Frogs associated with bromeliads in an abandoned cacao plantation in north-eastern Brazil.

The Brazilian Amphibian Conservation Action plan recognizes that species lists are a scientific priority for many areas across the Atlantic Forest of Brazil (Verdade et al. 2012). From the standpoint of biodiversity conservation, species lists provide scientific value to areas of imminent threat by anthropogenic actions because they help to understand the diversity that can potentially be affected (Verdade et al. 2012).

The Coastal Forest of the Bahia ecoregion was largely converted to a mosaic of native forest remnants immersed in a matrix dominated by cacao plantation (cabruca; Alger 1998). Cabruca is considered a forest-like environment because native canopy trees provide shade for understory cacao trees (Rice & Greenberg 2000). This ecosystem provides habitat for a diverse assemblage of native organisms (Rice & Greenberg 2000, Schroth et al. 2004, Faria et al. 2007, Dias et al. 2014, Teixeira et al. 2015). Over the last few decades, small-scale cacao farmers employing traditional technologies are struggling to survive low and fluctuating prices, and the constant threat of disease and pests (Oliveira & Luz 2005).

Over 543 species of frogs are known to occur in the Atlantic Forest (Haddad et al. 2013), and bromeliads are considered a biological promoter across this biome because a diverse assemblage of organisms use the rainwater that accumulates in bromeliad tanks (Bastazini et al. 2007). For example, frogs are a common and diverse taxon associated with bromeliads (Peixoto 1995, Ferreira & Mendes 2010), and some species are obligately reliant on bromeliads for aspects of their life history.

More specifically, species dependent upon bromeliads for tadpole metamorphosis are classified as bromeligenous, whereas species that use bromeliads for sheltering, rehydration, or feeding microhabitat are classified as bromelicolous (Peixoto 1995). Because bromeligenous species, in particular, have this extreme habitat specialization, they may be even more vulnerable to anthropogenic changes (e.g. Lourenço-de-Moraes et al. 2013, Lantyer-Silva et al. 2014).

In this context, we sought to generate a list of frog species associated with bromeliads in a cacao plantation in northeastern Brazil. We collected data on the seasonal habitat use of bromeliads and discuss conservation implication for the cacao plantation. While we recognize the study was conducted in one plantation, the results may have implications for other plantations or the region more generally.

Research was conducted in an abandoned cacao plantation (15°18'50.86" S, 39°30'00.80" W, 232 m a.s.l.) in the municipality of Camacan, Bahia state, Brazil. The study site occurs in the Coastal Forest of the Bahia ecoregion. The region is classified as Tropical rainforest climate (Af type), meaning it is hot and humid without a dry season according to the Köppen-Geiger climate classification (Peel et al. 2007). Mean annual temperature is 24 °C, and mean annual rainfall is 160.9 mm (Sá et al. 1982, Landau et al. 2003).

The study site was almost 5000 m² of cabruca that was abandoned after a devastating fungus infected the plantation. Despite the altered understory, this area remained a heterogeneous ecosystem for frogs with an abundance of epiphytic bromeliads and some temporary ponds. Sampling was conducted one day each month (April, July and October 2008 and January 2009) during daylight hours. Fifteen epiphyte bromeliads (up to 3 m high in the canopy) were studied during each sampling, for a total of 60 bromeliads. Tank and axils of bromeliads were visually sampled to avoid bromeliad destruction.

We identified frogs in the field and released them inside the same bromeliad. We followed Haddad et al. (2013) for classification of species into guilds (i.e. bromeligenous and bromelicolous). We compared the guilds across months using Pearson's chi-squared exact test (χ^2) and a Monte Carlo simulation with 999 replicates using the package 'MASS' (Ripley et al. 2014) with the program R 2.8.1 (R Development Core Team 2011).

