THERYA NOTES 2022, Vol. 3 : 30-35 DOI: 10.12933/therya_notes-22-65 ISSN 2954-3614

Discovery of underground shelters occupied by the Chacoan Marsh Rat after massive wildfires in Pantanal, Brazil

Hallazgo de refugios subterráneos ocupados por la rata colorada chaqueña tras incendios forestales en Pantanal, Brasil

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The drought and wildfires that swept through Pantanal, the major South American wetland, in 2020 severely impacted the local biota. The resilience of native species to these types of extreme events remains largely unknown. During post-wildfire surveys at recently affected sites, we found three burrows containing the semi-aquatic Chacoan marsh rats (*Holochilus chacarius*). We also found a callichthyid catfish (*Hoplosternum* sp.) and a trichodactylid crab (*Dilocarcinus pagei*) alive and co-habiting one of the burrows with *H. chacarius*. We report for the first time the use of underground structures with a flooded chamber by the Chacoan marsh rat. We discussed the importance of these burrows for post-fire survivorship and whether they may serve as shelters for *H. chacarius* and other species against wildfires and drought, under the light of previous studies with other taxa.

Key words: Dry season; *Holochilus chacarius*; Oryzomyini; Sigmodontinae; survivorship; wetlands; wildfire.

Las sequías e incendios forestales que afectaron el Pantanal, la mayor llanura inundada de Sudamérica en 2020 impactaron fuertemente la biota, cuya resiliencia a estos tipos de eventos extremos todavía es desconocida. Durante muestreos posteriores a los incendios en sitios impactados, encontramos tres cuevas habitadas por la rata colorada chaqueña, *Holochilus chacarius*. Además, encontramos a un bagre calíctido (*Hoplosternum* sp.) y a un cangrejo tricodactílido (*Dilocarcinus pagei*) cohabitando una de las cuevas con *H. chacarius*. Reportamos, por primera vez, el uso de una cueva inundada por la rata colorada. Discutimos la importancia de dichas estructuras para la supervivencia posterior al incendio y si pueden servir como refugio para *H. chacarius* y otras especies a eventos extremos de incendios y sequía, a la luz de estudios previos con otros taxones.

Palabras clave: Estación seca; *Holochilus chacarius*; humedales; incendio forestal; Oryzomyini, Sigmodontinae; supervivencia.

In the Pantanal wetlands of central South America (Brazil, Bolivia, and Paraguay), wildfires in the dry season are part of the ecosystem dynamics (Alho and Silva 2012; Hardesty *et al.* 2005). Therefore, it is expected that such wildfires directly affect the local populations of small mammals, as in other fire-driven ecosystems (*e.g.*, Koprowski *et al.* 2006; Conner *et al.* 2011; Leahy *et al.* 2015; Pacheco *et al.* 2021). In some anomalous years, the fires in Pantanal may cover larger areas, influenced by natural events associated with anthropogenic factors such as the opening of pastures and agricultural areas (Alho and Silva 2012; Garcia *et al.* 2021; Marengo *et al.* 2021; Marques *et al.* 2021). This was the case in 2020, when wildfires burned approximately 26 % of the Brazilian Pantanal (Garcia *et al.* 2021; Libonati *et al.* 2021) and directly affected local flora and fauna (Garcia *et al.* 2021; Tomas *et al.* 2021).

Information on post-wildfire resilience of vertebrates in the Brazilian Pantanal remains obscure. Environmental factors affecting the survival of fauna during wildfires are many and have complex interrelationships, but it seems that burrows and other cavities may serve as immediate protection (Engstrom 2010; Bova *et al.* 2011; Robinson

et al. 2013; van Mantgem *et al.* 2015). Additionally, previous studies in other ecosystems have indicated that small mammal individuals that survived after fires may play an important role in the recovery of populations in burned areas, when compared to immigrants from non-affected places (Banks *et al.* 2017; Hale *et al.* 2021).

During a survey to assess the first-order impact of wildfires on vertebrates in the Pantanal, we found flooded burrows occupied by individuals of the Chacoan marsh rat, *Holochilus chacarius* (Cricetidae, Sigmodontinae), alive immediately after a wildfire. *Holochilus chacarius* is a South American semi-aquatic rodent species which occurs in the Pantanal wetlands or Chaco areas in Paraguay, eastern Bolivia, northern Argentina, and western Brazil (Brandão and Nascimento 2015; Prado *et al.* 2021). Information on the behavior and biology of the species is largely restricted to anecdotal and natural history observations from Argentina (*e.g.*, Massoia 1971, 1976; Llanos 1944; Piantanida 1993; Díaz and Bárquez 2002) and Paraguay (Yahnke 2006). However, little is known about the species in the Brazilian Pantanal and most of such data are generalizations for the genus (see Oliveira and Bonvicino 2011).

