

Geographic range and conservation of the Cipo Canastero *Asthenes luizae*, an endemic furnariid of Brazilian sky islands

GUILHERME H. S. FREITAS , LÍLIAN M. COSTA, ANDERSON V. CHAVES, MARCELO F. VASCONCELOS, LEONARDO C. RIBEIRO, JULIANO C. SILVA, RONEY A. SOUZA, FABRÍCIO R. SANTOS and MARCOS RODRIGUES

Summary

Cipo Canastero *Asthenes luizae* is a relict ovenbird restricted to rocky outcrops at high elevations within the *campo rupestre* vegetation of the Espinhaço Range in the state of Minas Gerais, south-eastern Brazil. This poorly known species is considered 'Near Threatened', but recent studies have suggested that it should be listed under a higher category of threat. To contribute to the knowledge of this species and its conservation assessment and related planning, we compiled all literature records of the species distribution ($n = 16$ locations), collected new data on its occurrence ($n = 72$ locations), and calculated its geographic range using four different approaches. First, we defined the sky islands where the species occurs (nine units) using the lowest elevation value recorded (1,100 m asl) as a cut-off. Second, we performed species distribution modelling (SDM) across the sky islands and identified an area of 2,225.21 km². Third, we measured the species' extent of occurrence (EOO = 24,555.85 km²) and used SDM to estimate its upper limit (EOO_{up} = 30,697.58 km²). Fourth, we measured the area of occupancy (AOO = 228 km²) and used SDM to estimate its upper limit (AOO_{up} = 1,827.39 km²). We analysed the Cipo Canastero sky islands in terms of landscape metrics including size, isolation, protected area coverage, shape index, core area index, and proportion covered by SDM. We observed a very fragmented distribution, especially in the North sector of the species distribution, composed of small and isolated populations (separated by up to 112 km); the South sector is the core of its distribution and is composed of larger, more connected patches with differences in shape complexity that are not strongly influenced by an edge effect. The range sizes calculated, along with other reported information regarding population and habitat trends, justifies the inclusion of the species in at least the 'Vulnerable' category.

Introduction

Sky-island species are those with a range limited to high-elevation habitats that are geographically subdivided and isolated by valleys between different mountain ranges (McCormack *et al.* 2009). Due to this particularity, they are of great importance for the investigation of hypotheses about a variety of research topics (Antonelli *et al.* 2018), including biogeography (e.g. Chaves *et al.* 2015), climatic refuges (e.g. Fjeldså *et al.* 2012), diversification hypotheses (e.g. Salerno *et al.* 2012), climatic changes (e.g. Bitencourt *et al.* 2016), and conservation (e.g. Laurance *et al.* 2011). Determining the distribution of any sky-island species is a basic step towards the study of highland biota and is of paramount importance for the assessment of the conservation status of these species.

The highlands of South America are marked by high bird richness and endemism (Fjeldså *et al.* 2012). Until recently, very little was known about the highland birds of eastern Brazil (Vasconcelos and Pacheco 2012), but fortunately, many studies have been performed in recent decades, with new species being described (Gonzaga *et al.* 2007, Whitney *et al.* 2010, Freitas *et al.* 2012) and improved knowledge of species' distributions (Vasconcelos 2008, Souza *et al.* 2010, Vasconcelos and Rodrigues 2010, Vasconcelos *et al.* 2012, Lopes *et al.* 2016). The largest mountain complex in Brazil is the Espinhaço Range, which is mostly characterised by quartzite soils above an elevation of 900 m, with a mosaic of vegetation known as *campos rupestres* (rocky grasslands) – composed mostly of grasslands and rocky outcrops but also containing woodland patches (Silveira *et al.* 2016). The *campos rupestres* are among the most biologically diverse ecosystems in the world, with high levels of endemism in plants (Echternacht *et al.* 2011), anurans (Hanna *et al.* 2012), squamates (Nogueira *et al.* 2011), and birds (Vasconcelos 2008), including many narrow endemic and threatened species (Silveira *et al.* 2016).

