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Local extinction of *Scinax caldarum*, a tree frog in Brazil's Atlantic forest

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Here we report the local extinction of *Scinax caldarum*, an endemic tree frog species of the Brazilian Atlantic Forest. We also report a reduction of the range of this species to less than 15% of the area in which it occurred 27 years earlier. We consider the excessive use of agrochemicals to be the main factor explaining the decline, including in farms with environmental certification. The local extinction of *S. caldarum* is a bioindicator of the severe impact of crops such as coffee and sugar cane, which heavily rely on agrochemicals. Stricter regulation of pesticides is needed to avoid damage to ecosystems and loss of biodiversity.

Keywords: Amphibians; Atlantic forest; Conservation; Endemism; Frogs.

The tree frog *Scinax caldarum* (Fig. 1) typically occurs in open areas.. Reproduction takes place in standing water and the tadpoles are exotrophic (Haddad et al., 2013). The species was described in 1969 by Bertha Lutz with the type locality being the municipality (county) of Poços de Caldas in the southern part of the state of Minas Gerais, Brazil. In 1982, six specimens of *S. caldarum* were collected in Alfenas municipality, also in southern Minas Gerais (21°27'37.66"S; 45°56'54.35"W); the specimens were deposited in the herpetological collection of the National Museum in Rio de Janeiro (Catalog numbers: 64807 -- 64812. However, recent surveys in the municipality have not reported the species (D'Anunção et al., 2013; Ferrante et al., 2015, 2017), suggesting that it is locally extinct.

Splitting of terrestrial and aquatic habitats with barriers imposed by land-use change represents one of the strongest drivers of amphibian declines, including those in the Atlantic Rainforest (Becker et al., 2007, 2010), and the quality and type of the agricultural matrix surrounding rainforest fragments constitutes an aggravating factor (Lion et al., 2014). Water bodies available for reproduction of anurans in the municipality of Poços de Caldas are mainly located in forest remnants that are often surrounded by inhospitable matrices with intense use of agrochemicals, which could be an insurmountable barrier preventing individuals of the species from reaching their

reproductive environment. A comprehensive study carried out in the municipality found that water bodies in forest remnants surrounded by coffee and sugarcane matrices have few or no habitat generalist species (Ferrante et al., 2017), reinforcing the hypothesis of local extinction of *S. caldarum*.

To verify the occurrence of *S. caldarum* in the Alfenas region, we sampled 20 forest fragments and 22 agricultural areas surrounding the fragments. The sampling followed the methodology described in Ferrante et al. (2017). The sampling contemplated the neighboring municipalities of Areado and Alfenas, which are also locations that were within the area of occurrence of *S. caldarum* in 1982 (Fig. 2). The surveys were conducted between December 2011 and March 2012, which comprises the local rainy season (Roldão et al., 2012) and is the main amphibian breeding season in the Atlantic Forest (Haddad et al., 2013) including *S. caldarum* based on observations by ACML and RG in the type locality. Many of the sampled sites are located in farms growing sugarcane, coffee and pasture. Some of the farms have Rainforest Alliance and UTZ certifications, while others are not certified. Both sugarcane and coffee are crops with intensive use of pesticides and other agrochemicals. Only considering the certified farms, thirty-seven different pesticides are used in the sampled areas: Aureo, Blitz, Cantus, Abamectin, AzaMax, Lorsban 480 Br, Flumyazin, Glifos Plus, Glifosato Atanor, Galiagan, Goal, Zartan, Nimbus, Opera, Premier Plus, Prioriextra, Amistar WG, Durivo, Cuprozeb, Roundup, Sphere, Altacor, Warrant 700 WG, VERDADERO WG, Authority, Klorplan, Fegatex, Rovral, Aliete, Folicur, Stinger, Ally, K- Othrine 2P, Jaguar, Planador, Padron and Plenum.

No specimens of *S. caldarum* were found in Alfenas municipality despite a large sampling effort, including sampling in both forest remnants and in agricultural and other modified areas. We therefore consider this species to be locally extinct in Alfenas municipality. Although we have observed degradation and loss of native vegetation throughout the southern portion of Minas Gerais, including in certified farms (Fig. 2), generalist species, such as species of *Scinax* of the *ruber* group to which *S. caldarum* belongs (Haddad et al., 2013), have benefited from the loss of vegetation in forest remnants and have disappeared from fragments that are surrounded by matrices with a high proportion of agricultural crops with heavy agrochemical use (Ferrante et al., 2007). This strongly suggests that the local extinction is due to the harmful effect of the pesticides used in the landscape. The hypothesis of local extinction due to use of agrochemicals is further corroborated by the fact that other likely threats, such as mining, are restricted to the municipalities where the species still occurs (Caldas and Poços de Caldas).

