

Rapid Communication

Invasive frogs in São Paulo display a substantial invasion lag

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Abstract

The first report of the invasion of the Robber frog *Eleutherodactylus johnstonei* Barbour, 1914 in the municipality of São Paulo was made in 2014. However, we report here that sound records of this species in the same area of São Paulo, and deposited in a Brazilian sound archive, date back to 1995. Therefore, we expand the timeframe of the presence of this invasive population in the city, and provide information on its pathway of introduction, which is not accidental as previously suggested, but intentional. These data improve the knowledge on this invasion and indicate the urgent actions to avoid the expansion of this invasive species to other sites where its impact could be higher.

Key words: bioacoustics, sound archives, historical records, amphibian conservation, Anura, *Eleutherodactylus johnstonei*, species control

Introduction

Amphibian invasions are increasing at an unprecedented rate (Kraus 2009), with increasing anthropogenic activities and unpredictable environmental and economic consequences (Measey et al. 2016). Although frogs might be expected to be quickly recognized and reported due to prominent male vocalizations, increasingly authors are reporting a lag between initial introduction events and recognition of the invasion (e.g. van Sittert and Measey 2016). This phenomenon, also known as invasion debt, recognizes the time between introduction and establishment phases of an introduction (Essl et al. 2015; Rouget et al. 2016). Here we present an example of a hitherto unrecognized and surprisingly prolonged period of invasion debt in a loudly calling invasive frog, *Eleutherodactylus johnstonei* Barbour, 1914, Johnstone's Robber Frog.

Robber frogs, anurans of the genus *Eleutherodactylus*, are invasive in several countries (Frost 2018). Such invasions are causing conflicts, as in some countries, such as Bermuda, these frogs are

considered beneficial, as they are assumed to control insect pests and are not known to negatively impact local fauna (L. F. Toledo, personal observation based on local commentaries). In other countries, such as USA (Hawaii), French Guiana and Brazil, they are related to both economic and environmental impacts, including noise pollution and real estate depreciation (Kraus et al. 1999; Pimentel et al. 2000; Kraus and Campbell 2002; Lever 2003; Melo et al. 2014), decline of local invertebrates (Beard and Pitt 2005; Beard et al. 2008), and as a possible vector of the chytrid fungus (Beard and O'Neill 2005) and leptospirosis (Everard et al. 1990).

With respect to their potential negative effects, the precautionary principle suggests that all biological invasions should be avoided, and if not extirpated then controlled. In order to better control invasive species, one of the first actions would be the immediate recognition and reporting of the presence of the alien population. Rapid recognition of invasive species is critical to the assessment of their potential impacts (Darling and Blum 2007; Melo et al. 2014). Secondly,

