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Area of occupancy of *Brachycephalus coloratus* Ribeiro, Blackburn, Stanley, Pie & Bornschein, 2017 (Anura, Brachycephalidae), endemic to the Serra da Baitaca, Brazil, and its implications for the conservation and Green Status of the species

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Abstract

Brachycephalus coloratus was known only from its type locality in the Serra da Baitaca of Paraná, Brazil. Its extent of occurrence was estimated at 0.37 km², and its conservation status was proposed as Vulnerable. Here, we provide a second record for *B. coloratus* at Pão de Ló, Paraná, at 1,230 m of altitude. We estimate its current area of occupancy at 1.17 km² and propose its conservation status as Endangered. The assessment of the Green Status suggests that it is Depleted; the prevention of deforestation and fires could lead to high conservation returns.

Keywords

Brachycephalus pernix species group, endangered, highland dense ombrophilous forest, management, microendemism, Parque Estadual Serra da Baitaca

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Introduction

The genus *Brachycephalus* Fitzinger, 1826 includes 38 species of diurnal and miniaturized toadlets endemic to the Brazilian Atlantic Rainforest, with some species being restricted to one or a few adjacent mountain tops (Bornschein et al. 2016, 2019; Frost 2022). *Brachycephalus* species are characterized by a miniaturized body, which leads to considerable sampling challenges in their leaf-litter habitat, despite some species exhibiting bright

coloration. Nevertheless, many *Brachycephalus* species were discovered recently, with 21 of them being described in the last 10 years.

Brachycephalus coloratus Ribeiro, Blackburn, Stanley, Pie & Bornschein, 2017 is a recently described species with bright body colors that was known only from its type locality, Estância Hidroclimática Recreio da Serra, Serra da Baitaca, municipality of Piraquara, eastern Paraná, Brazil (Ribeiro et al. 2017). Its altitudinal distribution ranges from 1,145–1,230 m above sea level (a.s.l.) and its geographical distribution, as extent of occurrence (*sensu* IUCN 2012), was estimated as 0.37 km² (Bornschein et al. 2019). This restricted geographic distribution leads to a risk of extinction, and the species was classified as Vulnerable (Bornschein et al. 2019). Nevertheless, the species has been classified as Data Deficient by the Brazilian authorities (ICMBio 2022) and has not yet been evaluated by the IUCN. In this work, we present a new geographic and altitudinal record for *B. coloratus*, reassess its conservation status, and provide, for the first time, an evaluation of its Green Status (IUCN 2021).

Methods

We collected *Brachycephalus* sp. in leaf-litter samples intended for a montane snail survey (see Teixeira et al. 2022). Subsequently, we obtained the data on the presence at lower and higher altitudes, locally, through the records of calling individuals and identified the habitat type of occurrence according to Veloso et al.'s (1991) criteria. We recorded the geographical coordinates with a handheld GPS (datum WGS84) and estimated the altitude a.s.l. for these points using Google Earth Pro v. 7.1.4.1529, following Bornschein et al. (2016). To estimate the geographic distribution of *B. coloratus*, we followed Bornschein et al. (2019), analyzing altitudinal information and vegetation in Google Earth Pro. However, we considered the geographic distribution results as area of occupancy instead of extent of occurrence (*sensu* IUCN 2012), following Bornschein et al. (2021). We reassess the conservation status of the species following IUCN (2012) and IUCN Standards and Petitions Committee (2022) criteria, by calculating the geographic distribution, comparing the value with the range of the proposed categories, and assessing threats and impacts on the environment over time, based on literature (Ribeiro et al. 2017) and our own observations. Finally, we assess the Green Status of *B. coloratus* following IUCN Green Status of Species (2021). We define the spatial units based on proximity and threat processes, use fine-resolution weights, and perform regional adjustments for each unit.

The collected specimen was euthanized with 2% lidocaine hydrochloride, fixed in 10% formalin for 24 h, and stored in 70% ethanol. We deposited it at the Museu de História Natural Capão da Imbuia (MHNCI), Curitiba, Paraná, Brazil. Collection permits were granted by the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio; #55918-1, #58088-2, #72845-1) and Instituto Ambiental do Paraná (IAP; #08.17). The map (Fig. 3) was created using ArcGIS software by ESRI.

