

# Anuran detectability and calling phenology in urban ponds from the Brazilian Savanna

Natália Paludo Smaniotto, Leonardo Felipe Bairos Moreira

Instituto Nacional de Pesquisa do Pantanal (INPP), Museu Paraense Emílio Goeldi, Avenida Fernando Corrêa da Costa, 2367, Boa Esperança, 78060-900, Cuiabá, Mato Grosso, Brazil.

Recibido: 03 Agosto 2022

Revisado: 07 Noviembre 2022

Aceptado: 15 Diciembre 2022

Editor Asociado: D. Barraso

doi: 10.31017/CdH.2023.(2022-021)

## ABSTRACT

Over the last century, urban development has steadily resulted in wetland destruction, stream flow disturbance, and land clearing. Small intermittent wetlands are easily overlooked in large cities, and the secretive nature of amphibian species in these habitats can hinder see the big picture about the persistence of populations in urban habitats. Here, we determined anuran detectability associated with site-specific and survey-specific variables. We also identified the reproductive modes and described the calling activity along a four-year period in urban ponds of the Brazilian Cerrado ecoregion. We recorded 16 anuran species, but only nine were detected at levels suitable for modeling. Seven reproductive modes were observed in the assemblages, and although breeding choruses were more common in the rainy season, calling activity was also recorded in the dry season for 11 species. Anuran detectability was related to pond water depth, rainfall for the previous 24h, and day-of-year. Our results showed interplay between species-specific traits and water availability. We highlight that urban ponds can harbor a considerable proportion of anuran diversity; however, urbanization seems to constraint even generalist species recorded for the Cerrado ecoregion.

Key words: Temporary Wetlands; Cerrado; Amphibians; Water availability; Reproductive modes.

## RESUMO

Ao longo do último século, o desenvolvimento urbano resultou constantemente na destruição de áreas úmidas, alteração do curso de riachos e desmatamento. Pequenas áreas úmidas intermitentes são facilmente ignoradas nas grandes cidades, e a natureza inconspícua das espécies de anfíbios nestes habitats pode esconder o quadro geral sobre a persistência das populações em ambientes urbanos. Aqui, determinamos a detectabilidade de anuros associada a variáveis específicas do local e da amostragem. Nós também identificamos a diversidade de modos reprodutivos e atividade de vocalização ao longo de um período de quatro anos em lagoas urbanas do Cerrado. Registramos 16 espécies de anuros, mas apenas nove foram detectadas em níveis adequados para a modelagem. Sete modos reprodutivos foram observados nas assembleias e, embora coros reprodutivos tenham sido mais comuns na estação chuvosa, a atividade de vocalização também foi registrada na estação seca para 11 espécies. A detectabilidade de anuros foi relacionada à profundidade da água, precipitação nas 24h anteriores e dia do ano. Nossos resultados mostraram uma interação entre traços específicos das espécies e a disponibilidade hídrica. Destacamos que as lagoas urbanas podem abrigar uma porção considerável da diversidade de anuros. Entretanto, a urbanização parece restringir até mesmo espécies generalistas registradas para a ecorregião do Cerrado.

Palavras Chave: Áreas Úmidas Temporárias; Cerrado; Anfíbios; Disponibilidade hídrica; Modos reprodutivos.

## Introduction

Rapid urban development is a major threat for biodiversity, presenting unprecedented challenges to many plant and animal species. Ongoing habitat loss and fragmentation, human disturbances (e.g. heat islands, exposure to harmful chemicals, noise, and

light pollution), and changes in microbiota interactions are just a glimpse of how urbanization might change the profile of biodiversity in cities (Babini *et al.*, 2015a; Murray *et al.*, 2019). In urban environments, small wetlands (< 1ha) are often viewed as

wastelands and easily overlooked, mainly the intermittent ones. Nevertheless, these apparently isolated habitats are important refuges for biodiversity and the persistence of local populations of wetland-associated organisms, such as plants, invertebrates, and amphibians (Semlitsch and Bodie, 1998; Deane *et al.*, 2017; Hutto and Barrett, 2021).

As Brazil hosts a mega diversity of amphibians (Segalla *et al.*, 2021), it is unsurprising that some species can thrive in urban areas (e.g. Ferreira *et al.*, 2010; Menin *et al.*, 2019; Dorigo *et al.*, 2021). The challenge is that the Brazilian territory encompasses different forest and non-forest ecoregions, which reflect in patterns of species endemism and phylogenetic endemism across the country (Vasconcelos *et al.*, 2019). Among these highly diverse systems, the Cerrado ecoregion is a mosaic encompassing a broad spectrum of vegetation types—such as grasslands, open and dense savannas, and dry forests—affected by a strong seasonal climate (Del-Claro and Torezan-Silingardi, 2019). Despite the Cerrado harbors several endemic species of amphibians (Azevedo *et al.*, 2016), local assemblages show predominance of widely-distributed species that are considered habitat generalist with generalized breeding requirements (Brasileiro *et al.*, 2005; Gambale *et al.*, 2014; Santoro and Brandão, 2014; Ferreira *et al.*, 2017). Such use of multiple types of habitats and generalized reproductive modes (i.e. aquatic eggs deposited directly in the water or in foam nests on the water) have been pointed as adaptations to unpredictable habitats and dry environments (Gomez-Mestre *et al.*, 2012; Santoro and Brandão, 2014), but they also seem key to amphibian survival and successful reproduction in human-altered landscapes (Hamer and McDonnell, 2008; Ferreira *et al.*, 2017).

Amphibians inhabiting urban areas have received little attention, mainly in megadiverse tropical areas. Available information about aspects of reproductive ecology in the city's wetlands indicated issues related to habitat split, reduction in body size, and assemblage homogenization with decreases in arboreal amphibian species (Acosta *et al.*, 2005; Babini *et al.*, 2015a; Murray *et al.*, 2019). Still, research into urban ecology is in its beginnings in tropical environments. The lack of information about species occurrence, phenology, and population fluctuations hinders forecasts about impacts on environments that still resist urbanization. Two other subtle issues must be recognized here. First, species inventories and studies on amphibian-habitat relationships are often

based on either short-term data or derived from random samplings focused on the breeding season. However, temporary unsuitable weather or breeding site conditions, infrequent or unpredictable species breeding behavior may jeopardize abundance estimates and observed patterns (Greenberg *et al.*, 2017; Leão Pompeu *et al.*, 2020). Second, detection probability estimates for amphibians are often low ( $< 0.5$ ) and high variability in the detection for species in the same community has been reported in different environments (Barata *et al.*, 2017; Ribeiro *et al.*, 2018; Asad *et al.*, 2020).