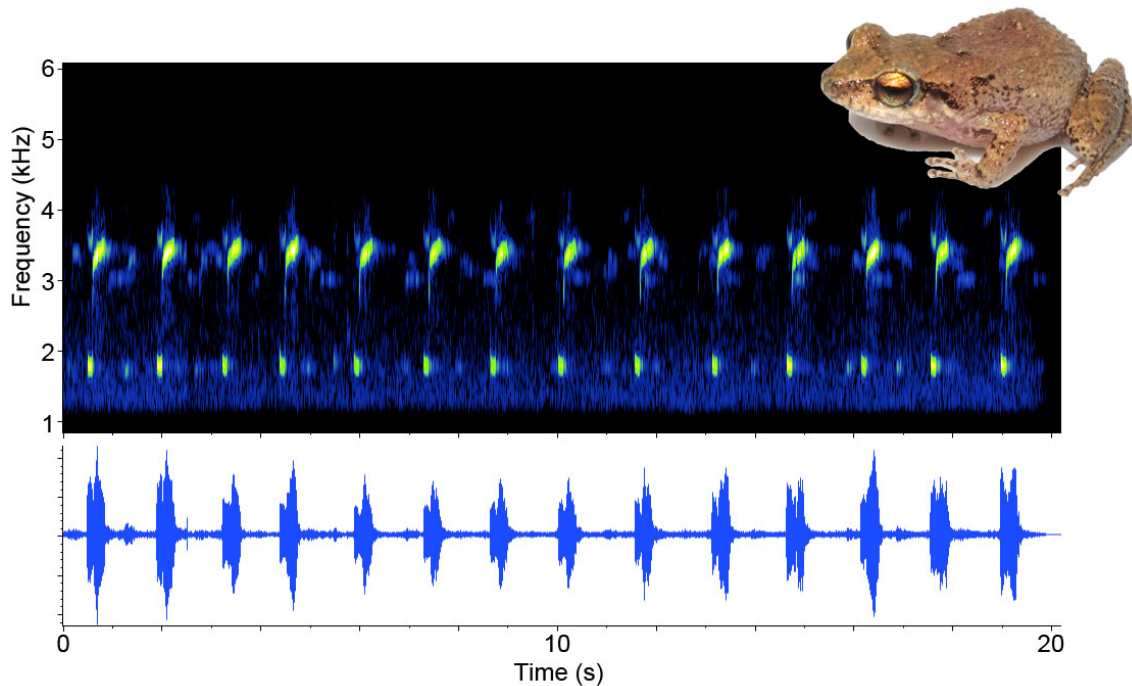


Figure 1. Adult male photographed in 2017, spectrogram (above) and oscillogram (below), made on Raven Pro 1.4, of the advertisement call recorded in 1995, and deposited at Fonoteca Neotropical Jacques Vielliard (FNJV 36457), of the invasive population of *Eleutherodactylus johnstonei* in São Paulo city.

it is highly recommended that these populations should not expand their area of occupation to additional sites. In spite of this, the example of robber frogs invasive in the city of São Paulo (*E. johnstonei*) has failed in these first two actions.

Methods

In order to access the first documented date for the introduction of the robber frog in the city of São Paulo, we looked for recordings deposited in Fonoteca Neotropical Jacques Vielliard (FNJV), Museu de Zoologia “prof. Adão José Cardoso”, Unicamp, Campinas, São Paulo, Brazil.

Results and discussion

Melo et al. (2014) reported the presence of *E. johnstonei* in São Paulo from individuals collected in 2012. Based on that, Forti et al. (2017) indicated that the species had not been registered before 2010. However, we hereby present an audio recording of calling males made in 1995 (Figure 1), matching the original *E. johnstonei* call description (Watkins et al. 1970). This recording was made in the neighborhood Alto da Boa Vista, less than one kilometer from the current

gardens where the frogs can be found. At that time, the recordist (Antonio Silveira) was unable to count the number of calling males, stating that it sounded like hundreds. This observation reveals that this species has been resident in the city of São Paulo for more than 20 years. Therefore, scientists took at least 19 years to discover and formally report the case of this invasion. In addition, A. Silveira informed us that a resident who enjoyed the sonority of the calls and wanted them in their home garden had deliberately brought these frogs from the Caribbean. Therefore, it was an intentional introduction, not as stated by Forti et al. (2017) who suggested an unintentional introduction, probably with ornamental plants, as in other sites where this species has been introduced (see Kaiser 1997; Lever 2003).

In recent fieldwork, collecting specimens of *E. johnstonei* for other studies (e.g. Mesquita et al. 2017), we contacted the house owners of the Brooklin neighborhood (−23.633904°S; −46.681959°W; 750 m above sea level) where the frog is currently invasive. They reported to us that the public gardening service of the municipality of São Paulo, while taking care of the vegetation on the sidewalk, are actively transporting the removed soil and plants, and passively and unintentionally transporting these frogs to other

neighborhoods, such as Lapa and Santana, or other municipalities, such as Osasco, in the state of São Paulo. Therefore, even after the scientific community reported the presence of this invasive population (Melo et al. 2014; Forti et al. 2017), and TV news and local newspapers highlighted the invasion, no action is taking place to stop the invasion, and, even worse, might be unwittingly introducing these frogs to other areas. As pointed out by Forti et al. (2017), these frogs are potentially negative to native wildlife, through predation (e.g. Beard and Pitt 2005), transmission of disease (Everard et al. 1990; Beard and O'Neill 2005), parasitism (Marr et al. 2008), and acoustic interference (e.g., Both and Grant 2012) that may hamper anuran communication. Identifying and curtailing potential pathways of jump dispersal would aid in maintaining a restricted and potentially manageable population, especially in the case of *E. johnstonei* (Rödger 2009). Therefore, we highlight the need for careful management of the soil and vegetation (for example, burning this organic material) in the Brooklin neighborhood of São Paulo, and the need for careful monitoring of other areas where these frogs may already have been introduced.

