

Article

Conservation Status of *Brachycephalus* Toadlets (Anura: Brachycephalidae) from the Brazilian Atlantic Rainforest

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Abstract: The number of described anurans has increased continuously, with many newly described species determined to be at risk. Most of these new species inhabit hotspots and are under threat of habitat loss, such as *Brachycephalus*, a genus of small toadlets that inhabits the litter of the Brazilian Atlantic Rainforest. Of 36 known species, 22 were described in the last decade, but only 11 have been assessed according to the IUCN Red List categories, with just one currently listed as Critically Endangered. All available data on occurrence, distribution, density, and threats to *Brachycephalus* were reviewed. The species extent of occurrence was estimated using the Minimum Convex Polygon method for species with three or more records and by delimiting continuous areas within the altitudinal range of species with up to two records. These data were integrated to assess the conservation status according to the IUCN criteria. Six species have been evaluated as Critically Endangered, five as Endangered, 10 as Vulnerable, five as Least Concern, and 10 as Data Deficient. Deforestation was the most common threat to imperiled *Brachycephalus* species. The official recognition of these categories might be more readily adopted if the microendemic nature of their geographical distribution is taken into account.

Keywords: deforestation; timber harvest; fire; invasion of exotic plants; conservation; public policy; protected areas; critically endangered; data deficient

1. Introduction

Frogs and toads (Anura) comprise more than 7000 species worldwide [1]. Special attention has been given to this group due to the large number of new species described each year as well as due to the increasing number of endangered species [2,3]. According to the IUCN Red List criteria [4,5], there are 1825 species of anurans at risk of extinction (25% of all species), making Anura the vertebrate order with the highest proportion of endangered species [5]. Since 1980, there have been records of a rapid population decline of nearly 450 anuran species [6–8]. The decline of these species can be mainly attributed to habitat loss and pathogens, such as chytrid fungi and Ranavirus [6,7,9–11]. Recently, Ranavirus has been reported in natural populations of frogs in South America, but the effects in wild anuran populations are still unknown [11]. Unlike Ranavirus, chytrid fungi (*Batrachochytrium dendrobatidis*) has been commonly reported as a cause of population decline in high altitude locations in Costa Rica and Panama [9]. Due to the rapid rate of the description of a new species, the proportion of endangered species, and sensitivity, Anura is the priority order for

a conservation assessment, particularly in countries with a high level of deforestation, such as in Brazil [3].

The Atlantic Rainforest, a biodiversity hotspot [12], is the largest in area after the Amazon forest, with its original extent covering more than 1.3 million km² [13,14]. It is located on the eastern coast of South America, stretching from northeastern to southern Brazil, with inland extensions to the east of Paraguay, northeast of Argentina, and central Brazil. This biome has been experiencing massive habitat loss due to agricultural expansion, urbanization, and historic loss of natural habitats [15]. Currently, only 28% of the original extent remains if secondary forests and forests affected by the edge effects are included [15]. The Atlantic Rainforest houses nearly 2500 species of vertebrates, including 550 anurans, of which 323 are endemic (63%) and 15 are currently considered to be threatened by extinction [1,5,16].

The genus *Brachycephalus* (Fitzinger, 1826) is endemic to the Atlantic Rainforest and includes small (less than 2.5 cm in snout-vent length) diurnal toadlets with a reduced number of digits, bright colors, neurotoxins in the skin, and direct development, and they live in leaf litter, specifically that of montane forests [17–23]. There are currently 36 recognized species of *Brachycephalus* [1], of which 22 have been described in the last decade [1]. Most have extremely restricted geographical distributions of less than 100 ha [12,24,25]. *Brachycephalus* is divided into three phenetic groups [26], two of which (*B. ephippiumsi* and *B. pernix* groups) are montane with few records at lower altitudes, whereas the remaining group (*B. didactylus* group) includes more ecologically plastic species that occur from the sea level up to high altitudes [23,27]. The dependence on a colder climate and isolation in the mountains as sky islands have been hypothesized as the reason that montane groups have diverged into so many species (19 of *B. pernix* and 12 of *B. ephippiumsi* groups), whereas the *B. didactylus* group includes only four species [23,28,29]. Another species (*B. atelopoide*) cannot be compared to any of the groups due to the unavailability of the holotype [23,30].

Species descriptions of *Brachycephalus* have not been accompanied by corresponding assessments of the conservation status. Only 11 species have been assessed for the IUCN Red List to date [31–41]: eight as Data Deficient (DD) and three as Least Concern (LC). The Ministério do Meio Ambiente (MMA, the Ministry of the Environment of the Brazilian government) evaluated only four species and categorized one as Critically Endangered (CR), two as DD, and one as Near Threatened (NT) [42–45]. The absence of conservation status assessments of most species and the evaluation of some of them as DD highlight the need for a comprehensive effort to assess the risk of extinction of the *Brachycephalus* species, most notably the microendemic taxa found in the *B. pernix* and *B. ephippiumsi* species groups (*sensu* [26]). Species evaluated as DD should be prioritized to generate enough data to properly classify them into a conservation category [46,47].

One way to direct effective initiatives for conservation species is through a prior assessment of their conservation status [3]. There is a widely adopted IUCN methodology for proposing a conservation status [3], which serves an important role in allowing for comparisons and for classifying conservation actions as well the proposition of public policies. The objectives of the study were (1) to review data on occurrence, altitudinal distribution, density, and threats to the *Brachycephalus* species, (2) to compile new data from the literature and unpublished observations, (3) to generate systematized data on geographic distribution, population sizes, and threats to place them into IUCN conservation categories, and (4) to discuss conservation priorities and future management actions.

2. Material and Methods

All available occurrence records of *Brachycephalus* spp. were compiled from the literature up to the time of compilation (June 2019). The data encompassed toponymy, species identification, geographical coordinates of the occurrence record, and altitude of the corresponding site. Data on altitudinal range were also considered when available. The process began with the latest compilation of locality and altitude data for *Brachycephalus* provided by Bornschein et al. [23], and the same selection criteria were adopted for subsequent records. For example, those associated with precise localities were retained,

and records that included only municipality names as occurrence information were discarded. Finally, the authors' previously unpublished data were included.

Occurrence records were plotted using Google Earth Pro v. 7.1.4.1529 and connected to form a polygon using the Minimum Convex Polygon approach (MCP; [48]) with modifications suggested by Reinert et al. [49] and adopted by Bornschein et al. [23]. These modifications allow for the exclusion of inappropriate habitats, such as bodies of water, pastures, silvicultures, urban areas, rock areas, and/or forest areas, beyond the altitudinal range of occurrence of the species.

Polygon delimitation required three or more occurrence records. For species with one or two records, polygons encompassing the altitudinal range of the species were created [23]. A continuous topography inside the polygon was considered a location (*sensu* IUCN and as IUCN [48]) that could potentially contain one or more records of a given species. The topography was considered discontinuous if it was isolated by altitudes beyond the altitudinal range of the respective species.

The MCP and altitudinal polygons were measured using GEPATH v. 1.4.5 to obtain the extent of occurrence (EO; IUCN [48]; see also [23,25,50]) of each species. Because some species have such reduced EO, they could potentially also be ranked by area of occupancy (AO), although AO was not measured in this study; however, species with less than 1000 ha of EO could also be categorized based on the criterion of an AO of less than 1,000 ha (criteria B2, for CR [48]) as well as species with an AO less than 50,000 ha (criteria B2, for EN [48]) because AO is always smaller than EO and is located within the EO polygon [48].

Population size was inferred for each species based on the estimates of area in m² inhabited by one individual compiled by Bornschein et al. [24]. Based on estimates of the number of calling males [24], a sex ratio of one female per male [24] was assumed. In cases with distinct estimates of densities per species [24], the mean density was used. The mean area in which one individual per species can be found and its respective EO was then used to calculate the population size.

Data on EO, number of locations, population size, and threats of the species were integrated to evaluate and to categorize its conservation status according to the IUCN Red List and Criteria [48]. For the recognition of threats, data from the literature, personal field experience of the authors collected in the EO of 29 species, and information on land use, forest quality, and trends of deforestation over the previous 10 years were considered. For temporal trends in land use, the time series of satellite images of Google Earth Pro v. 7.1.4.1529 was analyzed.

In the treatment of the data in relation to the IUCN criteria, the flow chart presented in Figure 1 was used. Six pathways were developed beginning with the evaluation of the number of localities (one to two; three or more). If the species had up to two recorded localities, its altitudinal range was calculated. If an altitudinal range was not associated with the record, this prevented creating a polygon and estimating the EO. The species was then considered DD (pathway 3 of Figure 1). If the records were associated with altitudinal range, an EO was created based on the lower and upper altitudinal limits. It was not always possible to infer the EO without encompassing inland areas far west of the record and outside the assumed natural range, sometimes nearly reaching Argentina, which is clearly unrealistic. In these situations, the species were considered DD (pathway 2 of Figure 1). When there were up to two records associated with an altitudinal range that encompassed a realistic polygon for EO (as indicated), the status of the species was evaluated (pathway 1 of Figure 1). Further pathways related to the procedure can be observed in Figure 1.

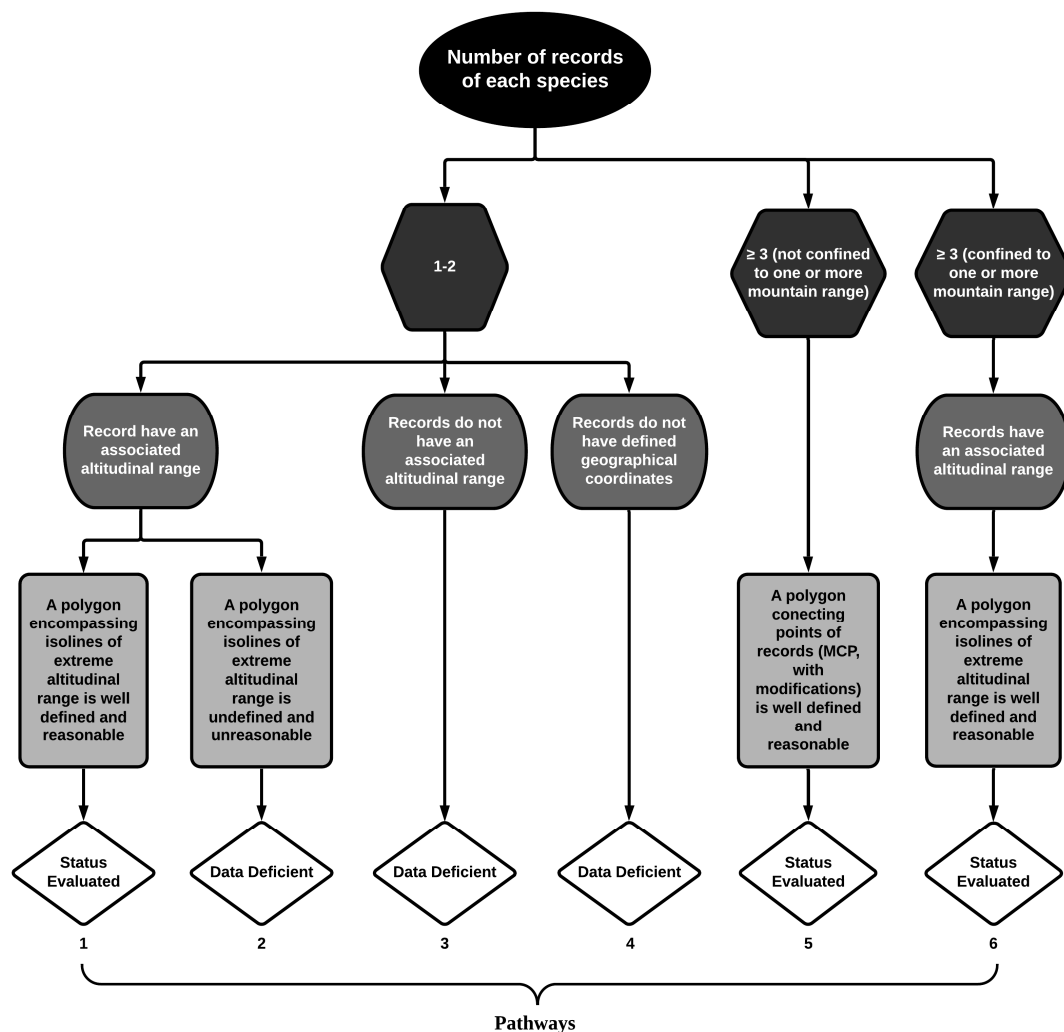


Figure 1. Flow chart indicating the approach to creating polygons of the extent of occurrence to compare the results with IUCN's species extinction risk classification criteria [48].