Although imperfect detection may depend on a myriad of conditions that vary geographically, it is notable that amphibian detectability depends on the individual species traits, survey conditions, aquatic vegetation, and hydroperiod (Moreira *et al.*, 2016; Ribeiro *et al.*, 2018; Asad *et al.*, 2020). In addition, amphibians often exhibit periodic cycles (i.e. phenology) of calling activity/reproduction that go along in concert with temperature, precipitation, and pond water availability (e.g. Andrade *et al.*, 2019; Souza *et al.*, 2020). A major issue is trade-offs and synergies between phenology and detectability. For example, shifts in phenology can be masked by imperfect detection if calling activity and detectability were linked to distinct environmental factors (Lowe *et al.*, 2016). Only a few studies on amphibians from rapidly urbanizing regions have incorporated detection probabilities to understand species-habitat relationships (Hamer, 2018; Hamer *et al.*, 2021). Although water availability seems to affect detectability at species level in urban areas, overall assemblage patterns are also depending on temperature and day-of-year.

Here we provide information on the anuran amphibian assemblages associated to temporary ponds in urban areas of the Brazilian Cerrado ecoregion. First, we determined detectability associated with site-specific and survey-specific variables. We expected seasonal variation in detectability (i.e. higher values during rainy periods), although some species could be detected regardless of season (Guimarães *et al.*, 2014; Barata *et al.*, 2017). Then, we identified the reproductive modes and described the calling activity over a four-year period (2015-2019).

## Materials and methods

### Study area

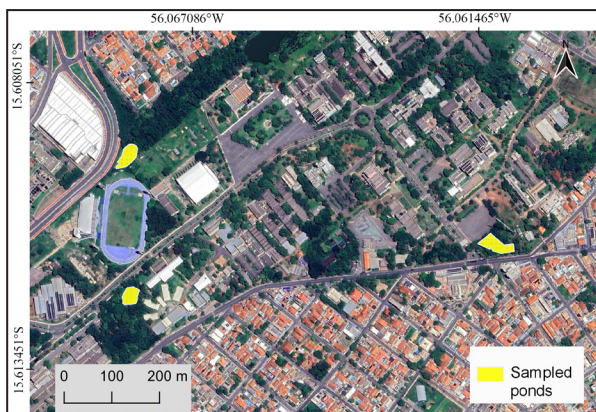
Cuiabá is the fourth largest city in Midwestern Brazil that together with Várzea Grande—a satellite

city—forms an urban agglomeration with a population of approximately 913 thousand people (IBGE 2020). Cuiabá has a tropical savanna climate, with an annual mean temperature of 26.8°C and annual mean precipitation of 1495 mm, concentrated from November to March (~70%; Souza *et al.*, 2013). Fifty-five species of amphibians inhabit the Greater Cuiabá area (Dorado-Rodrigues *et al.*, 2018) and many of these are known to breed in aquatic environments, although some species have terrestrial reproduction.

We conducted our fieldwork in sites located at the Universidade Federal de Mato Grosso (15.612114°S, 56.068240°W). Three small temporary ponds (Fig. 1), located 0.28–0.8 km apart, were selected to represent different types of habitats available for amphibians in urban areas of Cuiabá: i) feed by irregular inundation by headwater streams during heavy rains; ii) feed by surface runoff along roads and pluvial drainage associated to rain; iii) feed exclusively by precipitation. In the middle of the rainy season, all ponds support aquatic vegetation and small fish schools are found in the ponds feed by flood or pluvial drainage. All sampling sites were close to human infrastructure (i.e. roads, buildings). The vegetation in these areas consisted mostly of shrubs, grasses, and sparse trees of native and exotic species. Traffic noises, constant movement of people, and night lighting associated with vehicle headlights and street lighting are widespread in all ponds surrounding areas.

### Field methods

We surveyed each site 56 times: seven times in the dry season (May to September) and seven times in the rainy season (November to March) over four consecutive years (2015-2019). Between January and March 2015 we surveyed our ponds, as a pilot



**Figure 1.** Geographical location of the three sampled ponds in the urban area of Cuiabá, Mato Grosso State, Brazil.

study, to test ideas and the feasibility of our sampling design. All ponds were surveyed on the same night between 18:00h and 22:00h and the areas were sampled in random order. Two trained field observers followed two different 50-m transects perpendicular to the edge of the pond. Each transect was sampled by only one observer during 20 minutes. We registered the presence of all amphibians, visually (distinguishing between adult and juvenile frogs) or acoustically. Calling activity for each species heard was classified in two groups: i) call of individuals can be distinguished, with little overlapping, ii) full chorus, calls are constant, continuous and overlapping. All individuals were identified in the field and returned to the ponds. The species were grouped into their respective reproductive modes following the classification proposed by Nunes-de-Almeida *et al.* (2021).

Data on survey-specific factors thought to influence detection, colonization and local extinction probabilities were collected (Roloff *et al.*, 2011; Moreira and Maltchik, 2015). These include day-of-year, rainfall in the last 24-hour period, air temperature, pond water depth, hydroperiod, presence of superficial water, and time since the last rain. We transformed the calendar dates of each sampling into day-of-year (i.e. count the number of a given day in the year). To measure precipitation during the study period, we used a single rain gauge placed in the center of the study area. The temperature was measured at the beginning of each pond sampling. The water column depth corresponded to average values of four random measures using a ruler.

### Data analyses

For our analysis of detection estimates, we used a multi-season occupancy model that explicitly accounts for imperfect detection (MacKenzie *et al.*, 2006). The study consisted of eight primary sampling periods (seasons) and within each primary period seven surveys by pond (sampling nights). Only species with a detection probability  $\geq 0.15$  were modeled (O'Connell *et al.*, 2006). Ten out of the 12 species recorded during our pilot study were present in more than one pond, so we assumed a constant occupancy probability ( $\psi$ ) over the study. We choose not assesses factors associated with pond occupancy, because the closeness among sampled ponds. Still, colonization ( $\gamma$ ) and extinction ( $\epsilon$ ) probabilities may change among the primary sampling periods. We built models where  $\gamma$  was related to pond hydrope-

riod (i.e. number of samplings events with water in each season) and  $\epsilon$  was related to species abundance in the previous season.

We followed a two-step process for building occupancy models (Roloff *et al.*, 2011). First, we modeled those variables that we thought would influence detection probabilities ( $d$ ), including rainfall, pond water depth, presence of superficial water, air temperature, day-of-year and time since the last rain while holding other parameters constant ( $\psi$ ,  $\gamma$ ,  $\epsilon$ ). As we expected that detection probability may reach a peak at a particular date (e.g. onset of the rainy season), we included day-of-year as a quadratic term. We used a correct Akaike's information criteria (AICc; Burnham and Anderson, 2002) to rank candidate models for each species. Second, we examined occupancy models with the best model for detection probability (i.e.,  $\psi$  (.),  $\gamma$  (hydroperiod),  $\epsilon$  (abundance),  $d$  (best covariate)). Then, we conducted a goodness-of-fit-test based on 999 simulations to detect if violations of model assumptions had occurred and to evaluate the fit of the most supported model to the data. Variance inflation factor ( $\hat{c}$ ) values  $> 1$  indicate overdispersion, while values much higher than 1 (i.e.  $> 4$ ) indicate a lack of fit (MacKenzie and Bailey, 2004). Analyses were carried out using the R statistical computing environment (R Core Team, 2021), and its package unmarked (Fiske and Chandler, 2011). Juveniles can achieve large numbers for some anuran species and their emergence may be decoupled from adult breeding season (López *et al.*, 2011; López *et al.* 2017). Because such abundance shift could bias the detectability, we analyzed the data in two ways: i) all individuals; ii) excluding juveniles.