Climatic change over the last decade in the southern portion of Minas Gerais (Getirana, 2016) may have contributed to this extinction. However, while these events have been evident for more than 20 years since the last sighting of the species in the municipality of Alfenas, the same weather events have also been occurring in the municipalities where the species still occurs.

The total distribution area of *S. caldarum* in 1982 was 1228 km², considering the population in Alfenas. However, we can consider that the current range of the species is only 184 km², with the species occurring exclusively on the Poços de Caldas

plateau (Fig. 3). These area measurements were performed based on polygons encompassing the recorded occurrences, following the methodology of the World Conservation Union (IUCN) and Brazil's Chico Mendes Institute of Biodiversity (ICMbio). This plateau is a circular formation with a mean diameter of about 33 km; it is a result of orogenesis of volcanic origin in the Mesozoic era (Schorsche & Shea, 1992). This relief favored the isolation of several species of anurans that now are endemic, such as *Bokermannohyla vulcanie* and *Proceratophrys palustres* (Cruz & Feio, 2007, Neves et al., 2018). Although *S. caldarum* occurs in open or altered areas, imminent threats exist within the current range of this species on the Poços de Caldas Plateau. These include storage of toxic and radioactive mine tailings, new mining initiatives and expansion of agricultural crops with heavy use of agrochemicals. In addition, habitat fragmentation is still a threat, and this could be aggravated by severe climatic change in southeastern Brazil. The region has experienced continuous water stress, with prolonged dry periods and absence of a rainy season (Geritana, 2016). Continued deforestation in the Amazon could exacerbate these changes by reducing the water recycling that is essential to providing water vapor that is transported by winds to Minas Gerais and other parts of southeastern Brazil (Zemp et al., 2014; Ferrante & Fearnside, 2018).

The IUCN listed *Scinax caldarum* as Least Concern (LC) in view of its wide distribution in the past, mistaken records of its geographic distribution, the tolerance of species to habitat modification, presumed large population, and because the population would be unlikely to be declining fast enough to qualify for listing in a more threatened category (IUCN, 2019). Based on the current threats being significantly greater than the threats that exterminated the population in Alfenas in less than 27 years, we consider that *S. caldarum* should be categorized as Endangered (EN) under criteria B1ab(i+iii) of the IUCN RedList (IUCN, 2012). The arguments are: the range is now less than 5000 km², the population is endemic to the plateau, there is only one location of occurrence (sub criterion B1a), a continuous decline has been observed in the range of the species and in the quality of its habitat. Due to the harmful effects of mining on anurans (Sasaki et al., 2016), our results alert us to two needs: mining activities should be restricted through zoning in the area of occurrence of *S. caldarum* or other threatened species and mine tailings should be treated and affected areas should be recovered. In addition, species in the state of Minas Gerais must be continuously monitored; this should be a responsibility of any entrepreneur who performs activities harmful to species within their area of occurrence, taking full responsibility for population declines or local extinctions owing to agricultural or mining activities. Creation of a protected area (conservation unit) in Poços de Caldas is urgently needed, and this should include both forest areas and the natural grasslands that are the habitat of generalist species that are endemic to the region. More rigid laws are needed to control the use of agrochemicals near permanent preservation areas ("APPs") in the Atlantic Forest Biome.

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Figure 1.



Figure 1. *Scinax caldarum* in Poços de Caldas municipality, Minas Gerais, Brazil (Photo: Renato Gaiga).

Figure 2.