3. Results

A total of 185 locality records representing all 36 currently recognized *Brachycephalus* species in addition to 32 *Brachycephalus* sp. were generated (Table 1). An unidentified *Brachycephalus* species represented one between two described species that could not be adequately identified (i.e., old museum material collected before certain species were described) as well as new species awaiting formal description. Hereafter, only the described species are analyzed, leaving any evaluations to their own descriptors. The EO for 26 species (Table 1) was estimated, comprising several highly restricted EOs as well as larger ones: 23.8 ha for *B. fuscolineatus*, 37.4 ha for *B. coloratus*, 38.8 ha for *B. boticario*, 41.4 ha for *B. tridactylus*, 56.8 ha for *B. mirissimus* (all from the *B. pernix* group), 143,325.0 ha for *B. hermoigenesi*, 702,983.4 ha for *B. didactylus*, 3,021,786.1 ha for *B. sulfuratus* (*B. didactylus* group), and 1,792,535.1 ha for *B. ephippiumsi* (*B. ephippiumsi* group). The population sizes of eight species (Table 1) was also estimated. All were highly abundant with population sizes ranging from 78,344 individuals for *B. mirissimus* and 302,178,610 individuals for *B. sulfuratus*.

Table 1. Locality records of *Brachycephalus*.

Species	Group	Locality and State	Altitude ¹	Source
<i>B. didactylus</i>	<i>didactylus</i>	Monumento Natural Serra das Torres (21°00'04" S, 41°13'17" W), municipality of Atilio Vivácqua, Espírito Santo	600–900?	[51] as <i>B. didactylus</i> ; [52] as <i>B. didactylus</i>
<i>B. didactylus</i>	<i>didactylus</i>	Fazenda Santa Bárbara (22°25'17" S, 42°35'01" W), Parque Estadual dos Três Picos, municipality of Cachoeiras de Macacu, Rio de Janeiro	500–800	[53] as <i>B. didactylus</i> ; [54] as <i>B. didactylus</i>
<i>B. didactylus</i>	<i>didactylus</i>	Reserva Ecológica de Guapiaçu (22°24'00" S, 42°44'00" W), municipality of Cachoeiras de Macacu, Rio de Janeiro	300–520	[55] as <i>B. didactylus</i>]
<i>B. didactylus</i>	<i>didactylus</i>	Reserva Ecológica Rio das Pedras (22°59'00" S, 44°06'45" W), municipality of Mangaratiba, Rio de Janeiro	200–1110	[23] as <i>B. didactylus</i> ; [54] as <i>B. didactylus</i> ; [56] as <i>B. didactylus</i> ; [57] as <i>B. didactylus</i>
<i>B. didactylus</i>	<i>didactylus</i>	Sacra Família do Tinguá (22°29'11" S, 43°36'18" W), municipality of Engenheiro Paulo de Frontin, Rio de Janeiro	600	[17] as <i>B. didactylus</i> ; [27] as <i>B. didactylus</i> ; [58] as <i>B. didactylus</i> ; [59] as <i>B. didactylus</i> ; [60] as <i>B. didactylus</i> ; [61] as <i>B. didactylus</i> ; [62] as <i>B. didactylus</i> ; [63] as <i>B. didactylus</i> ; [64] as <i>B. didactylus</i> ; [65] as <i>B. didactylus</i> ; [66] as <i>B. didactylus</i>
<i>B. didactylus</i>	<i>didactylus</i>	Theodoro de Oliveira (first position: 22°22'11" S, 42°33'25" W), Parque Estadual dos Três Picos, municipality of Nova Friburgo, Rio de Janeiro	1100–1400?	[23] as <i>B. didactylus</i> ; [67] as <i>B. didactylus</i>
<i>B. didactylus</i>	<i>didactylus</i>	Tinguá (22°35'51" S, 43°24'54" W), municipality of Nova Iguaçu, Rio de Janeiro	35	[17] as <i>B. didactylus</i>
<i>B. didactylus</i>	<i>didactylus</i>	Vila Dois Rios (23°11'01" S, 44°12'23" W), Ilha Grande, municipality of Angra dos Reis, Rio de Janeiro	220–240	[23] as <i>B. didactylus</i> ; [68] as <i>B. didactylus</i> ; [69] as <i>B. didactylus</i> ; [70] as <i>B. didactylus</i>
<i>B. hermogenesi</i>	<i>didactylus</i>	Corcovado (23°28'20" S, 45°11'41" W), municipality of Ubatuba, São Paulo	30–250	This study, [18] as <i>B. hermogenesi</i> ; [23] as <i>B. hermogenesi</i> ; [25] as <i>B. hermogenesi</i> collected at Picinguaba; [27] as <i>B. hermogenesi</i> ; [63] as <i>B. hermogenesi</i>
<i>B. hermogenesi</i>	<i>didactylus</i>	Estação Biológica de Boracéia (23°39'10" S, 45°53'05" W), municipality of Salesópolis, São Paulo	825–900	[23] as <i>B. hermogenesi</i> ; [27] as <i>B. hermogenesi</i> ; [63] as <i>B. hermogenesi</i> ; [71] as <i>B. hermogenesi</i> ; [72] as <i>B. hermogenesi</i>
<i>B. hermogenesi</i>	<i>didactylus</i>	Fazenda Capricórnio (23°23'27" S, 45°04'26" W), municipality of Ubatuba, São Paulo	60	[18] as <i>B. hermogenesi</i> ; [23] as <i>B. hermogenesi</i> ; [27] as <i>B. hermogenesi</i> ; [63] as <i>B. hermogenesi</i> ; [72] as <i>B. hermogenesi</i>
<i>B. hermogenesi</i>	<i>didactylus</i>	Morro Cuscuzeiro (23°17'50" S, 44°47'21" W), on the border of municipalities of Paraty, Rio de Janeiro, and Ubatuba, São Paulo	730–1090	This study
<i>B. hermogenesi</i>	<i>didactylus</i>	Morro do Corcovado (23°27'06" S, 45°12'03" W), Parque Estadual da Serra do Mar, municipality of Ubatuba, São Paulo	250–1060	This study
<i>B. hermogenesi</i>	<i>didactylus</i>	Municipality of Paraibuna (c. 23°23'34" S, 45°39'42" W), São Paulo	?	[72] as <i>B. hermogenesi</i>
<i>B. hermogenesi</i>	<i>didactylus</i>	Núcleo Cunha (23°15'48" S, 45°02'39" W), Parque Estadual da Serra do Mar, municipality of Cunha, São Paulo	1045–1140	This study
<i>B. hermogenesi</i>	<i>didactylus</i>	Núcleo Picinguaba (23°22'21" S, 44°49'53" W), Parque Estadual da Serra do Mar, municipality of Ubatuba, São Paulo	0–700	[18] as <i>B. hermogenesi</i> ; [23] as <i>B. hermogenesi</i> ; [27] as <i>B. hermogenesi</i> ; [29] as <i>B. hermogenesi</i> ; [63] as <i>B. hermogenesi</i> ; [64] as <i>B. hermogenesi</i> ; [71] as <i>B. hermogenesi</i> ; [72] as <i>B. hermogenesi</i>

Table 1. Cont.

Species	Group	Locality and State	Altitude ¹	Source
<i>B. hermogenesi</i>	<i>didactylus</i>	Sertão da Cutia (not located), municipality of Ubatuba, São Paulo	?	[72] as <i>B. hermogenesi</i>
<i>B. hermogenesi</i>	<i>didactylus</i>	Trilha do Corisco (23°16'38" S, 44°46'39" W), municipality of Paraty, Rio de Janeiro	350–725	This study
<i>B. hermogenesi</i>	<i>didactylus</i>	Trilha do Ipiranga 50 m from the Rio Ipiranga (23°20'41" S, 45°08'21" W), Núcleo Santa Virgínia, Parque Estadual da Serra do Mar, municipality of São Luiz do Paraitinga, São Paulo	920–940	This study
<i>B. pulex</i>	<i>didactylus</i>	Serra Bonita (15°23'28" S, 39°33'59" W), municipality of Camacan, Bahia	800–930	[20] as <i>B. pulex</i>
<i>B. sulfuratus</i>	<i>didactylus</i>	Base of the Serra Água Limpa (24°28'52" S, 48°47'12" W), municipality of Apiaí, São Paulo	920	[23] as <i>Brachycephalus</i> sp. 1; [25] as <i>B. sulfuratus</i> ; [28] without species identification; [50] as <i>B. sulfuratus</i> ; [73] without species identification; [74] as <i>B. sulfuratus</i>
<i>B. sulfuratus</i>	<i>didactylus</i>	Biquinha (24°17'43" S, 47°36'26" W), municipality of Juquiá, São Paulo	40	This study
<i>B. sulfuratus</i>	<i>didactylus</i>	Braço do Norte (26°07'29" S, 48°43'48" W), municipality of Itapoá, Santa Catarina	240	[75] as <i>B. sulfuratus</i>
<i>B. sulfuratus</i>	<i>didactylus</i>	Caratuval, near the Parque Estadual das Lauráceas (24°51'17" S, 48°43'43" W), municipality of Adrianópolis, Paraná	900	[23] as <i>Brachycephalus</i> sp. 1; [25] as <i>B. sulfuratus</i> ; [27] as <i>Brachycephalus</i> sp. nov. 1; [28] without species identification; [50] as <i>B. sulfuratus</i> ; [73] without species identification; [74] as <i>B. sulfuratus</i>
<i>B. sulfuratus</i>	<i>didactylus</i>	Caratuval, Parque Estadual das Lauráceas (24°51'14" S, 48°42'01" W), municipality of Adrianópolis, Paraná	890	[23] as <i>Brachycephalus</i> sp. 1; [27] as <i>Brachycephalus</i> sp. nov. 1
<i>B. sulfuratus</i>	<i>didactylus</i>	Castelo dos Bugres (26°13'47" S, 49°03'20" W), municipality of Joinville, Paraná	790–860	[23] as <i>Brachycephalus</i> sp. 1; [27] as <i>Brachycephalus</i> sp. nov. 1; [72] as <i>B. sulfuratus</i> ; [75] as <i>B. sulfuratus</i>
<i>B. sulfuratus</i>	<i>didactylus</i>	Centro de Estudos e Pesquisas Ambientais da Univille (26°13'39" S, 48°41'31" W), Vila da Glória, Distrito do Saí, municipality of São Francisco do Sul, Santa Catarina	125	[72] as <i>B. sulfuratus</i>
<i>B. sulfuratus</i>	<i>didactylus</i>	Corvo (25°20'17" S, 48°54'56" W), municipality of Quatro Barras, Paraná	930	[23] as <i>Brachycephalus</i> sp. 1; [25] as <i>B. sulfuratus</i> ; [27] as <i>Brachycephalus</i> sp. nov. 1; [28] without species identification; [29] as <i>B. sulfuratus</i> ; [50] as <i>B. sulfuratus</i> ; [73] without species identification; [74] as <i>B. sulfuratus</i>
<i>B. sulfuratus</i>	<i>didactylus</i>	Estância Hidroclimática Recreio da Serra (25°27'14" S, 49°00'28" W), Serra da Baitaca, municipality of Piraquara, Paraná	1150–1205	This study
<i>B. sulfuratus</i>	<i>didactylus</i>	Fazenda Thalia (25°30'58" S, 49°40'12" W), municipality of Balsa Nova, Paraná	1025	[23] as <i>Brachycephalus</i> sp. 1; [25] as <i>B. sulfuratus</i> ; [27] as <i>Brachycephalus</i> sp. nov. 1; [28] without species identification; [50] as <i>B. sulfuratus</i> ; [73] without species identification; [74] as <i>B. sulfuratus</i>
<i>B. sulfuratus</i>	<i>didactylus</i>	near the Jurupará dam (23°56'30" S, 47°23'45" W), municipality of Piedade, São Paulo	690	[25] as <i>B. sulfuratus</i>

Table 1. Cont.