Results

New record. BRAZIL – **Paraná** • Quatro Barras, Parque Estadual Serra da Baitaca, Serra da Baitaca, Pão de Ló; 25°24′45″S, 048°59′58″W; 1,250 m a.s.l. (Fig. 1);

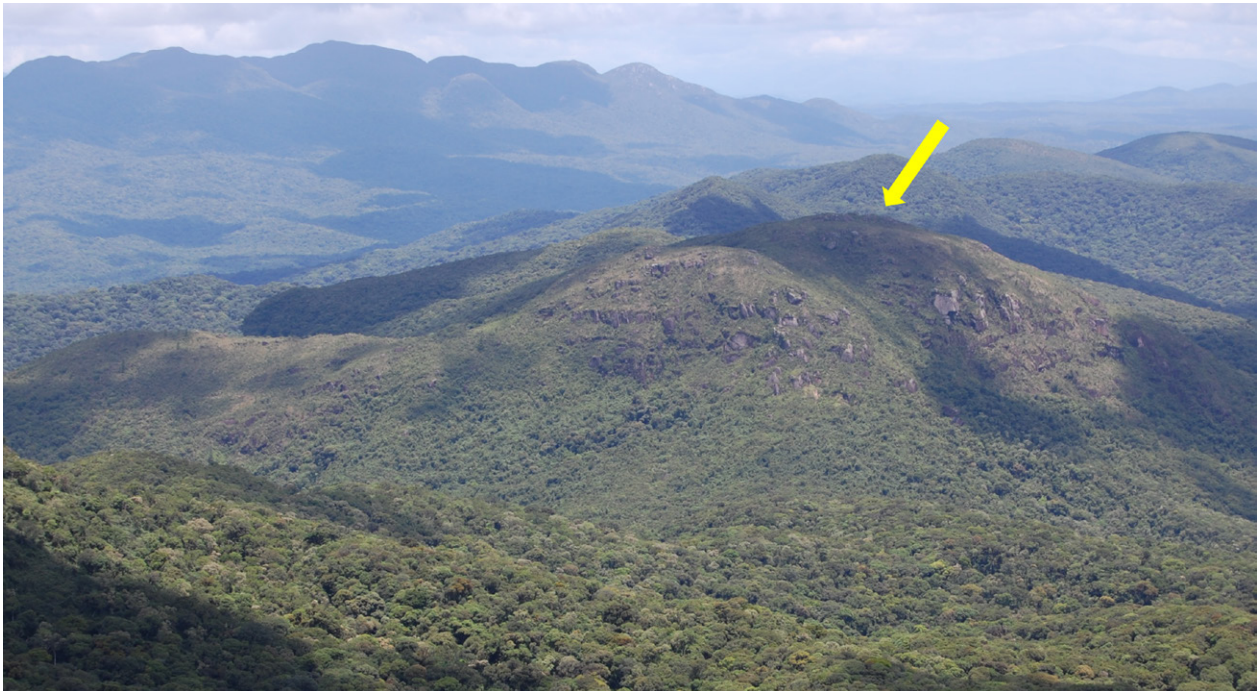

Figure 1. General view of the new locality of record of *Brachycephalus coloratus*, Pão de Ló, Parque Estadual Serra da Baitaca, municipality of Quatro Barras, Paraná, southern Brazil (yellow arrow), viewed from the top of Anhangava (type locality of *B. pernix*). Photographed by Luiz Fernando Ribeiro.

Figure 2. Adult male of *Brachycephalus coloratus* (MHNCI 11596) collected in Pão de Ló, Parque Estadual Serra da Baitaca, Serra da Baitaca, municipality of Quatro Barras, Paraná, southern Brazil. **A.** Lateral view. **B.** Dorsal view. **C.** Ventral view. Photographs by Luiz Fernando Ribeiro.

16.XII.2019; Júnior Nadaline, Cristiano Nadaline Gomes, and Larissa Teixeira leg.; 1 ♂; MHNCI 11596 (Fig. 2).

Identification. The collected specimen is a member of the *B. pernix* species group by the presence of a bufoniform body shape and *linea masculinea* (*sensu* Ribeiro et al. 2015; Pie et al. 2018). Within this group, the alive specimen matches the type series of *B. coloratus* by presenting a wide reddish dorsal stripe from the head to the pelvic region that contrasts with the greenish of the lateral of the body (Fig. 2). In preservative, the coloration of both *B. coloratus* and *B. pernix* are similar; however, the sides of the body in *B. coloratus* are dark brown, in contrast to *B. pernix*, which presents light brown sides with a reddish hue (see Ribeiro et al. 2017: fig. 5).

Geographic range. We record *B. coloratus* in a structured cloud forest, a highland dense ombrophilous forest (Floresta Ombrófila Densa Altomontana), with an average canopy height of more than 3 m, and between 1,230–1,250 m a.s.l. Considering this forest type and forest structure between 1,145–1,250 m a.s.l., we delimited three patches of suitable habitat for the species in the Serra da Baitaca. These are located between the geographical distribution of *B. pernix*, to the north, and the original geographical distribution path of *B. coloratus*, of 0.37 km², to the south (Fig. 3). These three new patches of suitable habitat are 0.21 km², 0.55 km², and 0.04 km², from north to south (Fig. 3). This 0.80 km² area, together with the original distribution, represents the presently known area of occupancy of the species