Herein, we report on burrows occupied by individuals of *H. chacarius* in a recently burned area in Pantanal, Brazil. We describe these burrows in detail, assess the evidence of use presented in the structures and discuss, under the light of previous studies with other taxa, whether they may serve as shelters for *H. chacarius* and other species against droughts and wildfires in the Pantanal wetlands.

Data were collected during fieldwork related to the Mogu Matá Network, a survey carried out to assess the first-order impact of wildfires on vertebrates in Pantanal. From August to November 2020 (the local dry season), we surveyed burned areas along transect lines, searching carcasses, injured animals, and indirect signs of the presence of survivors (*e.g.*, burrows; nests). On September 15th, 2020, we visited an area that had been burned in the previous 24 hours. The study site, a seasonally flooded swamp (16° 57′ 8″ S, 56° 54′ 40″ W), with patches of water-saturated pre-turf or peat, is situated adjacent to the MT-060 road (Transpantaneira), located in the municipality of Poconé, Mato Grosso state (MT), Brazil (Figure 1a). The original vegetation is typical of local wetlands and dominated by *Thalia geniculata* (Marantaceae; Nunes da Cunha and Junk 2011).

Due to the ongoing wildfires in the region, the environmental temperature was high and the peaty soil was still scorching or burning underground (Figure 1b). During transect surveying, we found burrows in the ground with signs of recent use. After documenting the burrows, we carefully removed the top layer of soil with a machete. We measured only those burrows that were occupied by rodents. We then described the inner structure of each burrow and took measurements with a measuring tape (to the nearest 1.0 cm). Specimens were collected and preserved in ethanol and skulls were cleaned with dermestid beetles for taxonomic identification and further incorporated in the Coleção de Mamíferos da Universidade Federal de Mato Grosso (UFMT), Cuiabá, MT, Brazil. The collection permit was provided by the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), Brazil (permit number 76244–1). Handling and collection procedures followed the guidelines of the American Society of Mammalogists (Sikes *et al.* 2016).

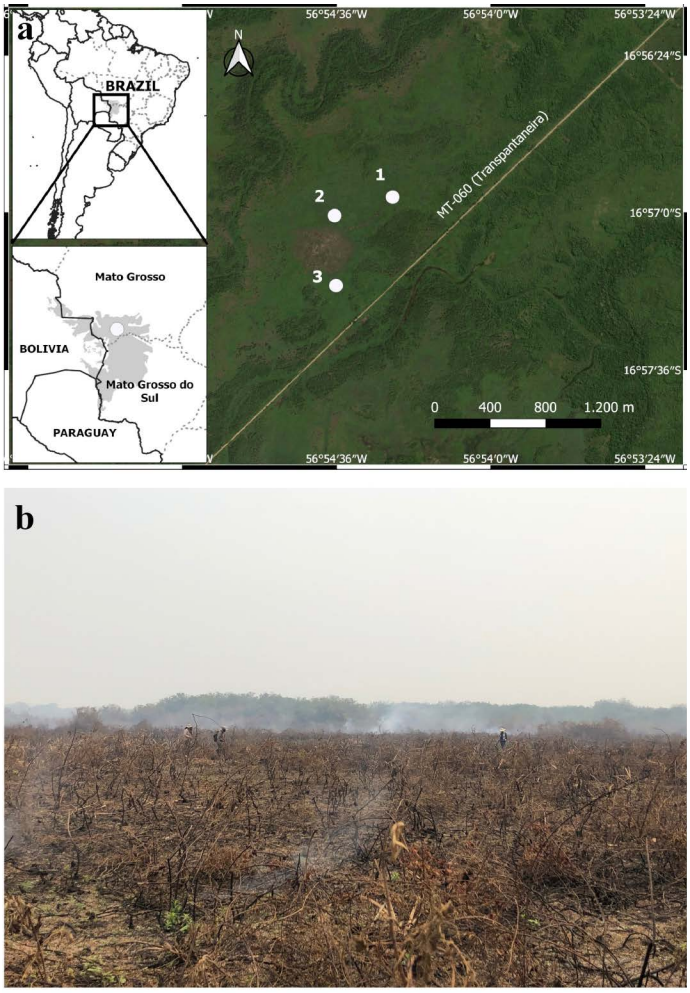

Figure 1. a) Map of the sampled area in the Pantanal, where the burrows of *Holochilus chacarius* were located in a seasonally flooded area. b) Sampled area where burrows of *H. chacarius* were recorded during a wildfire in the Brazilian Pantanal. Note in the background the researcher conducting transects and smoke from the active fire. Photo by M. Ardevino.