Species	Group	Locality and State	Altitude ¹	Source
<i>B. sulfuratus</i>	<i>didactylus</i>	Mananciais da Serra (25°29'32" S, 48°59'33" W), municipality of Piraquara, Paraná	970–1050	[23] as <i>Brachycephalus</i> sp. 1; [25] as <i>B. sulfuratus</i> ; [27] as <i>Brachycephalus</i> sp. nov. 1; [50] as <i>B. sulfuratus</i> ; [74] as <i>B. sulfuratus</i>
<i>B. sulfuratus</i>	<i>didactylus</i>	Morro Anhangava (25°22'51" S, 49°01'26" W), municipality of Quatro Barras, Paraná	915	[72] as <i>B. sulfuratus</i> ; [75] as <i>B. sulfuratus</i>
<i>B. sulfuratus</i>	<i>didactylus</i>	Morro do Cantagalo (26°10'31" S, 48°42'44" W), Vila da Glória, Distrito do Saí, municipality of São Francisco do Sul, Santa Catarina	160	[72] as <i>B. sulfuratus</i>
<i>B. sulfuratus</i>	<i>didactylus</i>	Morro do Garrafão (26°28'23" S, 49°15'57" W), municipality of Corupá, Santa Catarina	500–530	[25] as <i>B. sulfuratus</i> ; [76] as <i>B. sulfuratus</i>
<i>B. sulfuratus</i>	<i>didactylus</i>	Morro Garuva (26°02'29" S, 48°53'14" W), municipality of Garuva, Santa Catarina	215–495	This study
<i>B. sulfuratus</i>	<i>didactylus</i>	Núcleo Itutinga-Pilões (23°54'17" S, 46°29'22" W), Parque Estadual da Serra do Mar, municipality of Cubatão, São Paulo	55	This study
<i>B. sulfuratus</i>	<i>didactylus</i>	Parque Estadual da Ilha do Cardoso (25°06'53" S, 47°55'40" W), municipality of Cananéia, São Paulo	385	[63] as possibly <i>B. hermogenesi</i> ; [72] as <i>B. sulfuratus</i>
<i>B. sulfuratus</i>	<i>didactylus</i>	Parque Estadual Intervales (24°16'33" S, 48°25'04" W), municipality of Iporanga, São Paulo	820	This study
<i>B. sulfuratus</i>	<i>didactylus</i>	Recanto das Hortências (25°33'24" S, 48°59'38" W), municipality of São José dos Pinhais, Paraná	975	[23] as <i>Brachycephalus</i> sp. 1; [25] as <i>B. sulfuratus</i> ; [50] as <i>B. sulfuratus</i> ; [74] as <i>B. sulfuratus</i>
<i>B. sulfuratus</i>	<i>didactylus</i>	Reserva Particular do Patrimônio Natural Salto Morato (25°09'14" S, 48°18'06" W), municipality of Guaraqueçaba, Paraná	40–880	[23] as <i>Brachycephalus</i> sp. 1; [77] as <i>B. hermogenesi</i> ; [78] as <i>B. hermogenesi</i> ; [79] as <i>B. hermogenesi</i>
<i>B. sulfuratus</i>	<i>didactylus</i>	Salto do Inferno (25°00'02" S, 48°37'07" W), Rio Capivari, municipality of Bocaiúva do Sul, Paraná	610	[25] as <i>B. sulfuratus</i> ; [50] as <i>B. sulfuratus</i> ; [74] as <i>B. sulfuratus</i>
<i>B. sulfuratus</i>	<i>didactylus</i>	Serra do Guaraú (24°47'12" S, 48°07'11" W), on the border of the municipalities of Cajati and Jacupiranga, São Paulo	680–835	This study
<i>B. sulfuratus</i>	<i>didactylus</i>	Serra do Pico (26°08'31" S, 48°57'19" W), municipality of Joinville, Santa Catarina	340–720	This study
<i>B. sulfuratus</i>	<i>didactylus</i>	Torre Embratel (24°52'46" S, 48°15'27" W), municipality of Cajati, São Paulo	960–990	This study
<i>B. sulfuratus</i>	<i>didactylus</i>	Truticultura (26°01'33" S, 48°52'02" W), municipality of Garuva, Paraná	90	[23] as <i>Brachycephalus</i> sp. 1; [27] as <i>Brachycephalus</i> sp. nov. 1
<i>B. alipioi</i>	<i>ephippium</i>	Fazenda Aoki or Fazenda dos Japoneses (20°28'24" S, 41°00'36" W), boundary of the municipalities of Vargem Alta and Domingos Martins, Espírito Santo	1070–1100	[27] as <i>B. alipioi</i> ; [64] as <i>B. alipioi</i> ; [66] as <i>B. alipioi</i> ; [80] as <i>B. alipioi</i> ; [81] as <i>B. alipioi</i> ; [82] as <i>B. alipioi</i>
<i>B. alipioi</i>	<i>ephippium</i>	Forno Grande (20°31'41" S, 41°06'51" W), Parque Estadual de Forno Grande, municipality of Castelo, Espírito Santo	1430?	[27] as <i>B. alipioi</i>

Table 1. Cont.

Species	Group	Locality and State	Altitude ¹	Source
<i>B. alipioi</i>	<i>ephippium</i>	Alto Castelinho (20°30'34" S, 41°00'33" W), municipality of Vargem Alta, Espírito Santo	1100	This study, [25] as <i>B. alipioi</i>
<i>B. bufonoides</i>	<i>ephippium</i>	Serra de Macaé (22°18'02" S, 42°18'20" W), municipality of Nova Friburgo, Rio de Janeiro	1100?	[30] as <i>B. bufonoides</i> ; [66] as <i>B. bufonoides</i> ; [83] as <i>B. ephippiumsi bufonoides</i>
<i>B. crispus</i>	<i>ephippium</i>	Bacia B, Núcleo Cunha, Parque Estadual da Serra do Mar (23°15'15" S, 45°01'58" W), municipality of Cunha, São Paulo	800–1190	This study, [84] as <i>B. crispus</i>
<i>B. darkside</i>	<i>ephippium</i>	Mata do Pai Inácio (20°46'44" S, 42°29'10" W), Parque Estadual da Serra do Brigadeiro, municipality Miradouro, Minas Gerais	1340	[66] as <i>B. ephippiumsi</i> ; [85] as <i>B. ephippiumsi</i> ; [86] as <i>B. darkside</i>
<i>B. darkside</i>	<i>ephippium</i>	Trilha do Cruzeiro (20°52'41" S, 42°31'15" W), Parque Estadual da Serra do Brigadeiro, boundary of the municipalities of Ervália and Muriaé, Minas Gerais	1265–1500	[86] as <i>B. darkside</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Condomínio Ermida (23°14'13" S, 46°58'52" W), Serra do Japi, municipality of Jundiá, São Paulo	1225	[27] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Hotel Fazenda Pé da Serra (22°51'56" S, 45°31'40" W), municipality of Pindamonhangaba, São Paulo	700	[27] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Lago Azul (22°27'23" S, 44°36'34" W), Parque Nacional do Itatiaia, municipality of Itatiaia, Rio de Janeiro	750	[27] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Maromba (22°25'43" S, 44°37'11" W), Parque Nacional do Itatiaia, municipality of Itatiaia, Rio de Janeiro	1125	[27] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Monteiro Lobato (22°57'07" S, 45°50'20" W), municipality of Monteiro Lobato, São Paulo	700	[66] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Observatório de Capricórnio (22°53'54" S, 46°49'01" W), Serra das Cabras, Joaquim Egídio District, boundary of the municipalities of Campinas and Morungaba, São Paulo	1085	[19] as <i>B. ephippiumsi</i> ; [27] as <i>B. ephippiumsi</i> ; [66] as <i>B. ephippiumsi</i> ; [87] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Parque Municipal de Itapetinga (Grota Funda) (23°11'07" S, 46°31'47" W), municipality of Atibaia, São Paulo	900–1250	[27] as <i>B. ephippiumsi</i> ; [64] as <i>B. ephippiumsi</i> ; [81] as <i>B. ephippiumsi</i> ; [88] as <i>B. ephippiumsi</i> ; [89] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Reserva Biológica da Serra do Japi (23°17'07" S, 47°00'05" W), Serra do Japi, boundary of the municipalities of Jundiá and Cabreúva, São Paulo	1000	[27] as <i>B. ephippiumsi</i> ; [64] as <i>B. ephippiumsi</i> ; [66] as <i>B. ephippiumsi</i> ; [90] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Reserva Ecológica do Trabiju (22°48'01" S, 45°32'03" W), Trabiju, municipality of Pindamonhangaba, São Paulo	1000?	[66] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Reserva Pedra Branca (22°56'22" S, 45°41'04" W), municipality of Tremembé, São Paulo	890?	[66] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Santo Antônio do Pinhal (22°49'28" S, 45°40'20" W), municipality of Santo Antônio do Pinhal, São Paulo	1080	[66] as <i>B. ephippiumsi</i>

Table 1. Cont.

Species	Group	Locality and State	Altitude ¹	Source
<i>B. ephippiumsi</i>	<i>ephippium</i>	São Francisco Xavier (22°53'44" S, 45°58'04" W), municipality of São José dos Campos, São Paulo	1000	[27] as <i>B. ephippiumsi</i> ; [66] as <i>B. ephippiumsi</i> ; [91] as <i>B. ephippiumsi</i> ; [92] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Serra Negra (21°57'28" S, 43°47'20" W), municipality of Santa Bárbara do Monte Verde, Minas Gerais	?	[23] as <i>B. ephippiumsi</i> ; [65] as BMV MG2
<i>B. ephippiumsi</i>	<i>ephippium</i>	Serra da Concórdia (22°20'30" S, 43°44'04" W), Parque Estadual Serra da Concórdia, Barão de Juparanã, municipality of Valença, Rio de Janeiro	900?	[66] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Alto do Soberbo (22°27'15" S, 42°59'21" W), municipality of Teresópolis, Rio de Janeiro	1250	[66] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Comary (22°27'22" S, 42°58'24" W), municipality of Teresópolis, Rio de Janeiro	990	[66] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Floresta dos Macacos (22°58'15" S, 43°15'24" W), municipality of Rio de Janeiro, Rio de Janeiro	450?	[66] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Garrafão (22°28'04" S, 43°01'52" W), municipality of Guapimirim, Rio de Janeiro	1785?	[66] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Pedra Branca (22°55'55" S, 43°28'23" W), Serra da Pedra Branca, municipality of Rio de Janeiro, Rio de Janeiro	1000	[58] as <i>B. ephippiumsi</i> ; [66] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Represa do Rio Grande (22°55'58" S, 43°26'36" W), Parque Estadual da Pedra Branca, municipality of Rio de Janeiro, Rio de Janeiro	150?	[27] as <i>B. ephippiumsi</i> ; [66] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Reserva Ecológica Rio das Pedras (22°59'00" S, 44°06'45" W), municipality of Mangaratiba, Rio de Janeiro	200–1110	[56] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Riacho Beija-flor (22°27'04" S, 43°00'04" W), Parque Nacional da Serra dos Órgãos, municipality of Teresópolis, Rio de Janeiro	1195	[27] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Rocio District (22°28'23" S, 43°14'38" W), municipality of Petrópolis, Rio de Janeiro	950	[27] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Serra do Tinguá (22°35'31" S, 43°28'16" W), municipality of Nova Iguaçu, Rio de Janeiro	950?	[66] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Vale da Revolta (22°26'17" S, 42°56'19" W), municipality of Teresópolis, Rio de Janeiro	1035	[66] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Varginha (22°24'34" S, 42°52'11" W), municipality of Teresópolis, Rio de Janeiro	825?	[66] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Bonito (22°42'51" S, 44°34'39" W), Serra da Bocaina, municipality of São José do Barreiro, São Paulo	1660?	[66] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Estação Ecológica de Bananal (22°48'05" S, 44°22'12" W), Serra da Bocaina, municipality of Bananal, São Paulo	1200?	[93] as <i>B. ephippiumsi</i>

Table 1. Cont.

