest floor, using its massive fully webbed hands and feet to orient, and the eggs are deposited in tree holes. Edgardo and Heidi observed that the males remain with the developing eggs and immerse their body into the writhing mass of tadpoles on occasion, allowing the tadpoles to rasp their epidermis for nutrition. We believe this is the first example of direct paternal nutrition of offspring in an amphibian, but it appears that we will not have the opportunity to directly demonstrate such. In any case, this is an impressively large treefrog (up to 100 mm SVL) with a remarkable natural history. *Ecnomiohyla rabborum* was discovered afield in 2005 and formally named in 2008. In 2006, the chytrid fungus arrived at El Valle, having moved eastward from El Copé, in an advancing wave, exactly as predicted by Lips et al. (2006) and further characterized by Lips et al. (2008). Just as predictable was the utter decimation of the amphibian fauna there during 2006–2007, and our lack of any means of preventing it.

In 2006, crews at the nascent protection facility, EVACC (still under construction at the time!), scrambled to triage and treat infected frogs of many species, hoping to use them to establish captive survival-assurance colonies. Individuals of *E. rabborum* were distributed, for safekeeping, to facilities at EVACC, Zoo Atlanta, and Atlanta Botanical Garden. Captive programs for endangered species sometimes are successful (e.g., *Atelopus zeteki*, www.ranadorada.org) and sometimes they are not (e.g., Passenger Pigeon, as a singularly famous example). The end-story is that these individuals of Rabbs' Fringe-limbed Treefrog thrived for years but never bred under captive conditions. The last wild individual noted was a calling male heard (but not seen) in 2007. Edgardo and Heidi still lead field work in the area, but the species has not been found. The last female known died in captivity at Atlanta Botanical Garden in 2009. At this time of writing, a single adult male lives at the Atlanta Botanical Garden and another is at Zoo Atlanta (see cover image). It appears that nature has run its course before three teams of dedicated people were able to determine the needs of these frogs in order for them to reproduce. To have been a part of one of those teams has been a frustrating and sad experience.

Our esteemed colleague Tim Halliday—a longtime leader in the field of amphibian declines—has taken to calling himself "an extinction biologist." His sense is accurate, if morbid, and I posit that most of us working on amphibians in this era may consider adopting the term. As for me, I'm still adjusting to my new title of "Forensic Taxonomist." I have re-surveyed field sites and experienced the emptiness of not finding as many frogs as Bill Duellman did in the 1960s. I have co-led biotic surveys to places that are too ravaged to consider. I have named species from museum jars, lamenting all the while that I would never see them alive. But none of those feelings resonate like coming to my zoo everyday and seeing what is essentially the end of a spectacular species like Rabbs' Fringe-limbed Treefrog. There is no female that we know of, and one morning I will find the male at Zoo Atlanta dead of natural causes. I will collect tissue samples for phylogenetic studies, I will collect cells for San Diego Zoo's Frozen Zoo initiative (perhaps one day it can be cloned?), and then I will preserve the specimen for the museum shelf. Shall I post a video clip on YouTube so people can watch the frog move about, like the famous film clip of the last thylacine? Then I will return to my lab, take a jar off the shelf and proceed to describe another new species of frog that used to exist somewhere in the world. I am, after all, a Forensic Taxonomist.

It turns out that extinction is a difficult thing to demonstrate unequivocally, as it is founded largely on negative evidence. In my career, I never suspected that I would end up hoping to be wrong in so many of my academic endeavors. I am glad that we all were wrong about the extinction of Holdridge's Toad (*Incilius holdridgei* Taylor, 1952) in Costa Rica (Abarca et al. 2010). I hope we are wrong about the iconic Golden Toad (*Incilius periglenes* Savage, 1967) and that really it is simply underground (Crump et al. 1992), waiting out this entire ordeal.

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