Three of the burrows examined were occupied each by a single individual of *H. chacarius*. Two of the 3 individuals were collected as vouchers (UFMT 4897-98). One female was pregnant (Figure 2); there were neither nestlings nor juveniles. All examined burrows had similar characteristics (Figure 3). The burrows were characterized externally by a hole in the ground with a round entrance, closed with a ball-like piece of loosely woven dry grass and litter, forming a stopper (Figure 3c, d). No soil monticule was present outside. The hole led to an oblique underground tunnel, with trampled shredded litter covering its surface (Figure 3a). The tunnel ended in a relatively wider vertical inner chamber, where the rodents were found. Each *H. chacarius* individual was partially submerged in the water (Figure 3b). A

Figure 2. Skull of *Holochilus chacarius* UFMT 4897, female, with a close view of its superior molar series. The white bars represent 1 mm scale of skull (upper left and bottom) and teeth (upper right).

callichthyid catfish (*Hoplosternum* sp.) and a trichodactylid crab (*Dilocarcinus pagei*) were found alive inside one of the flooded chambers, together with *H. chacarius*. A summary description of the burrows, including additional pictures (*e.g.*, entrance after cleaning; ball-like structure made of grass), are provided in Figure 3 and Table 1.

The use of nests, burrows, and galleries is widespread and well documented in rodents (Lacey *et al.* 2000; Begall *et al.* 2007; Wilson *et al.* 2016, 2017), including several genera of the subfamily Sigmodontinae (Formoso and Sánchez 2014; Patton *et al.* 2015; Bovendorp *et al.* 2017). *Holochilus* nests are usually above ground or water, from ground level up to 3 m high, and made with partially shredded grass or litter (Burmeister 1879; Moojen 1943; Yepes 1941; Llanos 1944; Moojen 1952; Twigg 1965; Barlow 1969; Massoia 1971, 1976; Barreto and García-Rangel 2005; Sauthier *et al.* 2010; Gonçalves *et al.* 2015).

Exceptionally, Massoia (1971) reported nests of *H. chacarius* found inside subterranean galleries, in Formosa province, Argentina. The galleries included up to 3 entrances and were used by several individuals (Massoia 1971). In contrast, the underground structures we found were hole-like with a single entrance, partially flooded, and only 1 individual was present per burrow. Although we found no clear evidence that burrows could be nesting places of *H. chacarius*, it is plausible, as one of the *H. chacarius* individuals was pregnant. Additionally, the woven grass rolls at the entrances (Figure 3c-d) could be used as nesting material.

Although the similarities among the burrows suggest the same species constructed them, the fact that we found both a crab and rodent cohabiting a hole, introduces a degree of uncertainty about which species initially dug the burrow. Literature data on nests among roots and aerial parts of plants imply that *Holochilus* is capable of digging and climbing, besides cursorial and natatorial locomotion (Tulli *et al.* 2016), but fossorial behavior has not been observed in the genus. However, Massoia (1971) considers *H. chacarius* had constructed the subterranean galleries reported in his study.

Anatomical features in the forelimbs of semiaquatic and fossorial sigmodontines were hypothesized as convergent traits associated with overcoming water and soil resistance (Tulli *et al.* 2016; Coutinho and Oliveira 2017). However, most of the propulsion efforts during swimming in *Holochilus* are generated by hindlimb pedaling (Torres *et al.* 2020), weakening this supposition. Thus, considering that the fossorial behavior of *Holochilus* has not been demonstrated, we refrain from asserting that the rodents constructed the burrows by themselves.

It is known that crabs construct small holes and that other animals use these as refugia from drought in Pantanal (Simioni *et al.* 2014). Therefore, it is possible that *H. chacarius* enlarged and maintained preexisting crab burrows. Both rodent and crab could have been using the burrows primarily as a refuge from the drought or other disturbances, and the protection against fire was a secondary benefit. This can also be the case for the catfish *Hoplosternum*, which can breathe air through gulping, travel small distances in land, and survive under hypoxic conditions (Nico *et al.* 1996; Jucá-Chagas 2004). Consequently, we consider the possibility that small

Table 1. . Descriptive characteristics of three burrows occupied by *Holochilus chacarius* in a Pantanal area that was hit by a wildfire, in Poconé, Mato Grosso, Brazil. All measures are in cm.