We found 48 individuals of eight frog species occupying epiphytic bromeliads in the study site (Table 1). All species were members of the family Hylidae. Forty-five (mean = 0.8; standard deviation = 0.5) bromeliads were occupied by at least one frog. Of the eight species encountered (Fig. 1), five were bromelicolous (*Dendropsophus bipunctatus*, *D.* cf. *minutus*, *Hypsiboas faber*, *Scinax* cf. *juncae*, and *Trachycephalus mesophaeus*) and three were bromeligenous (*Phyllodytes* cf. *maculosus*, *P. melanomystax*, and *P. luteolus*). *Phyllodytes melanomystax* and *Scinax* cf. *juncae* were the most frequently captured species (Table 1). All species found in our study and evaluated by IUCN (2014) were listed as Least Concern. However, *P. luteolus and T. mesophaeus* have decreasing populations across Atlantic Forest (Table 1). Species richness of both bromeligenous (χ^2= 1, p= 0.913) and bromelicolous (χ^2= 2.08, p = 0.632) were constant throughout the year. Abundance of both guilds was also constant throughout the year (χ^2= 2.05, p = 0.584; χ^2= 6.20, p = 0.095; respectively).

Our study shows that the studied abandoned cacao plantation harbors frogs associated with bromeliads. Studies conducted in other ecosystems across the Atlantic Forest reveal similar number of frog species associated with bromeliads but caution should be raised making these comparisons considering the different sampling methods and environments in these studies (Table 2).

Bromeliad occupancy (75%) appears to be high at our study site compared to other study sites, which may be related to the low availability of bromeliads in the understory of cabruca. In the

Table 1. Abundance of hylid species found in bromeliads at an abandoned cacao plantation, northeastern Brazil. Pop.= Population trend according to the IUCN 2014. D= decreasing, S= stable, and U= unknown.

Species	Apr	Jul	Oct	Jan	Total	Pop.
Dendropsophus bipunctatus (Spix 1824)	2	-	-	1	3	S
Dendropsophus cf. *minutus* (Peters 1872)	-	1	-	-	1	U
Hypsiboas faber (Wied-Neuwied 1821)	1	2	-	1	4	S
Phyllodytes cf. *maculosus* Cruz, Feio & Cardoso 2007	1	2	1	3	7	U
Phyllodytes melanomystax Caramaschi, Silva & Britto-Pereira 1992	3	4	2	5	14	S
Phyllodytes luteolus (Wied-Neuwied 1824)	-	1	1	-	2	D
Scinax cf. *juncae* Nunes & Pombal 2010	3	4	1	4	12	U
Trachycephalus mesophaeus (Hensel 1867)	1	2	-	2	5	D
Total	11	16	5	16	48	

Table 2. Number of species found in bromeliads across Atlantic Forest.

Number of Species	Ecosystem	Source
6	Restinga (sandy-coastal plain)	Schineider & Teixeira 2001
5	Rocky outcrop	Pertel et al. 2006
6	Rocky outcrop	Pertel et al. 2007
6	Rocky outcrop	Teixeira & Rödder 2007
8	Several environments	Lacerda et al. 2009
6	Rocky outcrop and restinga	Ferreira & Mendes 2010
3	Rocky outcrop	Pertel et al 2010
5	Rocky outcrop	Pontes et al. 2013
3	Rocky outcrop	Mageski et al. 2014
4	Forest interior	Mageski et al. 2014

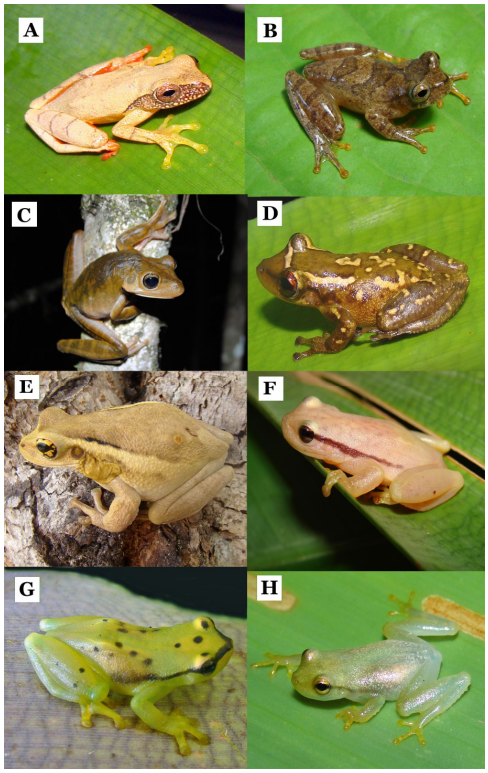

Figure 1. Bromelicolous hylid frogs recorded in an abandoned cacao plantation, northeastern Brazil: A) *Dendropsophus bipunctatus*; B) *D.* cf. *minutus*; C) *Hypsiboas faber*; D) *Scinax* cf. *juncae*; and E) *Trachycephalus mesophaeus*. Bromeligenous hylid frogs: F) *Phyllodytes* cf. *maculosus*; G) *P. melanomystax*; and H) *P. luteolus*.