Species	Group	Locality and State	Altitude ¹	Source
<i>B. ephippiumsi</i>	<i>ephippium</i>	Lídice District (22°50'01" S, 44°11'32" W), municipality of Rio Claro, Rio de Janeiro	650?	[58] as <i>B. ephippiumsi</i> ; [66] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Pedra Branca (23°10'38" S, 44°47'19" W), Serra da Bocaina, municipality of Parati, Rio de Janeiro	630?	[58] as <i>B. ephippiumsi</i> ; [66] as <i>B. ephippiumsi</i>
<i>B. ephippiumsi</i>	<i>ephippium</i>	Reserva Florestal de Morro Grande (23°42'08" S, 46°58'22" W), municipality of Cotia, São Paulo	990?	[94] as <i>B. ephippiumsi</i>
<i>B. garbeanus</i>	<i>ephippium</i>	Alto Caledônia (22°20'10" S, 42°33'20" W), municipality of Nova Friburgo, Rio de Janeiro	1070?	[66] as <i>B. garbeanus</i>
<i>B. garbeanus</i>	<i>ephippium</i>	Baixo Caledônia (22°21'33" S, 42°34'12" W), municipality of Nova Friburgo, Rio de Janeiro	1600–1900	[66] as <i>B. garbeanus</i> ; [67] as <i>B. garbeanus</i> ; [95] as <i>B. garbeanus</i> ; [96] as <i>B. garbeanus</i>
<i>B. garbeanus</i>	<i>ephippium</i>	Macaé de Cima (22°21'37" S, 42°17'50" W), municipality of Nova Friburgo, Rio de Janeiro	1130	[27] as <i>B. garbeanus</i> ; [64] as <i>B. ephippiumsi</i> ; [66] as <i>B. garbeanus</i> ; [81] as <i>B. garbeanus</i> ; [91] as <i>B. ephippiumsi</i> ; [92] as <i>B. ephippiumsi</i>
<i>B. garbeanus</i>	<i>ephippium</i>	Morro São João (22°22'47" S, 42°30'34" W), municipality of Nova Friburgo, Rio de Janeiro	1550?	[66] as <i>B. garbeanus</i>
<i>B. garbeanus</i>	<i>ephippium</i>	Serra de Macaé (22°18'02" S, 42°18'20" W), municipality of Nova Friburgo, Rio de Janeiro	1100?	[30] as <i>B. garbeanus</i> ; [66] as <i>B. garbeanus</i> ; [83] as <i>B. ephippiumsi garbeanus</i>
<i>B. garbeanus</i>	<i>ephippium</i>	Serra Nevada (22°21'46" S, 42°32'48" W), municipality of Nova Friburgo, Rio de Janeiro	1190	[66] as <i>B. garbeanus</i>
<i>B. garbeanus</i>	<i>ephippium</i>	Theodoro de Oliveira (second position: 22°21'48" S, 42°33'13" W), Parque Estadual dos Três Picos, municipality of Nova Friburgo, Rio de Janeiro	1400	[66] as <i>B. garbeanus</i> ; [67] as <i>B. garbeanus</i> ; [95] as <i>B. garbeanus</i>
<i>B. guarani</i>	<i>ephippium</i>	Morro Prumirim (23°20'50" S, 45°01'37" W), municipality of Ubatuba, São Paulo	500–900	[82] as <i>B. guarani</i> ; [84] as <i>B. guarani</i> ; [88] as <i>Brachycephalus</i> sp.
<i>B. margaritatus</i>	<i>ephippium</i>	Castelo Country Club (22°32'21" S, 43°13'08" W), municipality of Petrópolis, Rio de Janeiro	980	[66] as <i>B. margaritatus</i>
<i>B. margaritatus</i>	<i>ephippium</i>	Castelo Montebello (22°24'24" S, 42°58'06" W), municipality of Teresópolis, Rio de Janeiro	920	[66] as <i>B. margaritatus</i>
<i>B. margaritatus</i>	<i>ephippium</i>	Independência (22°32'58" S, 43°12'27" W), municipality of Petrópolis, Rio de Janeiro	860	[66] as <i>B. margaritatus</i>
<i>B. margaritatus</i>	<i>ephippium</i>	Morro Azul (22°28'34" S, 43°34'40" W), municipality of Engenheiro Paulo de Frontin, Rio de Janeiro	620	[65] as BPF RJ2; [66] as <i>B. margaritatus</i>
<i>B. margaritatus</i>	<i>ephippium</i>	Quitandinha (22°31'47" S, 43°12'26" W), municipality of Petrópolis, Rio de Janeiro	925	[66] as <i>B. margaritatus</i>
<i>B. margaritatus</i>	<i>ephippium</i>	Sacra Família do Tinguá (22°29'11" S, 43°36'18" W), municipality of Engenheiro Paulo de Frontin, Rio de Janeiro	600	[17] as <i>B. ephippiumsi</i> ; [27] as <i>B. ephippiumsi</i> ; [58] as <i>Brachycephalus</i> cf. <i>ephippium</i> ; [66] as <i>B. margaritatus</i>

Table 1. Cont.

Species	Group	Locality and State	Altitude ¹	Source
<i>B. nodoterga</i>	<i>ephippium</i>	Estação Biológica de Boracéia (second position: 23°38'00"S, 45°52'00"W), municipality of Salesópolis, São Paulo	945	[27] as <i>B. nodoterga</i> ; [30] as <i>B. nodoterga</i> ; [58] as <i>B. nodoterga</i> ; [59] as <i>B. nodoterga</i> ; [60] as <i>B. nodoterga</i> ; [61] as <i>B. nodoterga</i> ; [66] as <i>B. nodoterga</i> ; [97] as <i>B. nodoterga</i> ; [98] as <i>B. nodoterga</i> ; [99] as <i>B. nodoterga</i>
<i>B. nodoterga</i>	<i>ephippium</i>	Fazenda Paiva Ramos (23°28'21" S, 46°47'25" W), municipality of Osasco, São Paulo	820	[99] as <i>B. nodoterga</i>
<i>B. nodoterga</i>	<i>ephippium</i>	Pico do Ramalho (23°51'42" S, 45°21'28" W), Ilha de São Sebastião, municipality of Ilhabela, São Paulo	700–900	[27] as <i>B. nodoterga</i> ; [66] as <i>B. nodoterga</i> ; [99] as <i>B. nodoterga</i> ; [100] as <i>Brachycephalus</i> sp. aff. <i>nodoterga</i>
<i>B. nodoterga</i>	<i>ephippium</i>	Santana de Parnaíba (23°26'19" S, 46°56'06" W), municipality of Santana de Parnaíba, São Paulo	730	[99] as <i>B. nodoterga</i>
<i>B. nodoterga</i>	<i>ephippium</i>	Serra da Cantareira (23°27'13" S, 46°38'11" W), Parque Estadual da Cantareira, municipality of São Paulo, São Paulo	850?	[30] as <i>B. nodoterga</i> ; [59] as <i>B. nodoterga</i> ; [60] as <i>B. nodoterga</i> ; [61] as <i>B. nodoterga</i> ; [64] as <i>B. nodoterga</i> ; [66] as <i>B. nodoterga</i> ; [81] as <i>B. nodoterga</i> ; [82] as <i>B. nodoterga</i> , [83] as <i>B. ephippiumsi nodoterga</i> ; [84] as <i>B. nodoterga</i> , [98] as <i>B. nodoterga</i> ; [99] as <i>B. nodoterga</i>
<i>B. pitanga</i>	<i>ephippium</i>	Fazenda Capricórnio (23°22'36" S, 45°04'07" W), municipality of Ubatuba, São Paulo	450?	[27] as <i>B. pitanga</i> ; [61] as <i>B. pitanga</i> ; [65] as <i>B. pitanga</i> ; [101] as <i>Brachycephalus</i> sp. 2
<i>B. pitanga</i>	<i>ephippium</i>	Núcleo Santa Virgínia (23°19'23" S, 45°05'19" W), Parque Estadual da Serra do Mar, municipality of São Luis do Paraitinga, São Paulo	980–1140	[102] as <i>B. pitanga</i> ; [103] as <i>B. pitanga</i>
<i>B. pitanga</i>	<i>ephippium</i>	SP 125—municipality of São Luís do Paraitinga (23°22'57" S, 45°09'59" W), São Paulo	935–950	[23] as <i>B. pitanga</i>
<i>B. pitanga</i>	<i>ephippium</i>	Trilha do Ipiranga 50 m from the Rio Ipiranga (23°20'39" S, 45°08'16" W), Núcleo Santa Virgínia, Parque Estadual da Serra do Mar, municipality of São Luis do Paraitinga, São Paulo	900–960	[27] as <i>B. pitanga</i> ; [61] as <i>B. pitanga</i> ; [64] as <i>B. pitanga</i> ; [81] as <i>B. pitanga</i> ; [102] as <i>B. pitanga</i> ; [104] as <i>B. pitanga</i>
<i>B. toby</i>	<i>ephippium</i>	Morro do Corcovado (23°27'22" S, 45°11'53" W), Parque Estadual da Serra do Mar, municipality of Ubatuba, São Paulo	750–1060	This study, [27] as <i>B. toby</i> ; [81] as <i>B. toby</i> ; [82] as <i>B. toby</i> ; [84] as <i>B. toby</i> ; [98] as <i>B. toby</i>
<i>B. vertebralis</i>	<i>ephippium</i>	Morro Cuscuzeiro (23°17'51" S, 44°47'20" W), on the border of municipalities of Paraty, Rio de Janeiro, and Ubatuba, São Paulo	760–1110	This study, [27] as <i>B. vertebralis</i> ; [81] as <i>B. vertebralis</i> ; [84] as <i>B. vertebralis</i>
<i>B. vertebralis</i>	<i>ephippium</i>	Pedra Branca (23°10'38" S, 44°47'19" W), Serra da Bocaina, municipality of Parati, Rio de Janeiro	630?	[27] as <i>B. vertebralis</i> ; [30] as <i>B. vertebralis</i> ; [58] as <i>B. vertebralis</i> ; [64] as <i>B. vertebralis</i>
<i>B. actaeus</i>	<i>pernix</i>	Braço do Norte (26°07'29" S, 48°43'48" W), municipality of Itapoá, Santa Catarina	240	[75] as <i>B. actaeus</i>
<i>B. actaeus</i>	<i>pernix</i>	Centro de Estudos e Pesquisas Ambientais da Univille (CEPA) (26°13'39" S; 48°41'31" W), Vila da Glória, Distrito do Saí, municipality of São Francisco do Sul, Santa Catarina	120	[75] as <i>B. actaeus</i>
<i>B. actaeus</i>	<i>pernix</i>	Estrada do Saí (26°12'06" S; 48°41'37" W), Distrito do Saí, municipality of São Francisco do Sul, Santa Catarina	100	[75] as <i>B. actaeus</i>

Table 1. Cont.