	Burrow 1	Burrow 2	Burrow 3
H. chacarius individuals	not collected (unknown sex and age)	UFMT 4897 (adult pregnant female)	UFMT 4898 (sub-adult male)
Tunnel length	–	30	28
Inner vertical chamber diameter	–	9	–
Inner vertical chamber height	–	52	58
Depth of water column	–	29	17
Observation	–	fish and crab also present (see text)	–
Coordinates	16° 56′ 57″ S, 56° 54′ 24″ W	16° 57′ 01″ S, 56° 54′ 36″ W	16° 57′ 17 ″S, 56° 54′ 36″ W

burrowing animals, such as crabs or even rodents, could be micro-scale ecosystem engineers in the Pantanal (*i.e.*, species that modify the environment and can create suitable habitat for other species; Jones *et al.* 1994; Desbiez and Kluyber 2013).

Nevertheless, we interpret some signs at the burrows as indicatives of routine use by *H. chacarius*, such as the trampled vegetal pieces over the tunnel surface; the tunnel diameter, which was much larger than would be expected if crabs or fishes made the tunnel; the well excavated inner chamber several times larger than that reported for crab holes in Pantanal (Simioni *et al.* 2014); and the woven grass rolls which took some hours to be constructed (for observations in captivity, see Massoia 1971), blocking the entrances. Thus, regardless of which species firstly dug the holes, *H. chacarius* was certainly using the burrows, possibly as shelters from external factors before the wildfires.

Environmental factors affecting the survival of the fauna during wildfires are many and have complex interrelationships, but it seems that burrows and other cavities may serve as immediate protection (Engstrom 2010; Bova *et al.* 2011; Robinson *et al.* 2013; van Mantgem *et al.* 2015). The temperature and humidity inside burrows used by rodents are more stable compared to external conditions, although oxygen levels are influenced by soil type and water saturation (see Burda *et al.* 2007). As wildfires are relatively frequent in the Pantanal, the ability to seek refuge underground may benefit small mammals including *H. chacarius*, as observed in other taxa (Simioni *et al.* 2014). Some authors have shown that surviving individuals *in situ* may contribute to local population recovery, as well as those that immigrated from unaffected areas (Banks *et al.* 2017; Hale *et al.* 2021).

Massive wildfires (also called mega-fires) are a serious threat to mammals (Garcia *et al.* 2021; Pacheco *et al.* 2021). It has been estimated that wildfires, which burned around 2 million ha, directly killed more than 5.9 million mammals in Bolivia's Chiquitano dry forests in 2019, of which more than 60 % (> 3.6 million) were rodents (Pacheco *et al.* 2021). Recent studies showed that the 2020 extensive wildfires in the Brazilian Pantanal also had a severe impact, as the estimated burned area surpassed 4.5 million ha (Libonati *et al.* 2021), a land extension comparable to countries including Bhutan, Switzerland, Estonia, or Denmark. Also *ca*. 4.4 - 5.0 million mammals had died directly by these wildfires, *ca.* 3.6 - 3.8 were rodents (Tomas *et al.* 2021).

Factors that directly affect the small mammal populations after a wildfire strike, like food deprivation and increased predation (Sutherland and Dickman 1999; Conner *et al.* 2011; Leahy *et al.* 2015), would be aggravated after mega-fires, when resources and vegetation cover are less available. Thus, environmental traits could be key to enhance survivorship. The water-saturated holes may have helped to maintain the chamber with individuals of *H. chacarius* and other animals isolated from the fire and the heat, serving also as a hydration source in such hazardous conditions, a potentially rare resource in the dry season, especially during severe droughts (Marengo *et al.* 2021). Thus, by surviving locally, individuals would be able to improve population recovery, as reported for other species (Banks *et al.* 2017; Hale *et al.* 2021).

This contribution corroborates a single report of the use of underground structures by *H. chacarius* made half a century ago by Massoia (1971). We also add new data on the biology of this rodent, particularly regarding survivorship during wildfires in the threatened Pantanal wetland. Some questions remain unanswered, which could be subject of interest in future research: a) whether the burrows function as reproductive and / or nesting places; b) whether the use of burrows represents an adaptation to survive wildfires and drought; c) what the role of the surviving individuals in post-fire recovery of the population could be; and d) if *Holochilus* and / or trichodactylid crabs could be considered ecosystem engineers on a micro scale in the Pantanal, once the original constructor of the burrows and their occupancy processes are elucidated. We suggest that long-term monitoring of survivors and the population using genetic data, as well as other sampling techniques (*e.g.*, camera traps; borescope), will be fundamental in further studies concerning the relationship between the biology of *H. chacarius* and its relation to environmental disturbances, such as drought, wildfires and extreme temperatures.