Minimizing time to detection is important for most invasions that can be extirpated, if it occurs prior to becoming establishment: the spread debt (a sub-period of invasion debt: *sensu* Rouget et al. 2016). Moreover, control of such incipient populations is known to be possible for species of the genus *Eleutherodactylus* (Beachy et al. 2011). Here we identify a period of nearly 20 years during which an introduction of *E. johnstonei* had not been reported. There are very few invasive amphibians for which any subset of invasion debt has been quantified. However, van Sittert and Measey (2016) suggested as much as 35 years for populations of *Xenopus laevis* (Daudin, 1802) (introduction debt + establishment debt + spread debt), while for a population of the toads *Sclerophrys gutturalis* (Power, 1927), this period was as short as five years (Vimercati et al. 2017). We suggest that social media and formal monitoring acoustic programs are both important processes through which early detection of *Eleutherodactylus* species might be quickly recognized and rapidly controlled.

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References

- Beachy JR, Neville R, Arnott C (2011) Successful control of an incipient invasive amphibian: *Eleutherodactylus coqui* on O'ahu, Hawai'i. In: Pitt WC, Beasley JC, Witmer GW (eds), *Island Invasives: Eradication and Management*. CRC Press, Florida Boca Raton, pp 140–147
- Beard KH, O'Neill EM (2005) Infection of an invasive frog *Eleutherodactylus coqui* by the chytrid fungus *Batrachochytrium dendrobatidis* in Hawaii. *Biological Conservation* 126: 591–595, <https://doi.org/10.1016/j.biocon.2005.07.004>
- Beard KH, Pitt WC (2005) Potential consequences of the coqui frog invasion in Hawaii. *Diversity and Distributions* 11: 427–433, <https://doi.org/10.1111/j.1366-9516.2005.00178.x>
- Beard KH, Al-Chokhachy R, Tuttle NC, O'Neill EM (2008) Population density estimates and growth rates of *Eleutherodactylus coqui* in Hawaii. *Journal of Herpetology* 42: 626–636, <https://doi.org/10.1670/07-314R1.1>
- Both C, Grant T (2012) Biological invasions and the acoustic niche: the effect of Bullfrog calls on the acoustic signals of white-banded tree frogs. *Biology Letters* 8: 714–716, <https://doi.org/10.1098/rsbl.2012.0412>
- Darling JA, Blum MJ (2007) DNA-based methods for monitoring invasive species: a review and prospectus. *Biological Invasions* 9: 751–765, <https://doi.org/10.1007/s10530-006-9079-4>
- Essl F, Dullinger S, Rabitsch W, Hulme PE, Pyšek P, Wilson JR, Richardson DM (2015) Historical legacies accumulate to shape future biodiversity in an era of rapid global change. *Diversity and Distributions* 21: 534–547, <https://doi.org/10.1111/ddi.12312>
- Everard CO, Carrington DG, Korver H, Burke R, Everard JD, Gravekamp C (1990) Leptospirae in the whistling frog (*Eleutherodactylus johnstonei*) on Barbados. *The Journal of Tropical Medicine and Hygiene* 93: 140–145
- Forti LR, Becker CG, Tacioli L, Pereira VR, Santos ACFA, Oliveira IS, Haddad CFB, Toledo LF (2017) Perspectives on invasive amphibians in Brazil. *Plos ONE* 12: e0184703, <https://doi.org/10.1371/journal.pone.0184703>
- Frost DR (2018) Amphibian Species of the World: an Online Reference. Version 6.0. American Museum of Natural History, New York, USA. Electronic Database accessible at: <http://research.amnh.org/herpetology/amphibia/index.html>
- Kaiser H (1997) Origins and introductions of the Caribbean frog, *Eleutherodactylus johnstonei* (Leptodactylidae): management and conservation concerns. *Biodiversity & Conservation* 6: 1391–1407, <https://doi.org/10.1023/A:1018341814510>
- Kraus F (2009) Alien reptiles and amphibians: a scientific compendium and analysis, Volume 4. Springer Science & Business Media, 563 pp, <https://doi.org/10.1007/978-1-4020-8946-6>
- Kraus F, Campbell EW (2002) Human-mediated escalation of a formerly eradicable problem: the invasion of Caribbean tree frogs in the Hawaiian Islands. *Biological Invasions* 4: 327–332, <https://doi.org/10.1023/A:1020909205908>
- Kraus F, Campbell EW, Allison A, Pratt T (1999) *Eleutherodactylus* frog introductions to Hawaii. *Herpetological Review* 30: 21–25
- Lever C (2003) Naturalized reptiles and amphibians of the world. Oxford University Press, Oxford, U.K., 318 pp
- Marr SR, Mautz WJ, Hara AH (2008) Parasite loss and introduced species: a comparison of the parasites of the Puerto Rican tree frog (*Eleutherodactylus coqui*) in its native and introduced ranges. *Biological Invasions* 10: 1289–1298, <https://doi.org/10.1007/s10530-007-9203-0>
- Measey GJ, Vimercati G, Villiers FD, Mokhatla M, Davies SJ, Thorp CJ, Rebelo AD, Kumschick S (2016) A global assessment of alien amphibian impacts in a formal framework. *Diversity and Distributions* 22: 970–981, <https://doi.org/10.1111/ddi.12462>
- Melo MA, Lyra ML, Brischi AM, Geraldi VC, Haddad CFB (2014) First record of the invasive frog, *Eleutherodactylus johnstonei* Barbour, 1914 (Anura: Eleutherodactylidae) in São Paulo, Brazil. *Salamandra* 50: 177–180