Species	Group	Locality and State	Altitude ¹	Source
<i>B. actaeus</i>	<i>pernix</i>	Fazenda Morro Grande (26°17'47" S; 48°37'10" W), Morro Grande, Ilha de São Francisco, municipality of São Francisco do Sul, Santa Catarina	60	[75] as <i>B. actaeus</i>
<i>B. actaeus</i>	<i>pernix</i>	Fazenda Palmito Juriti (26°08'09" S; 48°43'54" W), municipality of Itapoá, Santa Catarina	100–170	[75] as <i>B. actaeus</i>
<i>B. actaeus</i>	<i>pernix</i>	Serra da Palha (26°17'50" S; 48°40'28" W), Laranjeiras, Ilha de São Francisco, municipality of São Francisco do Sul, Santa Catarina	20–90	[75] as <i>B. actaeus</i>
<i>B. actaeus</i>	<i>pernix</i>	Serra da Tiririca (26°07'42" S, 48°44'32" W), municipality of Itapoá, Santa Catarina	170–530	This study
<i>B. albolineatus</i>	<i>pernix</i>	Morro Azul (26°45'52" S, 49°12'20" W), on the border between the municipalities of Pomerode and Rio dos Cedros, Santa Catarina	725–740	This study
<i>B. albolineatus</i>	<i>pernix</i>	Morro Boa Vista (26°30'58" S, 49°03'14" W), on the border between the municipalities of Jaraguá do Sul and Massaranduba, Santa Catarina	790–835	[74] as <i>B. albolineatus</i> ; [105] as <i>B. albolineatus</i>
<i>B. albolineatus</i>	<i>pernix</i>	Morro do Garrafão (26°30'58" S, 49°03'14" W), municipality of Corupá, Santa Catarina	500–530	[76] as <i>B. albolineatus</i>
<i>B. albolineatus</i>	<i>pernix</i>	Morro do Schmidt (26°39'55" S, 49°12'55" W), municipality of Pomerode, Santa Catarina	810–870	This study
<i>B. auroguttatus</i>	<i>pernix</i>	Pedra da Tartaruga (26°00'21" S, 48°55'25" W), municipality of Garuva, Santa Catarina	1070–1100	[23] as <i>B. auroguttatus</i> ; [26] as <i>B. auroguttatus</i> ; [28] as <i>B. auroguttatus</i> ; [29] as <i>B. auroguttatus</i> ; [73] without species identification
<i>B. boticario</i>	<i>pernix</i>	Morro do Cachorro (26°46'42" S, 49°01'57" W), boundary of the municipalities of Blumenau, Gaspar, and Luiz Alves, Santa Catarina	685–795	[23] as <i>B. boticario</i> ; [26] as <i>B. boticario</i> ; [28] as <i>B. boticario</i> ; [29] as <i>B. boticario</i> ; [73] without species identification
<i>B. brunneus</i>	<i>pernix</i>	Abrigo 1 (25°13'29" S, 48°51'17" W), municipality of Campina Grande do Sul, Paraná	1440–1640	This study, [28] as not identified; [29] as <i>B. brunneus</i>
<i>B. brunneus</i>	<i>pernix</i>	Camapuã (25°15'59" S, 48°50'16" W), Serra dos Órgãos, boundary of the municipalities of Campina Grande do Sul and Antonina, Paraná	1595	[27] as <i>B. brunneus</i> ; [28] as <i>B. brunneus</i> ; [29] as <i>B. brunneus</i> ; [73] without species identification; [106] as <i>B. brunneus</i>
<i>B. brunneus</i>	<i>pernix</i>	Caranguejeira (25°20'27" S, 48°54'31" W), Serra da Graciosa, municipality of Quatro Barras, Paraná	1095–1110	[23] as <i>B. brunneus</i> ; [73] without species identification
<i>B. brunneus</i>	<i>pernix</i>	Caratuva (25°14'33" S, 48°50'04" W), Serra dos Órgãos, municipality of Campina Grande do Sul, Paraná	1300–1770	[27] as <i>B. brunneus</i> ; [28] as <i>B. brunneus</i> ; [29] as <i>B. brunneus</i> , [59] as <i>B. brunneus</i> ; [64] as <i>B. brunneus</i> ; [65] as <i>B. brunneus</i> ; [66] as <i>B. brunneus</i> ; including Pico Paraná; [73] without species identification; including Pico Paraná; [81] as <i>B. brunneus</i> ; [106] as <i>B. brunneus</i> ; [107] as <i>B. brunneus</i>
<i>B. brunneus</i>	<i>pernix</i>	Getúlio (25°14'18" S, 48°50'13" W), Serra dos Órgãos, municipality of Campina Grande do Sul, Paraná	1310–1490	[23] as <i>B. brunneus</i> ; [27] as <i>B. brunneus</i>

Table 1. Cont.

Species	Group	Locality and State	Altitude ¹	Source
<i>B. brunneus</i>	<i>pernix</i>	Mãe Catira (25°20'51" S, 48°54'25" W), Serra da Graciosa, municipality of Quatro Barras, Paraná	1135–1405	This study, [27] as <i>Brachycephalus</i> sp. nov. 2; [28] as not identified; [73] without species identification
<i>B. coloratus</i>	<i>pernix</i>	Estância Hidroclimática Recreio da Serra (25°27'14" S, 49°00'27" W), Serra da Baitaca, municipality of Piraquara, Paraná	1145–1230	[50] as <i>B. coloratus</i>
<i>B. curupira</i>	<i>pernix</i>	Morro do Canal (25°30'55" S, 48°58'56" W), municipality of Piraquara, Paraná	1320	This study, [23] as <i>Brachycephalus</i> sp. 4; [28] as not identified; [73] without species identification
<i>B. curupira</i>	<i>pernix</i>	Morro do Vigia (25°30'33" S, 48°58'58" W), municipality of Piraquara, Paraná	1250	[23] as <i>Brachycephalus</i> sp. 4; [27] as <i>Brachycephalus</i> sp. nov. 3; [28] as not identified; [29] as <i>B. curupira</i> ; [73] without species identification
<i>B. curupira</i>	<i>pernix</i>	Serra do Salto (25°42'07" S, 49°03'44" W), Malhada District, municipality of São José dos Pinhais, Paraná	1095–1160	[23] as <i>Brachycephalus</i> sp. 6; [27] as <i>Brachycephalus</i> sp. 2; [28] as not identified; [29] as <i>B. curupira</i> ; [50] as <i>B. curupira</i> , [73] without species identification
<i>B. ferruginus</i>	<i>pernix</i>	Olimpo (25°27'03" S, 48°54'59" W), Serra do Marumbi, municipality of Morretes, Paraná	965–1470	[27] as <i>B. ferruginus</i> ; [28] as <i>B. ferruginus</i> ; [29] as <i>B. ferruginus</i> , [60] as <i>B. ferruginus</i> ; [64] as <i>B. ferruginus</i> ; [66] as <i>B. ferruginus</i> ; [73] without species identification; [81] as <i>B. ferruginus</i>
<i>B. fuscolineatus</i>	<i>pernix</i>	Morro Braço da Onça (26°44'58" S, 48°55'41" W), municipality of Luiz Alves, Santa Catarina	525–530	[24] as <i>B. fuscolineatus</i>
<i>B. fuscolineatus</i>	<i>pernix</i>	Morro do Baú (26°47'58" S, 48°55'47" W), municipality of Ilhota, Santa Catarina	640–790	[26] as <i>B. fuscolineatus</i> ; [27] as <i>Brachycephalus</i> sp. nov. 9; [28] as <i>B. fuscolineatus</i> ; [29] as <i>B. fuscolineatus</i> ; [73] without species identification
<i>B. izecksohni</i>	<i>pernix</i>	Torre da Prata, Serra da Prata (25°37'25" S, 48°41'31" W), boundary of the municipalities of Morretes, Paranaguá, and Guaratuba, Paraná	980–1340	[27] as <i>B. izecksohni</i> ; [28] as <i>B. izecksohni</i> ; [29] as <i>B. izecksohni</i> ; [59] as <i>B. izecksohni</i> ; [64] as <i>B. izecksohni</i> ; [66] as <i>B. izecksohni</i> ; [73] without species identification; [81] as <i>B. izecksohni</i>
<i>B. leopardus</i>	<i>pernix</i>	Morro dos Perdidos (25°53'22" S, 48°57'22" W), municipality of Guaratuba, Paraná	1340–1420	[26] as <i>B. leopardus</i> ; [27] as <i>Brachycephalus</i> sp. nov. 4; [28] as <i>B. leopardus</i> ; [73] without species identification
<i>B. leopardus</i>	<i>pernix</i>	Serra do Araçatuba (25°54'07" S, 48°59'47" W), municipality of Tijucas do Sul, Paraná	1640–1645	[26] as <i>B. leopardus</i> ; [27] as <i>Brachycephalus</i> sp. nov. 4; [28] as <i>B. leopardus</i> ; [73] without species identification
<i>B. mariaeterezae</i>	<i>pernix</i>	Reserva Particular do Patrimônio Natural Caetezal, top of the Serra Queimada (26°06'51" S, 49°03'45" W), municipality of Joinville, Santa Catarina	1265–1270	[26] as <i>B. mariaeterezae</i> ; [27] as <i>Brachycephalus</i> sp. nov. 6; [28] as <i>B. mariaeterezae</i> ; [29] as <i>B. mariaeterezae</i> ; [73] without species identification
<i>B. mirissimus</i>	<i>pernix</i>	Morro Santo Anjo (26°37'41" S, 48°55'50" W), municipality of Massaranduba, Santa Catarina	470–540	[25] as <i>B. mirissimus</i>
<i>B. olivaceus</i>	<i>pernix</i>	Base of the Serra Queimada (26°04'57" S, 49°03'59" W), municipality of Joinville, Santa Catarina	985	[17] as <i>Brachycephalus</i> sp. nov. 7; [26] as <i>B. olivaceus</i>
<i>B. olivaceus</i>	<i>pernix</i>	Castelo dos Bugres (second position: 26°13'59" S, 49°03'13" W), municipality of Joinville, Santa Catarina	800–835	[26] as <i>B. olivaceus</i> ; [27] as <i>Brachycephalus</i> sp. nov. 7; [28] as <i>B. olivaceus</i> ; [73] without species identification; [108] as <i>B. olivaceus</i>
<i>B. olivaceus</i>	<i>pernix</i>	Morro do Boi (26°24'42" S, 49°12'59" W), municipality of Corupá, Santa Catarina	650–920	[23] as <i>B. olivaceus</i> ; [27] as <i>Brachycephalus</i> sp. 3; [29] as <i>B. olivaceus</i>

Table 1. Cont.