mountainous region, Pertel et al. (2006, 2010) found 18% and 27%, respectively, of terrestrial bromeliads occupied by frogs. In restinga habitat (sandy-coastal plains), Schineider & Teixeira (2001) found 41% of bromeliads occupied and Ferreira et al. (2012) found 27% of bromeliads occupied.

The study assemblage was entirely composed of species in the family Hylidae. The recorded bromeligenous species were all in the genus *Phyllodytes*, a group that is highly specialized on bromeliad microhabitats, where they spend most of their life (Weygoldt 1981, Caramaschi et al. 1992, Bokermann 1996). Among the bromeligenous species recorded, *Phyllodytes luteolus* was the least frequently encountered. This species is commonly reported from restinga ecosystems where the habitat structure is more open and there are higher levels of sunlight (Teixeira et al. 1997, Shineider & Teixeira 2001, Ferreira et al. 2012).

As expected, bromeligenous species maintained constant bromeliad occupancy throughout the sampled months; however, only one individual of bromelicolous species was found in October. October is the beginning of rainy season, the period that bromelicolous species move to breeding habitats (i.e. temporary and permanent ponds).

The bromelicolous species in our study are characterized by relatively wide geographic distributions across the Atlantic Forest (Frost 2015). While two bromelicolous species have been previously reported in bromeliads (Teixeira & Rödder 2007, Lacerda et al. 2009), two species were recorded in bromeliads for the first time (*D. bipunctatus* and *S.* cf. *juncae*).

This study illustrates the importance of bromeliads in shaded cacao plantations. It should be noted that bromeliad frogs may be just part of the anuran diversity present in our study site. Typically, leaf-litter frogs represent the majority of species in forest-like environments (Rödder et al. 2007, R. Ferreira unpubl. data). The recent reduction of cacao value on the market coupled with the deadly fungi that infects cacao are the main drivers of the collapse of the cacao culture. As a consequence, cacao has been extensively replaced by

Eucalyptus plantations, which is not commonly used by bromeliad frogs (Pardini et al. 2009, Almeida-Gomes & Rocha 2014; R. Ferreira unpubl. data). Future research should address ways to improve or implement short- and long-term conservation practices in the southern part of the Bahia state, a region that was historically dominated by cabrucas.

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References

Alger, K. (1998): The reproduction of the cocoa industry and biodiversity in Southern Bahia. In: Proceedings of the First International Workshop of Sustainable Cocoa Growing, Panama City, Panama.

Almeida-Gomes, M., Rocha, C.F.D. (2014): Habitat loss reduces the diversity of frog reproductive modes in an Atlantic Forest fragmented landscape. Biotropica 47: 113-118.

Andrade, E.V.E., Albertim, M., Moura, G.J.B. (2009): Primeiro registro do uso de Bromeliaceae por *Elachistocleis ovalis* (Schneider, 1799) (Anura: Microhylidae). Biota Neotropica 9: 257-259.

Bastazini, C.V., Munduruca, J.F.V., Rocha, P.L.B., Napoli, M.F. (2007): Which environmental variables better explain changes in anuran community composition? A case study in the restinga of mata de São João, Bahia, Brazil. Herpetologica 63: 459-471.

Bokermann, W.C.A. (1966): O gênero *Phyllodytes* Wagler, 1830 (Anura, Hylidae). Anais da Academia Brasileira de Ciências 38: 335-344.

Caramaschi, U., Silva, H.R., Britto-Pereira, M.C. (1992): A new species of *Phyllodytes* (Anura, Hylidae) from southern Bahia, Brazil. Copeia 1992: 187-191.

Carvalho-e-Silva, S.P., Garcia, P. (2004): *Trachycephalus mesophaeus*. The IUCN Red List of Threatened Species. Version 2014.1. Database accessible at: <www.iucnredlist.org>, accessed at: 2014.10.28.