## Results

We recorded a total of 16 species in the study area belonging to 10 genera and four families (Bufonidae, Hylidae, Leptodactylidae, and Microhylidae; Figs. 2-3). Here, individuals recorded as *Adenomera* sp. correspond to a species not yet formally described, with populations present in Cuiabá and Chapada dos Guimarães municipalities (C. Strüßmann, pers. communication). During the four years of the study period, we recorded a total of 3789 individuals, of which about 10% corresponded to juveniles ( $N = 325$ ).

We could not confirm the breeding activity (i.e. amplexant pairs, eggs, juveniles) of six species

(*Boana geographica*, *B. raniceps*, *Scinax fuscovarius*, *Adenomera* sp., *Leptodactylus siphax*, and *Pseudopaludicola motorzinho*) of the 16 species observed in calling activities. Three species corresponded to 65% of all amphibians recorded during the surveys (*Dendropsophus nanus*, *Leptodactylus fuscus*, and *Physalaemus albonotatus*; Table 1). Although, adult abundance recorded in the dry season was around 30% of the abundance recorded in the rainy season, juveniles were seen in similar numbers both in the dry and rainy seasons (Table 1). Hydroperiod was quite variable, with environments retaining water from a few days to more than seven months in some years.

## Calling phenology

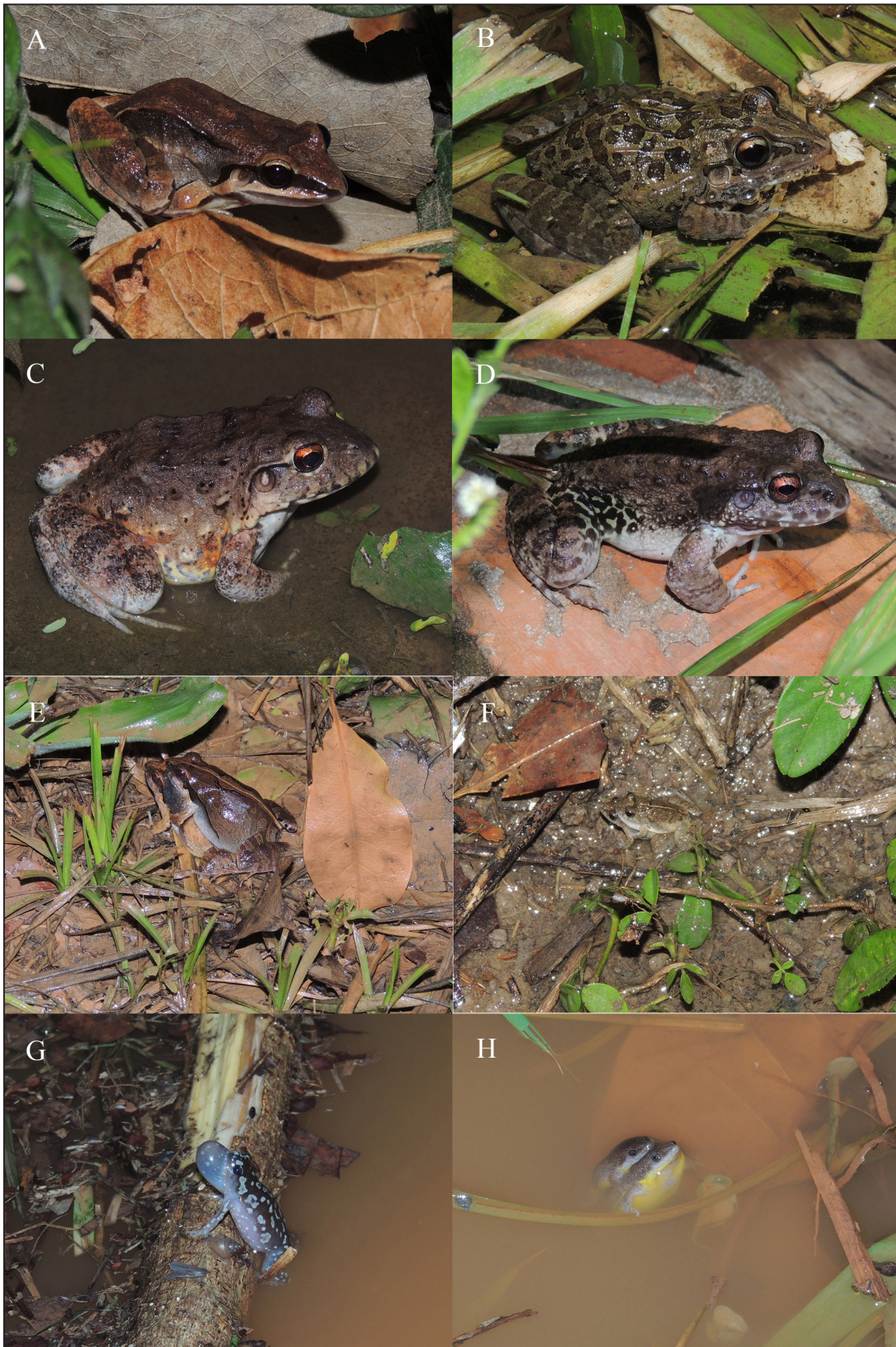
We recorded calling individuals for most species (11 of all 16 species) both in the dry and rainy seasons (Table 1). Even so, some species exhibited notable inter-annual variation in the phenology (see Supplementary 1). For example, calling records of three species (*D. nanus*, *Scinax nasicus*, and *Elachistocleis bicolor*) were sparse in the two first years of monitoring, increasing from the end of 2016. On the other hand, *L. siphax* callings were seldom recorded after December 2016. Except for *Adenomera* sp., calling activity of leptodactylids was common in both seasons. However, breeding choruses were registered only in the rainy season, mainly between November and February. Between March and August, observations of *Leptodactylus elenae* and *L. labyrinthicus* corresponded mainly to visual registers of individuals with small sizes and calling activity was hardly detected. For *L. fuscus*, we also registered a reduction in the calling activity during the transition from the rainy to dry season, but both adults and juveniles were often sighted. Breeding choruses of species belonging to Microhylidae family were recorded from November to January, although sparse callings of *E. bicolor* were recorded in the dry season. While breeding choruses of *S. nasicus* were recorded only in the rainy season, *D. nanus* also formed breeding choruses in the middle of the dry season (Supplementary 1). Juveniles of *D. nanus* and *S. nasicus* were often sight in the beginning of dry season. We registered seven reproductive modes (Table 1), *sensu* Nunes-de-Almeida *et al.* (2021), as follow: i) three modes with eggs deposited in the water (Mode 1, 2, and 3); ii) two modes with floating foam nests (Mode 45 and 50); iii) two modes with terrestrial foam nest in constructed burrows (Mode 62 and 64).