Species	Group	Locality and State	Altitude ¹	Source
<i>B. olivaceus</i>	<i>pernix</i>	Pico Jurapê (26°16'27" S, 49°00'13" W), municipality of Joinville, Santa Catarina	650–780	This study
<i>B. pernix</i>	<i>pernix</i>	Anhangava (25°23'19" S, 49°00'15" W), Serra da Baitaca, municipality of Quatro Barras, Paraná	1135–1405	[27] as <i>B. pernix</i> ; [28] as <i>B. pernix</i> ; [29] as <i>B. pernix</i> ; [62] as <i>B. pernix</i> ; [64] as <i>B. pernix</i> ; [65] as <i>B. pernix</i> ; [66] as <i>B. pernix</i> ; [73] without species identification; [81] as <i>B. pernix</i> ; [97] as <i>B. pernix</i> ; [101] as <i>B. pernix</i> ; [109] as <i>B. pernix</i> ; [110] as <i>B. pernix</i> ; [111] as <i>B. pernix</i>
<i>B. pombali</i>	<i>pernix</i>	Morro dos Padres (25°36'40" S, 48°51'22" W), Serra da Igreja, municipality of Morretes, Paraná	1060–1300	[27] as <i>B. pombali</i> ; [28] as <i>B. pombali</i> ; [29] as <i>B. pombali</i> ; [60] as <i>B. pombali</i> ; [64] as <i>B. pombali</i> ; [73] without species identification; [81] as <i>B. pombali</i>
<i>B. pombali</i>	<i>pernix</i>	trail to Morro dos Padres (25°35'58" S, 48°51'57" W), municipality of Morretes, Paraná	845–1060	[27] as <i>B. pombali</i>
<i>B. quiririensis</i>	<i>pernix</i>	Serra do Quiriri (26°01'17" S, 48°59'47" W), municipality of Campo Alegre, Santa Catarina	1240–1270	[23] as <i>B. quiririensis</i> ; [27] as <i>Brachycephalus</i> sp. nov. 5; [28] as <i>B. quiririensis</i> ; [29] as <i>B. quiririensis</i> ; [73] without species identification; [112] as <i>B. quiririensis</i>
<i>B. quiririensis</i>	<i>pernix</i>	Serra do Quiriri (first position: 26°01'42" S, 48°57'11" W; second position: 26°01'32" S, 48°58'24" W), municipality of Garuva, Santa Catarina	1320–1380	[27] as <i>Brachycephalus</i> sp. nov. 5; [108] as <i>B. quiririensis</i>
<i>B. tridactylus</i>	<i>pernix</i>	Serra do Morato (25°08'09" S, 48°17'59" W), Reserva Natural Salto Morato, municipality of Guaraqueçaba, Paraná	805–910	[23] as <i>B. tridactylus</i> ; [28] as <i>B. tridactylus</i> ; [113] as <i>B. tridactylus</i> ; [114] as <i>B. tridactylus</i>
<i>B. verrucosus</i>	<i>pernix</i>	Morro da Tromba (26°12'44" S, 48°57'29" W), municipality of Joinville, Santa Catarina	455–945	[23] as <i>B. verrucosus</i> ; [26] as <i>B. verrucosus</i> ; [27] as <i>Brachycephalus</i> sp. nov. 8; [28] as <i>B. verrucosus</i> ; [29] as <i>B. verrucosus</i> ; [73] without species identification
<i>B. atelopoide</i>	?	Piquete, São Paulo	?	[30] as <i>B. atelopoide</i> ; [83] as <i>B. ephippiumsi atelopoide</i>
<i>Brachycephalus</i> sp. (cf. <i>B. sulfuratus</i>)	<i>didactylus</i>	Alto Quiriri (26°05'34" S, 48°59'41" W), municipality of Garuva, Santa Catarina	240	[23] as <i>Brachycephalus</i> sp. 1; [27] as <i>Brachycephalus</i> sp. nov. 1
<i>Brachycephalus</i> sp. (cf. <i>B. sulfuratus</i>)	<i>didactylus</i>	Colônia Castelhanos (25°47'58" S, 48°54'40" W), municipality of Guaratuba, Paraná	290	[23] as <i>Brachycephalus</i> sp. 1; [27] as <i>Brachycephalus</i> sp. nov. 1; [72] as <i>B. sulfuratus</i> ; [115] as <i>Brachycephalus</i> aff. <i>hermogenesi</i> ; [116] as <i>B. hermogenesi</i>
<i>Brachycephalus</i> sp. (cf. <i>B. sulfuratus</i>)	<i>didactylus</i>	Dona Francisca (26°09'52" S, 48°59'23" W), municipality of Joinville, Santa Catarina	150	[23] as <i>Brachycephalus</i> sp. 1; [27] as <i>Brachycephalus</i> sp. nov. 1
<i>Brachycephalus</i> sp. (<i>B. sulfuratus</i> or <i>B. hermogenesi</i>)	<i>didactylus</i>	Estação Ecológica Juréia-Itatins (c. 24°27' S, 47°24' W), municipality of Iguape, São Paulo	?	[63] as <i>B. hermogenesi</i>
<i>Brachycephalus</i> sp. (cf. <i>B. sulfuratus</i>)	<i>didactylus</i>	Estrada do Rio do Júlio (26°17'02" S, 49°06'08" W), municipality of Joinville, Santa Catarina	650	[23] as <i>Brachycephalus</i> sp. 1; [117] as <i>Brachycephalus</i> sp.
<i>Brachycephalus</i> sp. (cf. <i>B. sulfuratus</i>)	<i>didactylus</i>	Fazenda Pico Paraná (25°13'29" S, 48°51'17" W), municipality of Campina Grande do Sul, Paraná	1050–1085	[23] as <i>Brachycephalus</i> sp. 1; [27] as <i>Brachycephalus</i> sp. nov. 1

Table 1. Cont.

Species	Group	Locality and State	Altitude ¹	Source
<i>Brachycephalus</i> sp. (cf. <i>B. sulfuratus</i>)	<i>didactylus</i>	Fazenda Primavera (24°53'08" S, 48°45'51" W), municipality of Tunas do Paraná, Paraná	1060	[23] as <i>Brachycephalus</i> sp. 1; [27] as <i>Brachycephalus</i> sp. nov. 1
<i>Brachycephalus</i> sp. (<i>B. sulfuratus</i> or <i>B. hermogenesi</i>)	<i>didactylus</i>	Municipality of Ibiúna (c. 23°39' S, 47°13' W), São Paulo	?	[72] as <i>B. hermogenesi</i>
<i>Brachycephalus</i> sp. (<i>B. sulfuratus</i> or <i>B. hermogenesi</i>)	<i>didactylus</i>	Municipality of Jucituba (c. 23°56' S, 47°04' W), São Paulo	?	[63] as <i>B. hermogenesi</i> ; [72] as <i>B. hermogenesi</i>
<i>Brachycephalus</i> sp. (cf. <i>B. hermogenesi</i>)	<i>didactylus</i>	Municipality of Paraty (c. 23°13'07" S, 44°43'15" W), Rio de Janeiro	?	[18] as <i>B. hermogenesi</i>
<i>Brachycephalus</i> sp. (<i>B. sulfuratus</i> or <i>B. hermogenesi</i>)	<i>didactylus</i>	Municipality of Peruíbe (24°18' S, 46°59' W), São Paulo	?	[72] as <i>B. hermogenesi</i>
<i>Brachycephalus</i> sp. (<i>B. sulfuratus</i> or <i>B. hermogenesi</i>)	<i>didactylus</i>	Municipality of Piedade (c. 23°54' S, 47°25' W), São Paulo	?	[81] as <i>B. hermogenesi</i> ; [118] as <i>B. hermogenesi</i>
<i>Brachycephalus</i> sp. (<i>B. sulfuratus</i> or <i>B. hermogenesi</i>)	<i>didactylus</i>	Municipality of Registro (c. 24°30' S, 47°51' W), São Paulo	?	[72] as <i>B. hermogenesi</i>
<i>Brachycephalus</i> sp. (<i>B. sulfuratus</i> or <i>B. hermogenesi</i>)	<i>didactylus</i>	Municipality of Ribeirão Grande (c. 24°06' S, 48°22' W), São Paulo	?	[63] as <i>B. hermogenesi</i>
<i>Brachycephalus</i> sp. (<i>B. sulfuratus</i> or <i>B. hermogenesi</i>)	<i>didactylus</i>	Municipality of Tapiraí (c. 23°57'55" S, 47°30'19" W), São Paulo	870	[63] as <i>B. hermogenesi</i> ; [118] as <i>B. hermogenesi</i>
<i>Brachycephalus</i> sp. (<i>B. sulfuratus</i> or <i>B. hermogenesi</i>)	<i>didactylus</i>	Parque Estadual de Jacupiranga (c. 24°38' S, 48°24' W), municipality of Eldorado, São Paulo	?	[72] as <i>B. hermogenesi</i>
<i>Brachycephalus</i> sp. (<i>B. hermogenesi</i> or <i>B. sulfuratus</i>)	<i>didactylus</i>	Parque Natural Municipal Nascentes de Paranapiacaba (23°46'10" S, 46°17'36" W), municipality of Santo André, São Paulo	840	[119] as <i>B. hermogenesi</i>
<i>Brachycephalus</i> sp. (cf. <i>B. sulfuratus</i>)	<i>didactylus</i>	Pico Agudinho (25°36'24" S, 48°43'33" W), Serra da Prata, municipality of Morretes, Paraná	385	[23] as <i>Brachycephalus</i> sp. 1; [27] as <i>Brachycephalus</i> sp. nov. 1

Table 1. Cont.

Species	Group	Locality and State	Altitude ¹	Source
<i>Brachycephalus</i> sp. (<i>B. sulfuratus</i> or <i>B. hermogenesi</i>)	<i>didactylus</i>	Reserva Betary (24°33'08" S, 48°40'49" W), municipality of Iporanga, São Paulo	190	This study
<i>Brachycephalus</i> sp. (<i>B. hermogenesi</i> or <i>B. sulfuratus</i>)	<i>didactylus</i>	Reserva Biológica do Alto da Serra de Paranapiacaba (23°46'40" S, 46°18'45" W), municipality of Santo André, São Paulo	800–850	[23] as <i>B. hermogenesi</i> ; [63] as <i>B. hermogenesi</i> ; [119] as <i>B. hermogenesi</i>
<i>Brachycephalus</i> sp. (<i>B. sulfuratus</i> or <i>B. hermogenesi</i>)	<i>didactylus</i>	Reserva Florestal de Morro Grande (23°42'08" S, 46°58'22" W), municipality of Cotia, São Paulo	990?	[23] as <i>B. hermogenesi</i> ; [63] as <i>B. hermogenesi</i> ; [72] as <i>B. hermogenesi</i> ; [94] as <i>B. hermogenesi</i>
<i>Brachycephalus</i> sp. (cf. <i>B. sulfuratus</i>)	<i>didactylus</i>	Sítio Ananias (25°47'08" S, 48°43'03" W), municipality of Guaratuba, Paraná	25	[23] as <i>Brachycephalus</i> sp. 1; [27] as <i>Brachycephalus</i> sp. nov. 1
<i>Brachycephalus</i> sp.	<i>ephippium</i>	Paranapiacaba (23°46'30" S, 46°17'57" W), municipality of Santo André, São Paulo	825	[27] as <i>Brachycephalus</i> sp. 1; [66] as <i>B. ephippiumsi</i>
<i>Brachycephalus</i> sp.	<i>ephippium</i>	Parque Natural Municipal Nascentes de Paranapiacaba (23°46'10" S, 46°17'36" W), municipality of Santo André, São Paulo	800–1164?	[120] as <i>Brachycephalus</i> sp.
<i>Brachycephalus</i> sp.	<i>ephippium</i>	Península do Bororé (23°47'11" S, 46°38'45" W), Represa Billings, Grajaú District, municipality of São Paulo, São Paulo	780	[27] as <i>Brachycephalus nodoterga</i> ; [99] as another species than <i>B. nodoterga</i> of [27]
<i>Brachycephalus</i> sp.	<i>ephippium</i>	Reserva Biológica do Alto da Serra de Paranapiacaba (23°46'40" S, 46°18'45" W), municipality of Santo André, São Paulo	800	[27] as <i>Brachycephalus</i> sp. 1
<i>Brachycephalus</i> sp.	<i>ephippium</i>	Theodoro de Oliveira (first position: 22°22'11" S, 42°33'25" W), Parque Estadual dos Três Picos, municipality of Nova Friburgo, Rio de Janeiro	1100–1200	[67] as <i>Brachycephalus</i> sp.; [95] as <i>Brachycephalus</i> sp. nov.
<i>Brachycephalus</i> sp.	<i>pernix</i>	Pedra Branca do Araraquara (25°56'00" S, 48°52'50" W), Serra do Araraquara, municipality of Guaratuba, Paraná	1000	[23] as <i>Brachycephalus</i> sp. 5
<i>Brachycephalus</i> sp.	<i>pernix</i>	Pico Paraná (25°15'10" S, 48°48'32" W), Serra dos Órgãos, municipality of Antonina, Paraná	1880	This study
<i>Brachycephalus</i> sp.	<i>pernix</i>	Serra Canasvieiras (25°36'58" S, 48°46'59" W), boundary of the municipalities of Guaratuba and Morretes, Paraná	1080	[23] as <i>Brachycephalus</i> sp. 5; [25] as <i>B. sp. Canasvieiras</i> ; [28] as not identified; [73] without species identification
<i>Brachycephalus</i> sp.	<i>pernix</i>	Tupipiá (25°15'13" S, 48°48'20" W), Serra dos Órgãos, municipality of Antonina, Paraná	1560	This study, [27] as <i>B. brunneus</i> ; [28] as <i>B. brunneus</i> ; [29] as <i>B. sp. Tupipiá</i> , [73] without species identification
<i>Brachycephalus</i> sp. (cf. <i>B. darkside</i> juvenile)	?	Parque Estadual da Serra do Brigadeiro (cf. 20°43'16" S, 42°29'05" W), municipality of Araponga, Minas Gerais	1330?	[85] as <i>Brachycephalus</i> cf. <i>didactylus</i>