- Mesquita AFC, Lambertini C, Lyra M, Malagoli LR, James TY, Toledo LF, Haddad CFB, Becker CG (2017) Low resistance to chytridiomycosis in direct-developing amphibians. *Scientific Reports* 7: 16605, <https://doi.org/10.1038/s41598-017-16425-y>
- Pimentel D, Lach L, Zuniga R, Morrison D (2000) Environment and economic costs of nonindigenous species in the United States. *BioScience* 50: 53–65, [https://doi.org/10.1641/0006-3568\(2000\)050\[053:EAECON\]2.3.CO;2](https://doi.org/10.1641/0006-3568(2000)050[053:EAECON]2.3.CO;2)
- Rödger D (2009) Human footprint, facilitated jump dispersal, and the potential distribution of the invasive *Eleutherodactylus johnstonei* Barbour 1914 (Anura Eleutherodactylidae). *Tropical Zoology* 22: 205
- Rouget M, Robertson MP, Wilson JR, Hui C, Essl F, Renteria JL, Richardson DM (2016) Invasion debt – Quantifying future biological invasions. *Diversity and Distributions* 22: 445–456, <https://doi.org/10.1111/ddi.12408>
- van Sittert L, Measey GJ (2016) Historical perspectives on global exports and research of African clawed frogs (*Xenopus laevis*). *Transactions of the Royal Society of South Africa* 71: 157–166, <https://doi.org/10.1080/0035919X.2016.1158747>
- Vimercati G, Hui C, Davies SJ, Measey GJ (2017) Integrating age structured and landscape resistance models to disentangle invasion dynamics of a pond-breeding anuran. *Ecological Modelling* 356: 104–116, <https://doi.org/10.1016/j.ecolmodel.2017.03.017>
- Watkins WA, Baylor ER, Bowen AT (1970) The call of *Eleutherodactylus johnstonei*, the whistling frog of Bermuda. *Copeia* 3: 558–561, <https://doi.org/10.2307/1442285>