**Figure 2.** Amphibians recorded at urban ponds from Cuiabá, Mato Grosso, Brazil. A-*Rhinella diptycha*, B-*Boana geographica*, C-*Boana raniceps*, D-*Dendropsophus nanus*, E-*Scinax fuscovarius*, F-*Scinax nasicus*, G-*Adenomera* sp., H-*Leptodactylus brevipes*.





**Figure 3.** Amphibians recorded at urban ponds from Cuiabá, Mato Grosso, Brazil. A-*Leptodactylus elenae*, B-*Leptodactylus fuscus*, C-*Leptodactylus labyrinthicus*, D-*Leptodactylus sypfax*, E-*Physalaemus albonotatus*, F-*Pseudopaludicola motorzinho*, G-*Chiasmocleis albopunctata*, H-*Elachistocleis bicolor*.



**Table 1.** Amphibian species recorded in temporary ponds in the urban area of Cuiabá, Mato Grosso State, Brazil, from 2015 to 2019. Ab: total abundance—adults (juveniles). (+): distinguishable calls. (\*): full chorus. Rm: reproductive mode

Family/ Species	Dry season		Rainy Season		Detection(N)	Rm
	Ab	Calling	Ab	Calling		
Bufonidae						
<i>Rhinella diptycha</i>	13		26(11)	+	31	2
Hylidae						
<i>Boana geographica</i>			1	+	1	2
<i>Boana raniceps</i>			2	+	1	3
<i>Dendropsophus nanus</i>	267(114)	+*	518(83)	+*	84	1
<i>Scinax fuscovarius</i>			3	+	4	2
<i>Scinax nasicus</i>	137(18)	+	157(3)	+*	101	3
Leptodactylidae						
<i>Adenomera</i> sp.	2	+	92	+*	24	62
<i>Leptodactylus brevipes</i>	75	+	180(7)	+*	60	50
<i>Leptodactylus elenae</i>	3(4)	+	162(2)	+*	29	64
<i>Leptodactylus fuscus</i>	105(14)	+	553(19)	+*	145	64
<i>Leptodactylus labyrinthicus</i>	9(4)	+	103(7)	+*	66	50
<i>Leptodactylus siphax</i>	2	+	15	+	13	50
<i>Physalaemus albonotatus</i>	185(12)	+	552(21)	+*	138	45
<i>Pseudopaludicola motorzinho</i>			2	+	1	2
Microhylidae						
<i>Chiasmocleis albopunctata</i>	6	+	108(4)	+*	17	1
<i>Elachistocleis bicolor</i>	23	+	162(3)	+*	60	1

### Detection probability

Seven species were deemed unsuitable for unbiased modeling because of low detection: *Adenomera* sp., *Chiasmocleis albopunctata*, *B. geographica*, *B. raniceps*, *L. siphax*, *P. motorzinho*, and *S. fuscovarius*. Models for *Rhinella diptycha* failed to converge and were discarded. Colonization and extinction rates were not related to any investigated variables for the nine species modeled (Table 2). Overall, the best models for detection probability included survey-specific variables related to water availability, although the relationship varied from species to species. The best model for each species received overwhelming support in all cases (i.e.  $\Delta AICc > 2 \equiv$  evidence ratio  $> 2.7$ ). Although none model showed a lack of fit, we found evidence for overdispersion for some leptodactylid species (Table 2).

Pond water depth showed positive effects on detectability for three species: *D. nanus*, *Leptodactylus brevipes*, and *P. albonotatus*. Our data suggested that *D. nanus* and *P. albonotatus* can be detected at levels  $\geq 0.70$  even at shallow water conditions (depth  $\approx 10$  cm), whereas *L. brevipes* require deeper habitats

(Fig. 4A). Rainfall in the last 24-hour period influenced positively in the detection probability for *E. bicolor* and *S. nasicus* (Fig. 4B). Detectability of three *Leptodactylus* species exhibited association with day-of-year. *Leptodactylus elenae* and *L. labyrinthicus* had lower detection values around day-of-year 70 ( $\sim 10$  Mar), while *L. fuscus* had a detection of about 0.50 in the same period (Fig. 4C). The slope for increase in the detection was slightly species dependent, with the two species in the *L. fuscus* group being detected at levels  $\geq 0.90$  from day-of-year 200 (late July, at middle of the dry season). Even after juvenile exclusion, the best models exhibited similar results for all species analyzed (see Supplementary 2).

### Discussion

While we observed variation in detectability among months for some species, our results did not seem directly related to seasonal rainfall distribution. It is interesting to note that detection probabilities recorded here were a reflection of the interplay between species-specific traits and water availabi-

**Table 2.** Parameters contained in the best models of detection probability for eight species of anurans in Cuiabá, Mato Grosso State, Brazil. Evidence ratio: ratio of Akaike weights between the two best ranked models

Species and model	Evidence ratio	$\hat{c}$	P		
			$\gamma$	$\epsilon$	d
<i>Dendropsophus nanus</i> $\psi(\cdot), \gamma(\text{hydroperiod}), \epsilon(\text{abundance}), d(\text{depth})$	>100	0.8	0.23	0.96	<0.001
<i>Scinax nasicus</i> $\psi(\cdot), \gamma(\text{hydroperiod}), \epsilon(\text{abundance}), d(\text{rainfall})$	3.7	0.9	0.99	0.94	0.008
<i>Leptodactylus brevipes</i> $\psi(\cdot), \gamma(\text{hydroperiod}), \epsilon(\text{abundance}), d(\text{depth})$	>100	0.7	0.34	0.56	<0.001
<i>Leptodactylus elenae</i> $\psi(\cdot), \gamma(\text{hydroperiod}), \epsilon(\text{abundance}), d(\text{day-of-year})$	>100	1.8	0.98	0.75	<0.001
<i>Leptodactylus fuscus</i> $\psi(\cdot), \gamma(\text{hydroperiod}), \epsilon(\text{abundance}), d(\text{day-of-year})$	30	0.9	0.99	0.95	<0.001
<i>Leptodactylus labyrinthicus</i> $\psi(\cdot), \gamma(\text{hydroperiod}), \epsilon(\text{abundance}), d(\text{day-of-year})$	>100	1.4	0.97	0.58	<0.001
<i>Physalaemus albonotatus</i> $\psi(\cdot), \gamma(\text{hydroperiod}), \epsilon(\text{abundance}), d(\text{depth})$	>100	0.7	0.99	0.96	<0.001
<i>Elachistocleis bicolor</i> $\psi(\cdot), \gamma(\text{hydroperiod}), \epsilon(\text{abundance}), d(\text{rainfall})$	14.1	1.0	0.95	0.3	<0.001