¹ Data with “?” were not available in literature.

The main threat to the species of *Brachycephalus* is deforestation, affecting not only their EO but also other aspects of their biology, such as population size and individual health. Indeed, deforestation affects 20 species. Other species are under threat due to their small EO. Forests within EOs were converted into agricultural areas (e.g., for coffee and palm plantations - *Archontophoenix alexandrae* H. Wendl. & Drude), tree monocultures (*Pinus* spp. and *Eucalyptus* spp.), urban areas and, more frequently, pastures. Some species also have part of their EO flooded by dams (e.g., *B. nodoterga*) or affected by landslides (e.g., *B. izecksohni*). Fire, edge effects, timber harvest, grazing, and the invasion of exotic plants are impacts that reduce the quality of EO. For instance, deforestation and loss of habitat quality are important threats to *B. mariaeterezae*, whose type locality suffers from fire, grazing, and timber harvests. Fire and grazing substantially affect the quality of forests, even the cloud forests of *B. quiririensis*. The estimated population sizes were above those used in the IUCN criteria and therefore were not useful to rank the studied species regarding their conservation status.

The conservation status of all described species (Figure 2, Table 2) were determined. Twenty-one species (58.3% of all species) were classified as at risk of extinction: six as CR (28.6%), five as Endangered (EN; 23.8%), and 10 as Vulnerable (VU; 47.6%). Five species (13.9% of all species) were classified as non-threatened (= LC) and the remaining ten species (27.8%) as DD. The reduced EO (criteria B1) contributes to the ranking status of the conservation of 16 species associated with the number of locations (criteria B1a; 16 species), threats that reduce the area of EO (criteria B1b(i); 16 species), and quality of the area of EO (B1b(iii); 16 species; Table 2). B2 criteria were adopted for eight species (Table 2). For the B2 criteria, the number of locations (criteria B2a; eight species) and the threats that reduced the AO area (criteria B2b(ii); eight species) and quality (criteria B2b(iii); eight species) were also considered. Only one additional criterion (D2) for five species with less than 2000 ha of AO was used, and no threat could be assessed for this AO.

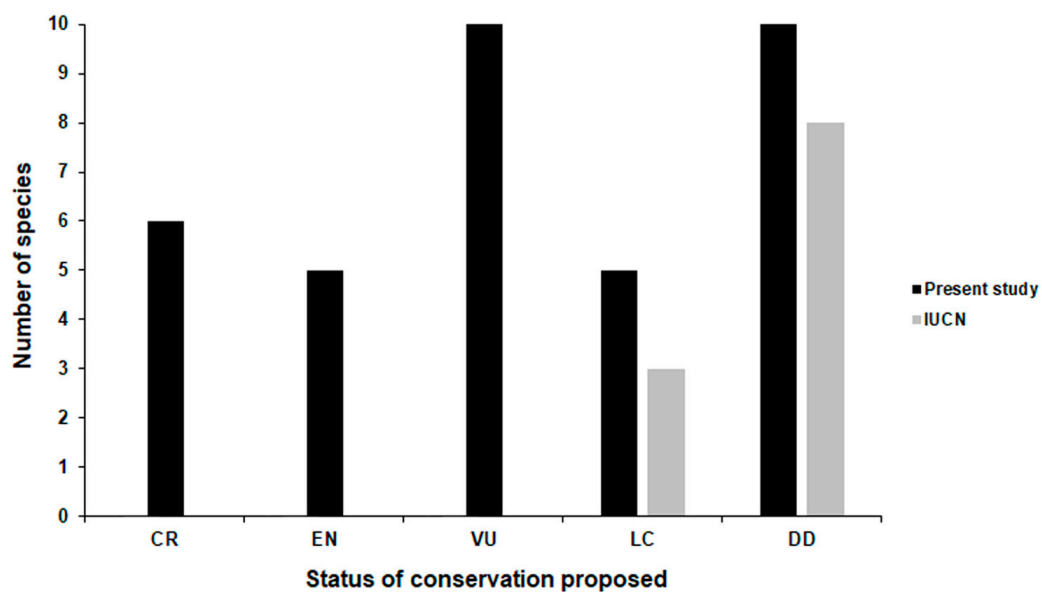


Figure 2. Status of conservation for the 36 species of *Brachycephalus* proposed in this study according to the IUCN [48] criteria and categories proposed by IUCN [31–41]. Abbreviation: CR = Critically Endangered; EN = Endangered; VU = Vulnerable; LC = Least Concern; DD = Data Deficient.

Table 2. Status of conservation of identified species of *Brachycephalus* according to IUCN [48]. Abbreviations: EO = extent of occurrence (see text for details); MMA = Ministério do Meio Ambiente (Brazil).

Species ¹	Localities ¹	Altitudinal Range (m a.s.l.) ^{1,2}	Evaluation of EO (ha)		Flow Chart Pathway ³	Population		Conservation Status—Criteria			
			Previous ²	This Study ²		Locations ²	Individuals ^{2,3}	IUCN	MMA	Others	This Study
<i>B. didactylus</i> group											
<i>B. didactylus</i>	8	35–1110	—	702,983.4	5	4	79,655,049	LC [41]	—	—	VU - B1ab(i,iii)
<i>B. hermogenesi</i>	11	0–1090	567,589.9 [23]	143,325.0	5	1	?	LC [33]	—	—	VU - B1ab(i,iii)
<i>B. pulex</i>	1	800–930	488.2 [23]	482.3	1	1	?	—	—	—	VU - D2
<i>B. sulfuratus</i>	26	40–1205	778,458.4 [23]	3,021,786.1	5	1	302,178,610	—	—	—	LC
<i>B. ephippiumsi</i> group											
<i>B. alipioi</i>	3	1070–1100	38,950.0 [47], 27,930.0 [43]	1,706.1	3	1	?	DD [35]	NT [43]	—	CR - B1ab(i,iii)
<i>B. bufonoides</i>	1	?	—	?	4	?	?	—	—	—	DD
<i>B. crispus</i>	1	800–1190	?	?	2	1	?	—	—	—	DD
<i>B. darkside</i>	2	1265–1500	—	5,700.8	1	1	?	—	—	—	CR - B1ab(i,iii)
<i>B. ephippiumsi</i>	31	200–1250	?	1,792,535.1	5	6	13,336,461	LC [38]	—	—	VU - B1ab(i,iii)
<i>B. garbeanus</i>	7	1130–1900	12,268.0 [23]	6,426.5	5	2	?	—	—	—	EN - B1ab(i,iii)+2ab(ii,iii)
<i>B. guarani</i>	1	500–900	?	?	2	1	?	—	—	—	DD
<i>B. margaritatus</i>	6	600–980	18,272.9 [23]	10,710.5	5	2	?	—	—	—	EN - B1ab(i,iii)
<i>B. nodoterga</i>	5	700–900	9,690.0 [47], 108,280.0 [42]	28,458.1	5	3	?	DD [31]	DD [42]	—	VU - B1ab(i,iii)
<i>B. pitanga</i>	4	900–1140	2,377.1 [23]	2,245.1	5	1	29,157,136	—	—	—	LC
<i>B. toby</i>	1	750–1060	?	?	2	1	?	—	—	—	DD
<i>B. vertebralis</i>	2	760–1110	161,990.0 [47], 18,580.0 [44]	?	2	2	?	DD [37]	DD [44]	—	DD
<i>B. pernix</i> group											
<i>B. actaeus</i>	7	20–530	—	15,841.6	6	2	?	—	—	—	EN - B1ab(i,iii)+2ab(ii,iii)
<i>B. albolineatus</i>	4	500–835	34.4 [74]	2,784.4	5	12	1,076,087	—	—	DD [74]	VU - B1ab(i,iii)
<i>B. auroguttatus</i>	1	1070–1100	—	?	3	1	?	—	—	—	DD
<i>B. boticario</i>	1	685–795	11.1 [23]	38.8	1	1	?	—	—	—	CR - B1ab(i,iii)+2ab(ii,iii)
<i>B. brunneus</i>	6	1095–1770	1,100.0 [47], 5,687.1 [23]	5,385.6	6	2	?	DD [39]	—	—	LC
<i>B. coloratus</i>	1	1145–1230	—	37.4	1	1	?	—	—	DD [50]	VU - D2
<i>B. curupira</i>	3	1095–1320	2,211.54 [23]	4,751.4	6	2	21,117,312	—	—	DD [50]	LC
<i>B. ferruginus</i>	1	965–1,470	38,950.0 [47], 5,475.5 [23]	5,994.3	1	1	?	DD [34]	—	—	LC
<i>B. fuscolineatus</i>	2	525–790	23.63 [23], 23.8 [24]	23.8	1	2	119,000	—	—	—	CR - B1ab(i,iii)+2ab(ii,iii)
<i>B. izecksohni</i>	1	980–1340	1,100.0 [47], 350.4 [23]	378.3	1	1	?	DD [40]	—	—	VU - D2
<i>B. leopardus</i>	2	1340–1645	176.7 [23]	363.1	1	3	?	—	—	—	EN - B1ab(i,iii)+2ab(ii,iii)

Table 2. Cont.