Dias, I.R., Medeiros, T.T., Nova, M.F.V., Solé, M. (2014): Amphibians of Serra Bonita, southern Bahia: a new hotpoint within Brazil's Atlantic Forest hotspot. ZooKeys 449: 105-130.

Faria, D., Paciencia, M.L.B., Dixo, M., Laps, R.R., Baumgarten, J. (2007): Ferns, frogs, lizards, birds and bats in forest fragments and shade cacao plantations in two contrasting landscapes in the Atlantic forest, Brazil. Biodiversity and Conservation 16: 2335-2357.

Ferreira, R.B., Mendes, S.L. (2010): Herpetofauna no campus da Universidade Federal do Espírito Santo, área urbana de Vitória, Brasil. Sitientibus Série Ciências Biológicas 10: 279-285.

Ferreira, R.B., Schineider, J.A., Teixeira, R.L. (2012): Diet, fecundity, and use of bromeliads by *Phyllodytes luteolus* (Anura: Hylidae) in Southeastern Brazil. Journal of Herpetology 6: 19-23.

Frost, D.R. (2015): Amphibian Species of the World: an Online Reference. In Version 6.0 American Museum of Natural History, New York, USA. <http://research.amnh.org/vz/herpetology/amphibia/>, accessed at: 2015.04.16.

Gardner, T.A., Ribeiro-Junior, M.A., Barlow, J., Avila-Pires, T.C.S., Hoogmoed, M.S., Peres, C.A. (2007): The value of primary, secondary, and plantation forests for a Neotropical herpetofauna. Conservation Biology 21: 775-787.

Haddad, C.F.B., Toledo, L.F., Prado, C.P.A., Loebmann, D., Gasparini, J.L., Sazima, I. (2013): Guia dos Anfíbios da Mata Atlântica: diversidade e biologia. Anolisbooks, São Paulo.

IUCN, International Union for the Conservation of Nature (2014): Electronic database <www.iucn.org>, accessed at: 2014.10.28.

Lacerda, J.V.A, Assis, B., Santana. D.J., Feio, R.N. (2009): Anurans in bromeliads, Parque Estadual da Serra do Brigadeiro, state of Minas Gerais, southeastern Brazil. CheckList 5: 800-806.

Landau, E.C., Hirsch, A., Musinsky, J. (2003): Cobertura vegetal e uso do solo do sul da Bahia - Brasil, escala 1:100.000, data dos dados: 1996-1997. Corredor de biodiversidade da Mata Atlântica do sul da Bahia. CD-ROM, Ilhéus.

Lantyer-Silva, A., Solé, M., Zina, J. (2014): Reproductive biology of a bromeligenous frog endemic to the Atlantic Forest: *Aparasphenodon arapapa* Pimenta, Napoli and Haddad, 2009 (Anura: Hylidae). Anais da Academia Brasileira de Ciências 86(2): 867-880.

Lourenço-de-Moraes, R., Lantyer-Silva, A., Toledo, L.F., Solé, M. (2013): Tadpole, oophagy, advertisement call, and geographic distribution of *Aparasphenodon arapapa* Pimenta, Napoli and Haddad 2009 (Anura, Hylidae). Journal of Herpetology 47: 575-579.

Mageski, M., Ferreira, R.B., Zocca, C., Teixeira, R.L., Rödder, D. (2014): The unusual occurrence of a population of *Dendropsophus elegans* (Anura: Hylidae) in an inselberg of southeastern Brazil. Herpetology Notes 7: 363-365.

Mageski, M., Coutinho, H., Clemente-Carvalho, R.B.G. (2014): Distribuição espacial e seleção de hábitat por anfíbios anuros em Mata Atlântica sobre a formação Barreiras no sudeste do Brasil. Natureza On Line 12 (5): 230-234.

Oliveira, M.L., Luz, E.D.M.N. (2005): Identificação e manejo das principais doenças do cacaueiro no Brasil. CEPLAC/CEPEC/SEFIT, Ilhéus.

Pardini, R., Faria, D., Accacio, G.M., Laps, R.R., Mariano-Neto, E., Paciencia, M.L.B., Dixo, M., Baumgarten, J. (2009): The challenge of maintaining Atlantic forest biodiversity: A multi-taxa conservation assessment of specialist and generalist species in an agro-forestry mosaic in southern Bahia. Biological Conservation 142: 1178-1190.