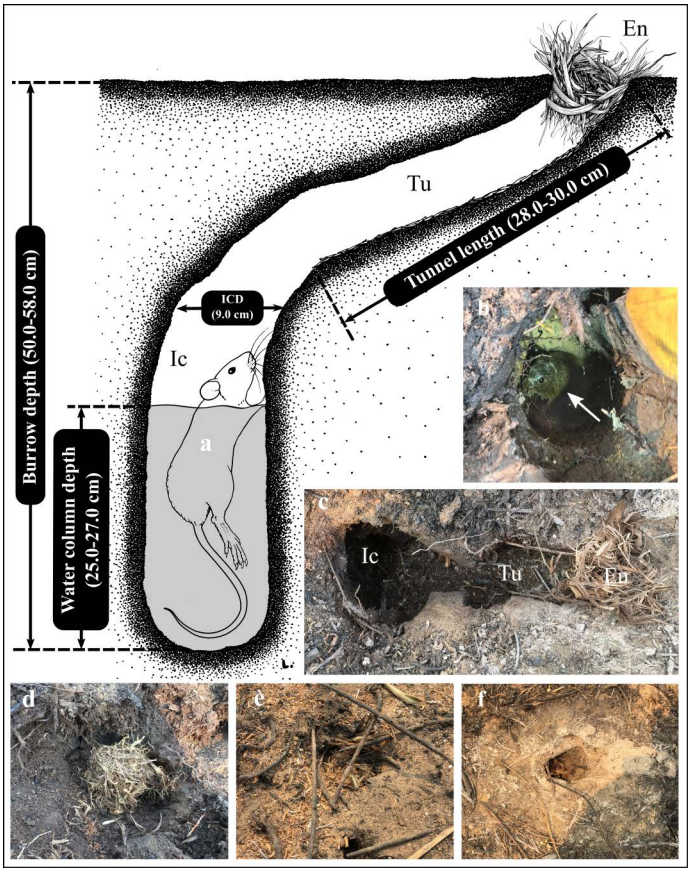

Figure 3. Schematic representation of the burrows where individuals of *Holochilus chacarius* were found in a recently burned area in the Pantanal (a). An individual is shown inside the inner chamber (b, white arrow) and top view (c) showing its inner structure: the entrance with the ball-like stopper (En); oblique tunnel (Tu); and flooded inner chamber (Ic), also note the inner chamber diameter (ICD); d) ball-like structure made of grass found in the entrance of burrows; e) an entrance with the ball-like stopper and f) entrance of the burrow after cleaning. Illustration by G. S. Libardi and photos by M. Ardevino.

Acknowledgements

T. B. F., Semedo is supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq #301208/2021-2); WMT by Pronex/Fundect/Embrapa (SEG 42.16.00.006.00.03.001) and C. Strüssman thanks CNPq for a research fellowship (CNPq #3123038/2018-1). We thank Museu Paraense Emílio Goeldi, WWF-Brasil, and "Mogu Matá Network" for funding our fieldwork; V. Layme, G. Valle, M. Ardevino, T. Graça for assistance during the field trips; M. Ardevino for gently providing photos from the study site; and L. V. S. Campos Filho (Pouso Alegre Lodge), for kindly offering stay and food during fieldwork and A. Albernaz (MPEG) and P. Valdujo (WWF-Brasil) for the logistic support. We thank the Laboratório de Scarabaeoidologia (UFMT, Cuiabá, MT, Brazil) and V. Costa-Silva, who provided access to the equipment used to make the skull photos, obtained as part of the subproject EECBio of UFMT/FINEP (agreement FINEP # 01.12.0359.00). We extend our gratitude to J. R. do Prado and J. Torres for confirming the identification of rodents, P. Venere for identifying the fish, P. Teta for valuable suggestions on previous version of the manuscript, and A. Devlin for reviewing the English. We thank two anonymous reviewers for their contributions to the improvement of this note.

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Associated editor: José R. Soto-Shoender
Submitted: October 14, 2021; Reviewed: January 6, 2022.
Accepted: February 7, 2022; Published on line: February 21, 2022.