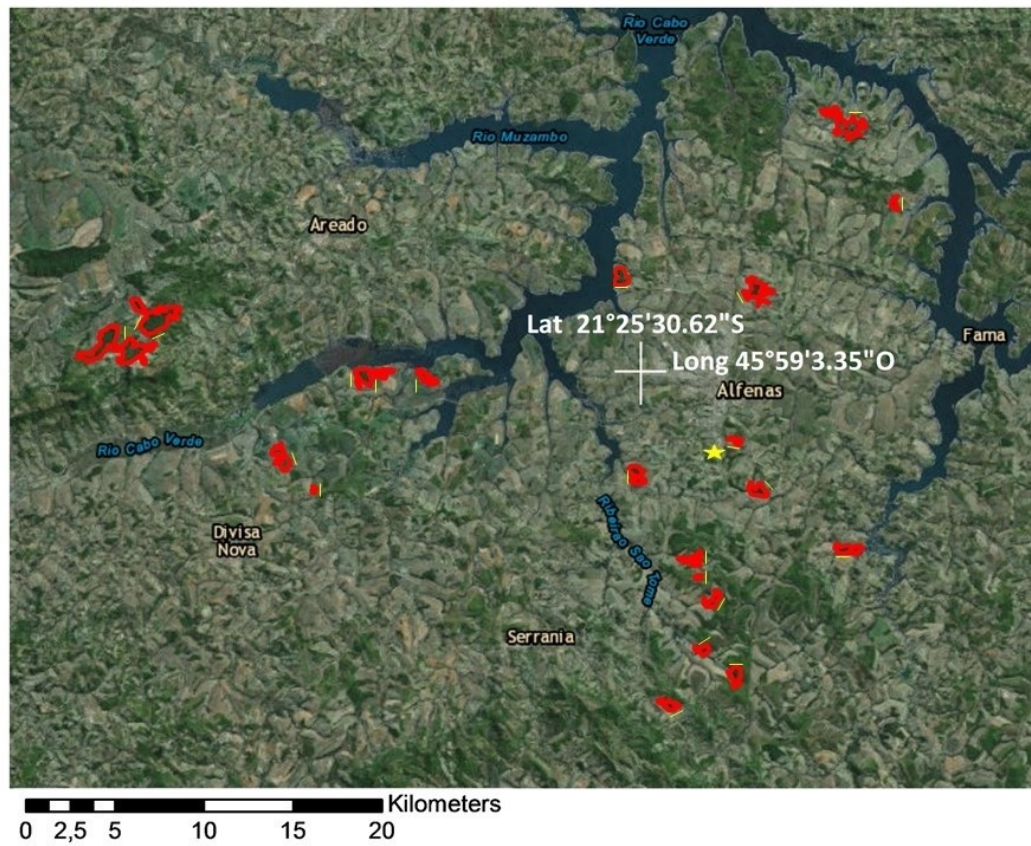


Figure 2. Landscape sampled in the Alfenas region: Yellow star represents the collection point of *Scinax caldarum* in 1982; fragments circled in red represent sampled sites; yellow transects represent areas sampled in cultivated area.

Figure 3.

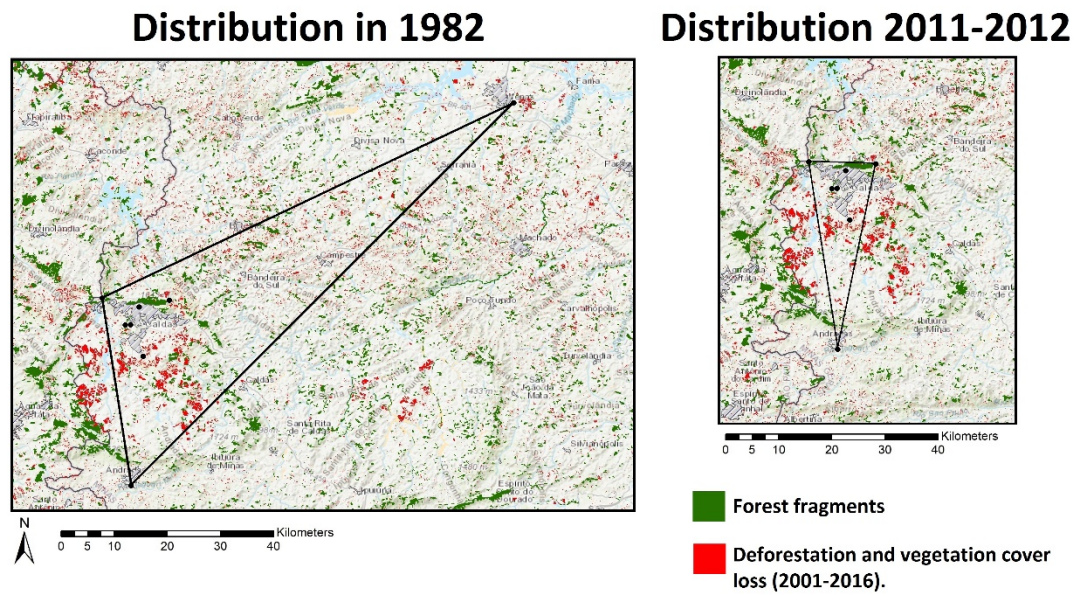


Figure 3. Range of occurrence of *S. caldarum* in 1982 and 2011-2012 according to the most recent census.