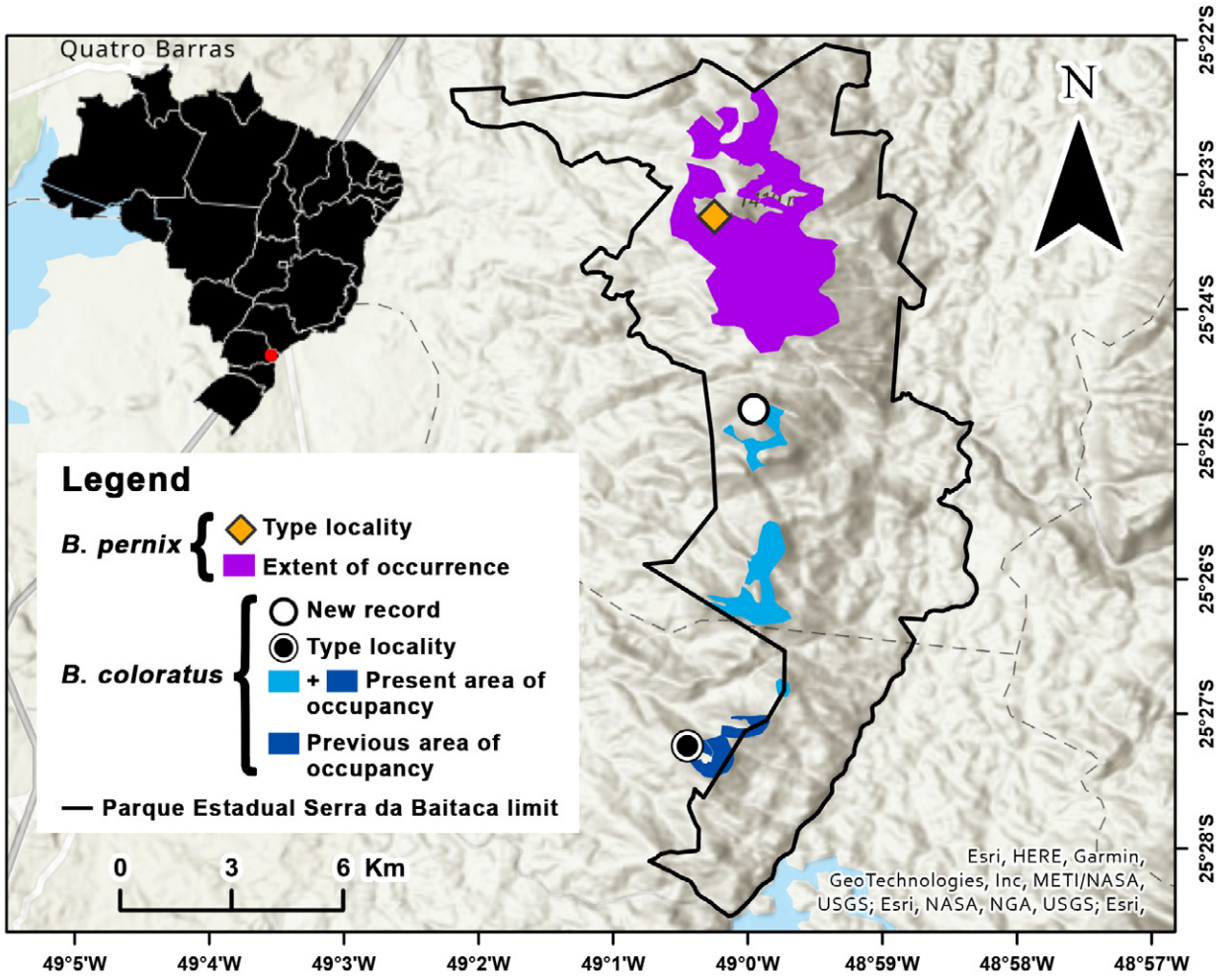

Figure 3. Geographical distribution and occurrence records of *Brachycephalus coloratus* and *B. pernix*. Type locality and previous area of occupancy of *B. coloratus* as per Ribeiro et al. (2017) and Bornschein et al. (2019), respectively. The original geographic distribution of *B. coloratus* was estimated as extent of occurrence (Bornschein et al. 2019), but reassessed as area of occupancy. Type locality and extent of occurrence of *B. pernix* as Pombal et al. (1998) and Bornschein et al. (2019), respectively, but hitherto unpublished. Map source: Map created using ArcGIS® software by ESRI.

(= 1.17 km^2), following pathway #1 of Bornschein et al. (2019). Of the total area of occupancy, 0.33 km^2 (28.26%) is outside the Parque Estadual Serra da Baitaca (Fig. 3).