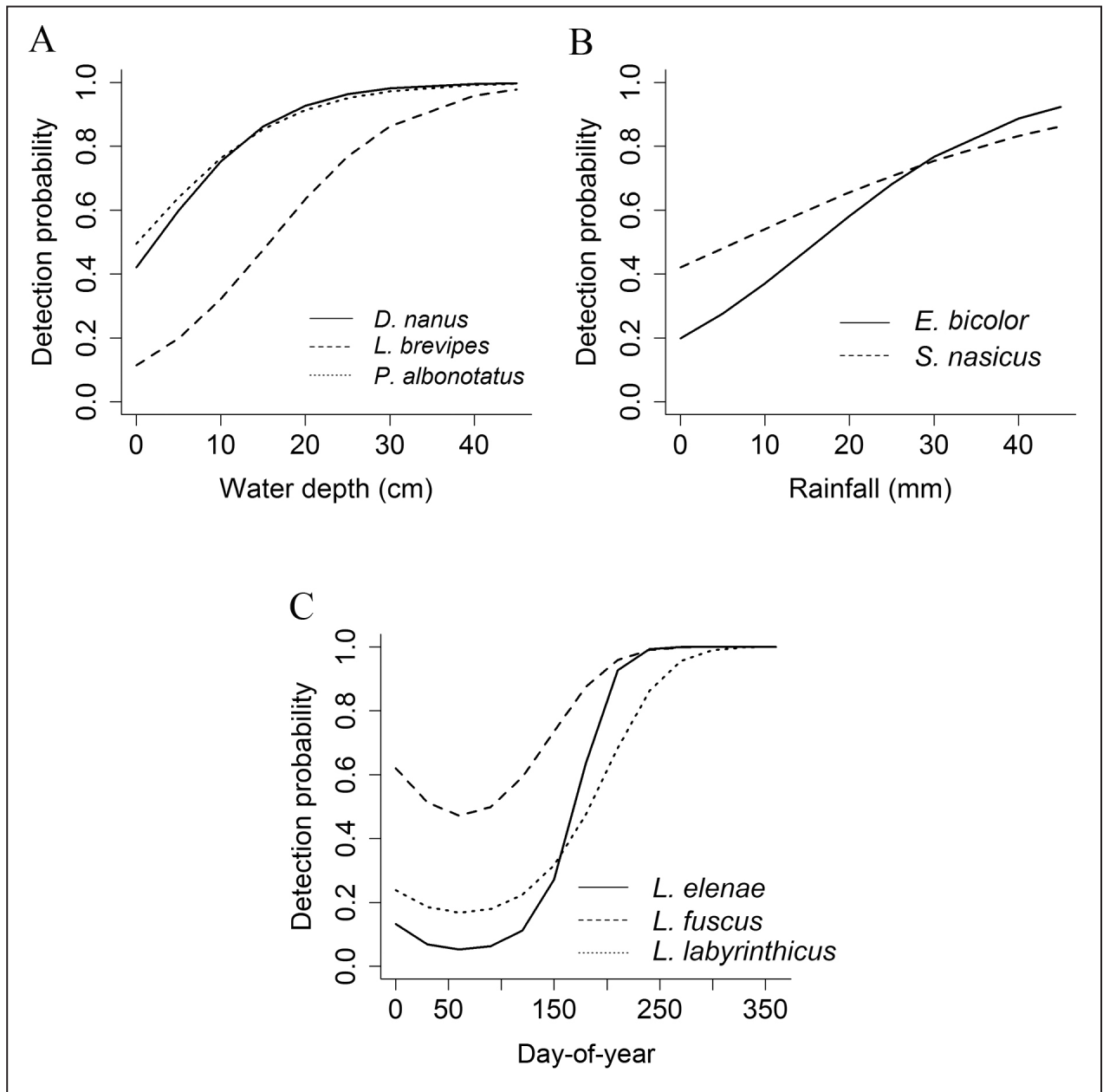
lity. Similar to previous studies in Cerrado areas (Santoro and Brandão, 2014; Vaz-Silva *et al.*, 2020), the anuran assemblages from urban areas of Cuiabá were characterized by the predominance of reproductive modes where eggs are deposited directly in the water without the protection of foam. Still, we also observed strategies involving aquatic (floating on the water or laid in constructed depressions) and terrestrial foam nests. Most species were continuously detected along the four years, and the exceptions were few species that were detected only once (*Boana geographica*, *B. raniceps*, and *Pseudopaludicola motorzinho*) or at few occasions (N=4; *Scinax fuscovarius*).

Here, many species detected at levels suitable for modeling are widely distributed and considered generalist species (Brasileiro *et al.*, 2005; Valdujo *et al.*, 2012). Despite being able to occupy different types of habitats, these species may exhibit distinct behavioral traits that in turn reflect on the visual detection. Previous studies highlighted the importance of specific ecological responses of amphibian species to deal with the low environmental heterogeneity in urban wetlands (Acosta *et al.*, 2005; Babini *et al.*, 2015a). So, results from our study may be explained by: i) species different calling behaviors; ii) microhabitat where to lay their eggs; iii) adults and post-metamorphic juveniles' movement patterns.

Although *Elachistocleis bicolor* and *Scinax nasicus* have distinct life habits (fossorial x scansorial), both species are explosive breeders associated to heavy rains (Prado *et al.*, 2005). In this sense, the positive association between detectability and rainfall in the last 24-hour period was not unexpected. Species with prolonged breeding behavior were more closely associated with changes in water depth. *Dendropsophus nanus* and *Physalaemus albonotatus*, which eggs are deposited on the surface of the water, showed a fast increase in the detection rates following pond filling. On the other hand, *Leptodactylus brevipes*, which used constructed depressions at edges of flooded areas, showed a smoother increase. Although *L. brevipes* was generally observed in shallow areas—we observed adults attending tadpole schools in several occasions—the depression construction may be somewhat dependent of pond depth, as the water inside the depression should probably permeate from the adjacent pond.