Peel, M.C., Finlayson, B.L., Mcmahon, T.A. (2007): Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences 11: 1633-1644.

Peixoto, O.L. (1995): Associação de anuros a bromeliáceas na Mata Atlântica. Revista Universidade Rural, Série Ciências da Vida 17: 75-83.

Pertel, W., Teixeira, R.L., Rödder, D. (2006): Anurans inhabiting soil bromeliads in Santa Teresa, southeastern Brazil. Amphibia 5: 16-19.

Pertel, W., Ferreira, R.B., Rödder, D., Teixeira, R.L. (2007): Frösche in und um Bromelien im Atlantischen Regenwald in Espírito Santo Brasilien. Terraria 01: 64-69.

Pertel, W., Teixeira, R.L., Ferreira, R.B. (2010): Comparison of diet and use of bromeliads between a bromelicolous and a bromeligenous anuran at an inselberg in the southeastern of Brazil. Caldasia 32: 149-159.

Pontes, R.C., Santori, R.T., Gonçalves-e-Cunha, F.C., Pontes, J.A.L. (2013): Habitat selection by anurofauna community at rocky seashore in coastal Atlantic Forest, Southeastern Brazil. Brazilian Journal of Biology 73: 533-542.

R Development Core Team (2011): R: a language and environment for statistical computing. R Foundation for Statistical Computing.

Rice, R.A., Greenberg, R. (2000): Cacao cultivation and the conservation of biological diversity. Ambio 29: 167-173.

Ripley, B., Venables, B., Bates, D.M., Hornik, K., Gebhardt, A., Firth, D. (2014): Support Functions and Datasets for Venables and Ripley's MASS.

Rödder, D., Teixeira, R.L., Ferreira, R.B., Dantas, R.B., Pertel, W., Guarneire, G.J. (2007): Anuran hotspots: the municipality of Santa Teresa, Espírito Santo, southeastern Brazil. Salamandra 43: 91-110.

Sá, D.F., Almeida, H.A., Silva, L.F., Leão, A.C. (1982): Fatores edafo-climáticos seletivos ao zoneamento da cacauicultura no sudeste da Bahia. Revista Theobrama 12: 169-187.

Schineider, J.A.P., Teixeira, R.L. (2001): Relacionamento entre anfíbios anuros e bromélias da restinga de Regência, Linhares, Espírito Santo, Brasil. Iheringia 91: 41-48.

Schroth, G., Fonseca, G.A.B., Gascon, C., Vasconcelos, H., Izac, A.M., Harvey, C. (2004): Agroforestry and Conservation of Biodiversity in Tropical Landscapes. Island Press Inc, New York.

Teixeira, R.L., Zamprogno, C., Almeida, G.I., Schineider, J.A. (1997): Tópicos ecológicos de *Phyllodytes luteolus* (Amphibia, Hylidae) da restinga de Guriri, São Mateus, ES. Revista Brasileira de Biologia 57: 647-654.

Teixeira, R.L., Rödder, D. (2007): A rapid assessment of an anuran community inhabiting tank bromeliads in saxicolous habitat of southeastern Brazil. Amphibia 6: 46-53.

Teixeira, R.L., Ferreira, R.B., Silva- Soares, T., Mageski, M.M., Pertel, W., Rodder, D., Barros, E.H., Engler, J.O. (2015): Anuran community of a cacao agroecosystem in southeastern Brazil. Salamandra 51(2): 1-4.

Verdade, V.K., Valdujo, P.H., Carnaval, A.C.O.Q.L., Schiesari, C., Toledo, L.F., Mott, T., Andrade, G., Eterovick, P.C., Menin, M., Pimenta, B.V.S., Lisboa, C.S., Paula, D.C., Silvano, D. (2012): A leap further: the Brazilian Amphibian Conservation Action Plan. Alytes - International Journal of Batrachology 29: 28-43.

Weygoldt, P. (1981): Beobachtungen zur Fortpflanzungsbiologie von *Phyllodytes luteolus* (Wied 1824) im Terrarium (Amphibia: Salientia: Hylidae). Salamandra 17: 1-11.

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