The area of occupancy of *B. coloratus* is, then, composed of four patches of habitat (= locations, *sensu* IUCN [2012]). The northeastern location presents continuing decline in quality of area of occupancy due to regular fires (less than one fire per year). The southernmost location has inferred to have experienced deforestation due to an urban expansion project. In accordance with the presented data, *B. coloratus* can be considered threatened by extinction as Endangered, B2ab(ii,iii).

With a Green Score of 43.4%, currently *B. coloratus* is Largely Depleted (Table 1). Although most of the species' area of occupancy is within the Parque Estadual Serra da Baitaca, the conservation legacy of the park, assessed as the difference between the "Current" and "Counterfactual current" scenarios, is 0.0% (Table 1). For the "Future-with-conservation" scenario, with inhibit deforestation and control of fires considered, the species would be Fully Recovered, with a Green Score of 100.0% because the naturally small units would not be declining or under a specific threat, but performing at baseline levels. The Conservation Gain of these actions, calculated as the difference between the "Future-with-conservation" and "Current" scenarios, is 56.6% (Table 1), classified as high.

Table 1. Criteria to evaluate the Green Status of *Brachycephalus coloratus*. Abbreviation: W_{best} = the best weight for the species state in the spatial unit.

Scenario	W_{best}			Green Score (%)
	Northern*	Central†	Southern‡	
Counterfactual Current	1.5	10	1.5	43.4
Current	1.5	10	1.5	43.4
Future-with-conservation	10	10	10	100

* Equivalent to the northernmost location of *B. coloratus* (Fig. 3).
† Equivalent to the two central locations of *B. coloratus* (Fig. 3).
‡ Equivalent to the southernmost location of *B. coloratus* (Fig. 3).

Discussion

Our new data present an advance in the knowledge of the geographic distribution of *B. coloratus*, and, in addition, highlights that new localities near each other may not significantly change the size of the geographic

distribution of this species, presenting an illustration of the concept of microendemism. The new record of *B. coloratus* is located, in a straight line, 2.7 km away from the type locality of *B. pernix* and 0.79 km from the extent of occurrence of this species (Bornschein et al. 2019). Between these two areas there is a valley at approximately 1,080 m a.s.l. that is outside of both species' currently altitudinal range distribution (Bornschein et al. 2019; this study). The close geographic distribution among species of a genus in which sympatry is very rare (Bornschein et al. 2016, 2019), suggests that they would be a fascinating model to study speciation in the group and past distribution.

The estimate of the geographic distribution of *B. coloratus*, necessary to assess the conservation status of a species when population data are unknown, is proposed to be evaluated using the minimum convex polygon method (IUCN 2012). This requires at least three non-aligned species points records, so that their union generates a polygon encompassing an area. However, as many species of *Brachycephalus* have only one or two points of records, it has been proposed that a distribution area polygon can be generated when the altimetric range of record is known, providing a reasonable polygon unless it includes areas that are hundreds of kilometers from the region of occurrence of the genus (Bornschein et al. 2019). This adaptation of the method allowed us the reassessment of the conservation status of *B. coloratus*.

Brachycephalus coloratus is one of the 21 species of the genus at risk of extinction (Bornschein et al. 2019, 2021), highlighting the need for conservation that these small montane frogs deserve. Pão de Ló is degraded by fires, especially caused by visitor campfires, and visitor numbers have increased in recent years. Contributing to the seriousness of the problem is the prediction of an increase in global drought events (Pörtner et al. 2021) and the inference that the mountains of the Atlantic Forest may be susceptible to droughts (Mari et al. 2022).

For the first time, the Green Status of a *Brachycephalus* species and conservation gains with the application of management efforts are evaluated. This assessment brought to light the Brazilian government's difficulties in protecting its endangered species, since there was no conservation gain with the creation of the Parque Estadual Serra da Baitaca (Table 1). The application of management actions can result in a high conservation gain. Managements could include 1) reversal of authorization for urban expansion in the type locality of *B. coloratus*, outside the state park (see Ribeiro et al. 2017), 2) control of the number of visitors to the state park, 3) environmental education for visitors, aimed at preventing fires, and 4) provision of permanent fire brigades.

The evaluation of the Green Status of *B. coloratus* proved to be an efficient tool for diagnosing the current situation and evaluating the dependence and effectiveness of management measures to set conservation priorities. We recommend the evaluation of the Green Status of other endangered species of *Brachycephalus* to verify how much management actions represent gains for conservation. These results can have a very positive additional effect to motivate the environmental authorities, which sometimes seem not to be sufficiently sensitized only with the risk of extinction of the species (Bornschein et al. 2019).

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Authors' Contributions

Formal analysis: JN, GSS, MRB. Investigation: JN, GSS, LFR, LT, MRP, MRB. Visualization: LFR, LT. Writing – original draft: JN, GSS, LFR, MRB. Writing – review and editing: JN, GSS, LFR, LT, MRP, MRB.

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