Intriguingly, some species showed low detectability at the end of the rainy season with increasing towards the dry season. The apparent overdispersion identified in the models for *Leptodactylus elenae* and *L. labyrinthicus* indicates a possible clumping in the observed records. At first glance, increasing detectability could be attributed to juveniles migrating from the pond. However, the patterns observed here





**Figure 4.** Relationship between detection probability of eight anuran species and (A) pond water depth, (B) rainfall in the last 24-hour period, (C) Day-of-year, at urban ponds from Cuiabá, Mato Grosso, Brazil, between 2015-2019. Only species with significant association are shown in each panel.

remained after the juvenile's exclusion. Movement ecology of amphibians is currently poorly understood, but species' behavioral differences seem to play a major role in key movement decisions, with some generalist species having less motivation to leave the natal pond (Pittman *et al.*, 2014; Bredeweg *et al.*, 2019). Studies have observed that many species recorded here seem engage in dispersal during the transition from the rainy to dry season (Watling *et al.*, 2009; Moreira *et al.*, 2017). On the other hand, the relative high detectability along the year suggests

that both juveniles and adults of *L. fuscus* are less motivated to depart from the ponds. As species responses and phenology may exhibit large differences between wet and dry years (e.g. Lowe *et al.*, 2016; Hamer, 2018), our findings reinforce the need for long-term studies encompassing annual variation along both wet and drought periods.

Also noteworthy is the low number of juvenile records, except for *D. nanus*. Studies on recruitment in amphibian assemblages have reported that the juvenile records often exceed the total number of

adults (Hocking et al., 2008; López et al., 2011). With that in mind, we presume that the low recruitment indicates that many individuals might not successfully metamorphose in the studied ponds. We can only speculate on impacts on tadpole mortality or metamorphosis rates, such as altered hydroperiod and contaminants (Babini et al., 2015b; Brannely et al., 2019). Because of lack of data, we were not able to determine detectability in juveniles. Still, we cannot rule out detection juvenile' bias that may act simultaneously with other mechanisms.

In line with accumulating evidence of urban amphibian assemblages (Acosta et al., 2005; Babini et al., 2015a; Menin et al., 2019; Dorigo et al., 2021), our results showed that intermittent ponds in urban areas can harbor a considerable proportion of anuran diversity. Despite the small size and accentuated degradation of surrounding environments, we found 30% of all anuran species recorded for Cuiabá municipality. The overall species richness (16 spp.) is lower compared to species richness recorded in Cerrado remnants affected by human activities (~30 spp.), such as crops or hydropower plants (Araujo and Almeida-Santos, 2011; Morais et al., 2012; Silva et al., 2015). In the case of Neotropical amphibians, an emerging trend for surveys in a range of urban areas—from rainforests to non-forest biomes—is similar richness. For instance, short-term studies performed in different Amazonian ecoregions reported between 15–20 species (Knispel and Barros, 2011; Pereira Jr et al., 2013; Menin et al., 2019). Considering only primary data, similar results were also reported for areas in the Cerrado (17–20 spp. Ferreira et al., 2017; Ganci et al., 2022), Dry Chaco (8–12 spp. Acosta et al., 2005; Palavecino and Garcia, 2008; Babini et al., 2015a), Humid Chaco (15 spp. Pesci et al. 2018), Pantanal and Uruguayan savanna ecoregions (16 spp. Ávila and Ferreira, 2004; Entiauspe-Neto and Freitas, 2016).

To conclude, detection rates of amphibians were related to water availability in urban wetlands, and they were highly variable between species. This study showed some occurrence/phenology patterns that may not be apparent in typical snapshot survey studies. It is essential that monitoring programs account for imperfect detection considering species individually and include assessments encompassing seasonality (i.e. both conditions ideal for detecting species and drought periods). Widespread amphibian species, as recorded here, are also challenged by widespread threats that likely alter the local environ-

ment in distinct ways (Nowakowski et al., 2018). Rapid climate change, reduced resources, and man-made stress call for a multidisciplinary approach to maximize the persistence of amphibian populations also in urban landscapes. Future studies can combine behavioral and morphological traits to anticipate what will happen and help maintain ecosystem services associated with amphibians (e.g. biological control, nutrient cycling). We hope that our results highlight the role of temporary/ephemeral ponds as a refuge for biodiversity. Isolated urban wetlands are not expendable, because their importance for freshwater biodiversity is far from the shallow now.

### Acknowledgments

We are grateful to A. Pansonato and C. Strüßmann for help in the species identification, and those who helped in the fieldwork. We would like to thank the Universidade Federal de Mato Grosso (UFMT) for their support during the execution of this research. LFBM and NPS are supported by a fellowship from CNPQ (PCI-DB # 300912/2022-6 and PCI-DC # 300917/2022-8).

### Literature cited

- Acosta, R.; Mesones, R.V. & Núñez, A. 2005. Fauna de los anuros em la ciudad de Salta, Argentina. *Revista de Biología Tropical* 53: 569-575.
- Andrade, E.B.; Leite, J.R.S.A & Weber, L.N. 2019. Composition, phenology, and habitat use of anurans in a cerrado remanent in Northeastern Brazil. *Herpetological Conservation and Biology* 14: 546-559
- Araujo, C.O. & Almeida-Santos, S.M. 2011. Herpetofauna de um remanescente de cerrado no estado de São Paulo, sudeste do Brasil. *Biota Neotropica* 11: 47-62.
- Asad, S.; Abrams, J.F.; Guharajan, R.; Sikui, J.; Wilting, A. & Rödel, M.O. 2020. Stream amphibian detectability and habitat associations in a reduced impact logging concession in Malaysian Borneo. *Journal of Herpetology* 54: 385-392.
- Ávila, R.W. & Ferreira, V.L. 2004. Riqueza e densidade de vocalizações de anuros (Amphibia) em uma área urbana de Corumbá, Mato Grosso do Sul, Brasil. *Revista Brasileira de Zoologia* 21: 887-892.
- Azevedo, J.A.R.; Valdujo, P.H. & Nogueira, C.C. 2016. Biogeography of anurans and squamates in the Cerrado hotspot: coincident endemism patterns in the richest and most impacted savanna on the globe. *Journal of Biogeography* 43: 2454-2464.
- Babini, M.S.; Salas, N.E.; Bionda, C.L. & Martino, A.L. 2015a. Implications of urbanization on the presence, distribution and reproductive ecology of the anuran fauna of a city in central Argentina. *Revista Mexicana de Biodiversidad* 86: 188-195.
- Babini, M.S.; Bionda, C.L.; Salas, N.E. & Martino, A.L. 2015b. Health status of tadpoles and metamorphs of *Rhinella arenarum* (Anura, Bufonidae) that inhabit agroecosystems and its implications for land use. *Ecotoxicology and Environmental Safety* 118: 118-125.