Species ¹	Localities ¹	Altitudinal Range (m a.s.l.) ^{1,2}	Evaluation of EO (ha)		Flow Chart Pathway ³	Population		Conservation Status—Criteria			
			Previous ²	This Study ²		Locations ²	Individuals ^{2,3}	IUCN	MMA	Others	This Study
<i>B. mariaeterezae</i>	1	1265–1270	—	?	3	1	?	—	—	—	DD
<i>B. mirissimus</i>	1	470–540	56.8 [25]	56.8	1	1	78,344	—	—	CR [25]	CR - B1ab(i,iii)+2ab(ii,iii)
<i>B. olivaceus</i>	4	650–985	12,531.6 [23]	18,850.1	5	2	?	—	—	—	EN - B1ab(i,iii)+2ab(ii,iii)
<i>B. pernix</i>	1	1135–1405	1,950.0 [47], 432.1 [23], 400 [45]	389.4	1	1	?	DD [32]	CR - B1ab(iii)+2ab(iii)	—	VU - D2
<i>B. pombali</i>	2	845–1300	31,300.0 [47]	?	2	1	?	DD [36]	—	—	DD
<i>B. quiririensis</i>	2	1240–1380	1339.0 [23]	629.0	1	1	?	—	—	—	CR - B1ab(i,iii)+2ab(ii,iii)
<i>B. tridactylus</i>	1	805–910	41.4 [23]	41.4	1	1	?	—	—	—	VU - D2
<i>B. verrucosus</i>	1	455–945	—	?	2	1	?	—	—	—	DD
<i>Incertae sedis</i>											
<i>B. atelopoide</i>	1	?	—	?	4	?	?	—	—	—	DD

¹ According Table 1. ² Data with “?” could not be estimate because of lack of information in literature. ³ According Figure 1.

4. Discussion

Based on the assessments, the number of endangered species of *Brachycephalus* should increase from one to 21 (Table 2). This is a significant shift and poses the question regarding why only one species had been formally recognized as threatened until now (Table 2). There are two possible reasons: (1) a delay due to the fact that many species have only been recently described and (2) a resistance based on current policies of the MMA to change a species conservation status in a short period of time (see below). Twenty-two species have been described in the last 10 years, 14 of which are only known from their type locality, and there is a natural tendency to expect them to be more widely distributed; however, studies in recent years have been gradually revealing new species rather than new records of known species, and new records of already described species have not substantially altered their geographical distributions (e.g., [24,29,76,99]). For example, a new locality record for *B. fuscolineatus* published after its description increased its EO by just 0.19 ha [24], and this species still has the smallest estimated EO for any *Brachycephalus* species (Table 2). Two new records of *B. curupira* (Table 1, [29]) double its EO, which remains small (= 4751.4 ha; Table 2). A new record of *B. albolineatus* published after its description [76] and two new localities included in Table 1 substantially extend its EO, but as in the case of *B. curupira*, this remains small (= 2784.4 ha; Table 2). A new record for *B. nodoterga* [99] did not change the EO of the species because it is located within its EO polygon. *Brachycephalus* was not found in 13 localities from southern São Paulo to northeastern Santa Catarina with an altitude comparable to other localities where *Brachycephalus* populations were present. Overall, the reduced geographical distributions of *Brachycephalus* is the rule for the montane species of the genus, i.e., the *B. ephippiumsi* and *B. pernix* groups [23]. *Brachycephalus ephippium* is the only exception of a montane species group with a large EO, but it is expected that some, if not all, populations may be identified as distinct species in future studies [23].

With respect to the resistance to incorporate drastic changes into the official number of endangered *Brachycephalus* species, this proposal is warranted despite the current policy of the MMA indicated. The MMA joined several international agreements that set targets for the conservation of the country's threatened biodiversity, and these efforts have been implemented in the successful execution of National Action Plans for the Conservation of Brazilian Endangered Species (Planos de Ação Nacional - PANs). The national scientific community and the MMA have been working together to list threats and conservation actions to all threatened species of the country and to review and to monitor these actions annually. This is possibly the reason that the MMA tended to prefer moving forward with conservation strategies of species that are already listed as threatened rather than revising the list. The effort to prioritize conservation initiatives prior to substantial updates to the list of endangered species is recognized, but the need for MMA to revise the list and to recognize the species listed in this article as threatened is also acknowledged given that they are not yet legally protected.

The most prevalent threat to *Brachycephalus* is deforestation, much of which is no longer done with heavy machinery and chainsaws. Recently, deforestation in the Atlantic Rainforest has become more subtle and involves the selective removal of trees and shrubs, particularly through inconspicuous strategies, such as bark girdling, which leads to the opening of the canopy and an increased tendency for wind to knock down additional trees. These actions are deliberately conducted a few meters into the forest edge to avoid detection by environmental inspectors. This type of deforestation has been carried out at an alarming rate in Paraná and in the northeast of Santa Catarina for at least 25 years to cultivate bananas, and more recently, to cultivate palm trees (*Archontophoenix alexandrae*). Deforestation for agricultural activities could also result in soil contamination, affecting species that depend on specific microhabitats and that have permeable skin [121]. Finally, deforestation could exacerbate edge effects, altering microhabitats and microclimatic conditions, which changes sunlight exposure, soil moisture, and plant species composition in the edges [15]. Indeed, *B. fuscolineatus* was not encountered in forest edges but only in more nuclear vegetation [24].

Deforestation in lowlands can lead to a decrease in the altitudinal distribution of cloud forests [122], potentially shifting the distributions of montane species of *Brachycephalus* to higher altitudes. This

possibility of altitudinal species displacement could also be driven by climate change [23]. In tropical forests, temperatures can vary from 0.4 °C to 0.7 °C per 100 m altitude variation [123]. The thermal variation in the altitudinal gradient in a site with the occurrence of *Brachycephalus* (*B. pernix*) was determined as 0.56 °C of the reduction every 100 m of altitude [124]. A difference in the precipitation levels at this site was also evaluated, with an increase of 40 mm in mean annual precipitation every 100 m at elevation [124]. Studies on litter anurans of the Atlantic Rainforest, including *Brachycephalus*, have shown that population densities are particularly affected by air humidity, air temperature, and altitude [52,55,78,90]. This climatic dependence and its relationship with the altitude gradient raises concerns for the long-term conservation of *Brachycephalus* species that occur in mountains with a restricted altitudinal amplitude.

Lowering the category of threat for *B. pernix* from CR [45] to VU (Table 2) is proposed. The effects of trampling and timber harvests by tourists in the type locality of the species are likely to be minor, which is entirely distributed within a protected area (Parque Estadual Serra da Baitaca; Table S1). There is a threat of fire in part of the EO of the species, but the vegetation cover is regenerating well in this area after many years of management by volunteer mountaineers, reducing fire susceptibility.

It is recognized that there is some level of subjectivity to apply EO and the number of locations of threatened species. This is because each parameter shows some overlap between EN and VU categories. *Brachycephalus hermogenesi* and *B. nodoterga* fit the EN category, but both are recommended to be considered for the VU category because part of their EO is in protected areas (Table S1).

The presence of threatened *Brachycephalus* in protected areas is a useful tool to rank the species for which conservation actions are more urgent. In Table S1, 10 species without records in protected areas are recognized with three classified as CR (*B. boticario*, *B. mirissimus*, and *B. quiririensis*), two as EN (*B. actaeus* and *B. leopardus*), one as VU (*B. albolineatus*), and four as DD (*B. atelopoide*, *B. auroguttatus*, *B. bufonoides*, *B. leopardus*, and *B. verrucosus*). There are no known living populations of two species (*B. atelopoide* and *B. bufonoides*). The remaining eight species belonging to the *B. pernix* group occur in southern Paraná (*B. leopardus*) and Santa Catarina (*B. actaeus*, *B. albolineatus*, *B. auroguttatus*, *B. boticario*, *B. mirissimus*, *B. quiririensis*, and *B. verrucosus*). Also, it is argued that DD species need special attention to direct further studies to complete adequate assessments of their conservation status as soon as possible.

Santa Catarina stands out as the state in which emergency conservation actions should converge. Creating protected areas is an important way to protect species, however, the conservation of the top three priority species would require the creation of three new protected areas. A protected area for the CR *B. quiririensis* could already house other species of *Brachycephalus* that are not in any reserve, namely *B. leopardus* (EN) and *B. auroguttatus* (DD). Nonetheless, to be effective, a protected area would first require the expropriation of the land in addition to management actions aimed at recovering forest quality. Given that there are dozens of protected areas waiting for expropriation, this path to conservation does not seem likely at the moment. Private protected areas are an alternative (e.g., Reserva Particular do Patrimônio Natural—RPPN), and some of them already protect two species of *Brachycephalus* (*B. mariaeterezae* and *B. tridactylus*; Table 1 and Table S1). This is the most stable category of protected areas in Brazil and cannot be undone; however, one aspect that does not stimulate the creation of more private protected areas is the lack of government incentives to private owners, except for exemption from territorial taxes. There is an impediment to transferring public financial resources to private persons, even if they are addressing conservation measures.

The conservation of *Brachycephalus* should also include alternatives to the creation of protected areas. One approach would be to lease land with the occurrence of threatened *Brachycephalus* at a percentage of the regional value of production per hectare of mountainous lands, which would be an incentive for landowners to leave their land intact. This must be governed by a renewable contract. For this strategy to be put into practice, it is vital to attract international resources. It would also be interesting to attract additional resources of the lease value to promote environmental recovery. The management of invasive alien species, both plants and animals, is unfortunately incipient in Brazil due

to the high involved costs, thus discouraging the proposition of new management projects. The state of Santa Catarina has emphasized its concern with the conservation of microendemic anurans in its region, creating a specific program for this purpose (Portaria Instituto Estadual do Meio Ambiente - IMA N° 283/2018 - 19/12/2018). This is an interesting effort that can put actions discussed into practice and can also result in other effective and innovative actions for the conservation of *Brachycephalus* in Santa Catarina. In the long term, successful practices can be replicated in other regions of Brazil.

5. Conclusions

Advances in knowledge regarding the geographical distribution of the *Brachycephalus* species have confirmed that they are in fact restricted, and this restriction is the reason for classifying 58% of the species of the genus as threatened according to IUCN criteria. Restricted geographical distributions should be considered an attribute of the species of the *Brachycephalus* montane groups. This coincides with the tendency of species with small ranges to be geographically concentrated and disproportionately under the threat of extinction [125] as well as with the tendency of newly described species to be more threatened than those described earlier [3]. With an increased understanding of the nature of most *Brachycephalus* species as microendemic species, international (IUCN) and national (MMA) agencies might be more likely to update their conservation status based on this proposal. Furthermore, Brazil has the highest amphibian richness in the world and the highest description of new species in recent years, but it is one of the countries with the lowest update rates of conservation status [3].

Deforestation and loss of habitat quality impact almost all species of *Brachycephalus* (22 species). Species of the genus are locally highly abundant, but they respond in density and geographical distribution to temperature and humidity [23,24,27], which vary along the altitudinal gradient [122,124]. Climate change can influence climatic conditions along the altitudinal gradient, confining the distribution of species even further to higher altitudes in the future.

The common action to protect endangered species in Brazil is to create protected areas. The creation of a new protected area in southern Paraná (Serra do Araçatuba) and adjacent to Santa Catarina (Serra do Quiriri) is proposed, but only because it would protect three species (*B. quiririensis*—CR, *B. leopardus*—EN, and *B. auroguttatus*—DD). In the marshes and grasslands associated with the forest of occurrence of these three *Brachycephalus* species is another endangered frog, *Melanophryniscus biancae*, which is a candidate for EN [126,127]. One reserve including the distribution of these four species would have about 11,000 ha—6,000 ha of forests, and 5,000 ha of grasslands [126]—and would also protect the springs of important rivers, such as the Negro, Cubatão, and Pirabeiraba. The creation of several other protected areas to safeguard the remaining threatened species without occurrence in reserves is impractical in the current Brazilian economic scenario. A program to lease strategic private land for owners to keep them intact with the support of international resources is a possibility for the conservation of the species in the short and medium term.

Supplementary Materials: The following are available online at <http://www.mdpi.com/1424-2818/11/9/150/s1>, Table S1: Records and distribution of the extent of occurrence (EO) of the species of *Brachycephalus* in relation to protected areas (PA).

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