- Barata, I.M.; Griffiths, R.A. & Ridout, M.S. 2017. The power of monitoring: optimizing survey designs to detect occupancy changes in a rare amphibian population. *Scientific Reports* 7: 1-9.
- Brannelly, L.A.; Ohmer, M.E.B.; Saenz, V. & Richards-Zawacki, C.L. 2019. Effects of hydroperiod on growth, development, survival and immune defences in a temperate amphibian. *Functional Ecology* 33: 1952-1961.
- Brasileiro, C.A.; Sawaya, R.J.; Keifer, M.C. & Martins, M. 2005. Amphibians of an open cerrado fragment in southeastyhern Brazil. *Biota Neotropica* 5: 1-17.
- Bredeweg, E.M.; Morzillo, A.T.; Thurman, L.L. & Garcia, T.S. 2019. The integrative effects of behavior and morphology on amphibian movement. *Ecology and Evolution* 9: 1278-1288.
- Burnham, K.P. & Anderson, D.R. 2002. Model selection and multi-model inference: a practical information-theoretic approach. 2<sup>o</sup> ed. Springer. New York.
- Deane, D.C.; Fordham, D.A.; He, F. & Bradshaw, C.J.A. 2017. Future extinction risk of wetland plants is higher from individual patch loss than total area reduction. *Biological Conservation* 209: 27-33.
- Del-Claro, K. & Torezan-Silingardi, H.M. 2019. The study of biotic interactions in the brazilian cerrado as a path to the conservation of biodiversity. *Anais da Academia Brasileira de Ciencias* 91: 1-6.
- Dorado-Rodrigues, T.F.; Pansonato, A. & Strüssmann, C. 2018. Anfíbios e répteis em municípios da Bacia do Rio Cuiabá: 461-496. In: Figueiredo, D.M.; Dores, E.F.G.C.; Lima, Z.M. (eds.), Bacia Do Rio Cuiabá: Uma Abordagem Socioambiental, EdUFMT. Cuiabá.
- Dorigo, T.A.; Siqueira, C.C.; Oliveira, J.C.F.; Fusinato, L.A.; Santos-Pereira, M.; Almeida-Santos, M.; et al. 2021. Amphibians and reptiles from the Parque Nacional da Tijuca, Brazil, one of the world's largest urban forests. *Biota Neotropica* 21: e20200978
- Entiauspe-Neto, O.M. & Freitas, M.A. 2016. Herpetofauna from an urban Pampa fragment in southern Brazil: composition, structure and conservation. *Check List* 12: 1-15.
- Ferreira, C.M.M.; Ribas, A.C.A. & Souza, F.L. 2017. Species composition and richness of anurans in Cerrado urban forests from central Brazil. *Acta Herpetologica* 12: 157-165.
- Ferreira, R.B.; Silva-Soares, T. & Rödder, D. 2010. Amphibians of Vitória, an urban area in south-eastern Brazil: first approximation. *Salamandra* 46: 187-196.
- Fiske, I. & Chandler, R. 2011. Unmarked: An R package for fitting hierarchical models of wildlife occurrence and abundance. *Journal of Statistical Software* 43: 1-23.
- Gambale, P.G.; Woitovicz-Cardoso, M.; Vieira, R.R.; Batista, V.G.; Ramos, J. & Bastos, R.P. 2014. Anuran richness and composition in remnants of Cerrado of Central Brazil. *Iheringia - Serie Zoologia* 104: 50-58.
- Ganci, C.C.; Proverte, D.B.; Püttker, T.; Lindenmayer, D. & Almeida-Gomes, M. 2022. High species turnover shapes anuran community composition in ponds along an urban-rural gradient. *Urban Ecosystems* 25: 633-642.
- Gomez-Mestre, I.; Pyron, R.A. & Wiens, J.J. 2012. Phylogenetic analyses reveal unexpected patterns in the evolution of reproductive modes in frogs. *Evolution* 66: 3687-3700.
- Greenberg, C.H.; Johnson, S.A.; Owen, R. & Storfer, A. 2017. Amphibian breeding phenology and reproductive outcome: an examination using terrestrial and aquatic sampling. *Canadian Journal of Zoology* 95: 673-684.
- Guimarães, M.; Doherty, P.F. & Munguía-Steyer, R. 2014. Strengthening population inference in herpetofaunal studies by addressing detection probability. *South American Journal of Herpetology* 9: 1-8.
- Hamer, A.J. & McDonnell, M.J. 2008. Amphibian ecology and conservation in the urbanising world: A review. *Biological Conservation* 141: 2432-2449.
- Hamer, A.J. 2018. Accessible habitat and wetland structure drive occupancy dynamics of a threatened amphibian across a peri-urban landscape. *Landscape and Urban Planning* 178: 228-237.
- Hamer, A.J.; Schemera, D. & Mahony, M.J. 2021. Multi-species occupancy modeling provides novel insights into amphibian metacommunity structure and wetland restoration. *Ecological Applications* 31: e02293.
- Hocking, D.J.; Rittenhouse, T.A.G.; Rothermel, B.B.; Johnson, J.R.; Conner, C.A.; Harper, E.B. & Semlitsch, R.D. 2008. Breeding and recruitment phenology of amphibians in Missouri oak-hickory forests. *American Midland Naturalist*: 160: 41-60.
- Hutto, D. & Barrett, K. 2021. Do urban open spaces provide refugia for frogs in urban environments? *PLoS ONE* 16: 1-19.
- IBGE, Instituto Brasileiro de Geografia e Estatística. 2020. Coordenação de População e Indicadores Sociais. Brasília.
- Knispel, S.R. & Barros, F.B. 2011. Anfíbios anuros da região urbana de Altamira (Amazônia Oriental), Pará, Brasil. *Biotemas* 22: 191-194.
- Leão Pompeu, C.C.; De Sá, F.P. & Haddad, C.F.B. 2020. Seasonal reproductive dynamics of a Lek-Breeding Neotropical treefrog is not organized by male size (Anura, Hylidae). *South American Journal of Herpetology* 18: 33-41.
- López, J.A.; Scarabotti, P.A. & Ghirardi, R. 2011. Seasonal patterns of abundance and recruitment in an amphibian assemblage from the Paraná river floodplain. *Interciencia* 36: 538-544.
- López, J.A.; Antoniazzi, C.E.; Llanes, R.E. & Ghirardi, R. 2017. Age structure, growth pattern, sexual maturity, and longevity of *Leptodactylus latrans* (Anura: Leptodactylidae) in temperate wetlands. *Amphibia-Reptilia* 38: 371-379.
- Lowe, K., Castley, J.G. & Hero, J.M. 2016. Calling phenology and detectability of a threatened amphibian (*Litoria olongburensis*) in ephemeral wetlands varies along latitudinal cline: Implications for management. *Austral Ecology* 41: 938-951.
- MacKenzie, D.I. & Bailey, L.L. 2004. Assessing the fit of site-occupancy models. *Journal of Agricultural, Biological, and Environmental Statistics* 9: 300-318.
- MacKenzie, D.I.; Nichols, J.D.; Royle, J.A.; Pollock, K.H.; Bailey, L.L. & Hines, J.E. 2006. Occupancy estimation and modeling. Elsevier. Amsterdam.
- Menin, M.; Ferreira, R.F.B.; Melo, I.B.; Gordo, M.; Hattori, G.Y. & Sant'anna, B.S. 2019. Anuran diversity in urban and rural zones of the Itacoatiara municipality, central Amazonia, Brazil. *Acta Amazonica* 49: 122-130.
- Morais, A.R.; Bastos, R.P.; Vieira, R. & Signorelli, L. 2012. Herpetofauna da Floresta Nacional de Silvânia, um remanescente de Cerrado no Brasil Central. *Neotropical Biology and Conservation* 7: 114-121.
- Moreira, L.F.B. & Maltchik, L. 2015. Our time will come: Is anuran community structure related to crop age? *Austral Ecology* 40: 827-835.
- Moreira, L.F.B.; Solino-Carvalho, L.A.; Strüssmann, C. & Silveira, R.M.L. 2016. Effects of exotic pastures on tadpole

- assemblages in Pantanal floodplains: assessing changes in species composition. *Amphibia-Reptilia* 37: 179-190.
- Moreira, L.F.B.; Dorado-Rodrigues, T.F.; Ferreira, V.L. & Strüssmann, C. 2017. An inter-dependence of flood and drought: disentangling amphibian beta diversity in seasonal floodplains. *Marine and Freshwater Research* 68: 2115-2122.
- Murray, M.H.; Sánchez, C.A.; Becker, D.J.; Byers, K.A.; Worsley-Tonks, K.E.L. & Craft, M.E. 2019. City sicker? A meta-analysis of wildlife health and urbanization. *Frontiers in Ecology and the Environment* 17: 575-583.
- Nowakowski, A.J.; Frishkoff, L.O.; Thompson, M.E.; Smith, T.M. & Todd, B.D. 2018. Phylogenetic homogenization of amphibian assemblages in human-altered habitats across the globe. *Proceedings of the National Academy of Sciences* 115: E3454-E3462.
- Nunes-de-Almeida, C.H.L.; Haddad, C.F.B. & Toledo, L.F. 2021. A revised classification of the amphibian reproductive modes. *Salamandra* 57: 413-427.
- O'Connell, A.F.J.; Talancy, N.W.; Bailey, L.L.; Sauer, J.R.; Cook, R. & Gilbert, A.T. 2006. Estimating site occupancy and detection probability parameters for meso- and large mammals in a coastal ecosystem. *Journal of Wildlife Management* 70: 1625-1633.
- Palavecino, P.M. & Garcia, G.F. 2008. Sobre la batracofauna de la ciudad de Salta y alrededores (Salta, Argentina): estudios puntuales y datos de colección. *Boletín de la Sociedad Herpetológica Mexicana* 16: 27-35.
- Pesci, G.P.; Sánchez, J.M.; Leão, S.M. & Pelegrin, N. 2018. Reptiles y anfibios de una localidad del Chaco Húmedo en Formoso, Argentina. *Cuadernos de Herpetología* 32: 47-54.
- Pereira Jr, A.P.; Campos, C.E.C. & Araújo, A.S. 2013. Composição e diversidade de anfibios anuros do campus da Universidade Federal do Amapá. *Biota Amazônia* 3: 13-21.
- Pittman, S.E.; Osbourn, M.S. & Semlitsch, R.D. 2014. Movement ecology of amphibians: A missing component for understanding population declines. *Biological Conservation* 169: 44-53.
- Prado, C.P.A.; Uetanabaro, M. & Haddad, C.F.B. 2005. Breeding activity patterns, reproductive modes, and habitat use by anurans (Amphibia) in a seasonal environment in the Pantanal, Brazil. *Amphibia-Reptilia* 26: 211-221.
- R Core Team. 2021. R: A language and environment for statistical computing. *R Foundation for Statistical Computing*. Viena.
- Ribeiro, J.W.; Siqueira, T.; Brejão, G.L. & Zipkin, E.F. 2018. Effects of agriculture and topography on tropical amphibian species and communities. *Ecological Applications* 28: 1554-1564.
- Roloff, G.J.; Grazia, T.E.; Millenbah, K.F. & Kroll, A.J. 2011. Factors associated with amphibian detection and occupancy in southern Michigan forests. *Journal of Herpetology* 45: 15-22.
- Santoro, G.R.C.C. & Brandão, R.A. 2014. Reproductive modes, habitat use, and richness of anurans from Chapada dos Veadeiros, central Brazil. *North-Western Journal of Zoology* 10: 365-373.
- Segalla, M.; Berneck, B.; Canedo, C.; Caramaschi, U.; Cruz, C.A.G.; Garcia, P.C.A.; et al. 2021. List of Brazilian Amphibians. *Herpetologia Brasileira* 10: 121-2016.
- Semlitsch, R.D. & Bodie, J.R. 1998. Are small, isolated wetlands expendable? *Conservation Biology* 12: 1129-1133.
- Silva, M.C.; Oliveira, R.H.; Morais, D.H.; Kawashita-Ribeiro, R.A.; Brito, E.S. & Ávila, R.W. 2015. Amphibians and reptiles of a cerrado area in Primavera do Leste municipality, Mato Grosso state, central Brazil. *Salamandra* 51: 187-194.
- Souza, A.P.; Lima, L.; Zamadei, T.; Martim, C.C.; Almeida, F.T. & Paulino, J. 2013. Classificação climática e balanço hídrico climatológico no estado de Mato Grosso. *Nativa* 1: 34-43.
- Souza, A.O.; Oliveira, S.R.; Dias, G.P.; Bastos, R.P. & Morais, A.R. 2020. Annual and daily patterns of calling activity in male *Scinax fuscomarginatus* (Anura: Hylidae) from Central. *Zoologia* 37: e54148.
- Valdujo, P.H.; Silvano, D.L.; Colli, G. & Martins, M. 2012. Anuran species composition and distribution patterns in Brazilian Cerrado, a Neotropical Hotspot. *South American Journal of Herpetology* 7: 63-78.
- Vasconcelos, T.S.; da Silva, F.R.; dos Santos, T.G.; Prado, V.H.M. & Provete, D.B. 2019. *Biogeographic Patterns of South American Anurans*. Springer Nature. Cham.
- Vaz-Silva, W.; Maciel, N.M.; Nomura, F.; Morais, A.R.; Batista, V.G.; Santos, D.L.; et al. 2020. Guia de identificação das espécies de anfibios (Anura e Gymnophiona) do estado de Goiás e do Distrito Federal, Brasil Central. Scielo Books. Curitiba.
- Watling, J.I.; Gerow, K. & Donnelly, M.A. 2009. Nested species subsets of amphibians and reptiles on Neotropical forest islands. *Animal Conservation* 12: 467-476.

#### SUPPLEMENTARY FILES

Supplementary materials cited in this article are available upon request from Corresponding Author (<https://doi.org/10.6084/m9.figshare.21747686.v1>)

**Supplementary 1.** Occurrence and calling activity of each anuran species registered at three urban ponds from Cuiabá, Mato Grosso State, Brazil, between 2015-2019.

**Supplementary 2.** Parameters contained in the best models of detection probability for eight species of anurans in Cuiabá, Mato Grosso State, Brazil. Only adult data were included in the analyses.