In the sky-island archipelagos formed by the mountain tops of eastern Brazil, there are nine endemic birds, including four ovenbirds (Furnariidae), two species of the *Cinclodes* genus and two of the *Asthenes* genus, all with a unique distribution, ecology, and evolutionary history (Chaves *et al.* 2015). The poorly known Cipo Canastero *Asthenes luizae* is strongly associated with rocky outcrops in higher elevations of the Espinhaço Range, to which it is endemic (Vasconcelos *et al.* 2008, Gomes and Rodrigues 2010, Costa 2015, Costa *et al.* 2019, Freitas *et al.* 2019b). Cipo Canastero was only described in 1990 based on one population discovered in Serra do Cipó, central Minas Gerais, south-eastern Brazil (Pearman 1990, Vielliard 1990). The species is currently known from approximately one dozen localities distributed from the type locality to Monte Azul, in the northern part of Minas Gerais (Andrade *et al.* 1998, Cordeiro *et al.* 1998, Vasconcelos *et al.* 2002, Vasconcelos and Rodrigues 2010).

Cipo Canastero is currently classified as 'Near Threatened' because of its small range and its habitat, which may be declining in area, extent and/or quality (BirdLife International 2019), but a recent extent of occurrence (EOO) calculation indicated that it should be categorised as 'Vulnerable' (Pena *et al.* 2014). Moreover, an adequate assessment of its area of occupancy (AOO) is still lacking. Additional potential threats to the species are brood parasitism by the Shiny Cowbird *Molothrus bonariensis* and frequent fires (Costa 2015, BirdLife International 2019), in addition to the consequences of a highly fragmented habitat that results in small and isolated populations. To improve conservation assessment and planning for Cipo Canastero, we review and characterise the geographic range of the species based on four different approaches (Gaston and Fuller 2009). By compiling all known species records and including many new locations based on our own research, we estimated the range size of Cipo Canastero, 1) delimiting the sky-islands where the species was recorded, 2) projecting the species potential distribution using species distribution modelling (SDM), and calculating 3) the extent of occurrence (EOO), and 4) the area of occupancy (AOO).

Methods

Cipo Canastero occurrence

We compiled Cipo Canastero records from the literature and from our own records derived from field expeditions conducted in the last decade to document the Brazilian sky-island birds (see details in Vasconcelos 2009, Chaves 2014, Costa 2015, Freitas 2015). These expeditions covered most of the largest eastern Brazilian mountain ranges (113 localities listed in Vasconcelos 2009 and Chaves 2014). In each locality, we spent 1–3 days searching for Cipo Canastero using playback and active searches in the *campos rupestres*. We documented species occurrence with sound records, photographs and collected specimens deposited in the Centro de Coleções Taxonômicas of the Universidade Federal de Minas Gerais (CCT-UFMG) and the Museu de Ciências Naturais of the Pontifícia Universidade Católica (MCNA), both in Belo Horizonte, Minas Gerais.

During the field expeditions, we recorded the location points of observed individuals using a handheld GPS receiver (nominal error c.5 m). These birds were found based on their frequent vocalisation used for territorial defence (Freitas *et al.* 2019b). We discarded localities closer than c.180 m to each other considering the minimum distance between individual territories (Freitas *et al.* 2019b). We checked the geographical coordinates of published records using satellite images from Google Earth (available at <https://www.google.com/earth>). The names of the localities were based on Brazilian government topographic maps at scale of 1:100,000 wherever possible (available at <https://biblioteca.ibge.gov.br> and <https://bdgex.eb.mil.br/bdgex>).

Cipo Canastero sky islands

To define the sky islands where Cipo Canasteros occur, we established an elevational boundary, based on the lowest elevation of recorded locations. These areas correspond to the distribution of habitat (Gaston and Fuller 2009) and reflect the geographic distribution of subpopulations, i.e. “distinct groups in the populations between which there is little demographic or genetic exchange” (IUCN 2019). In highland species, this altitudinal limit represents the water level in archipelagos for island species. We used a digital elevation model based on LANDSAT images (resolution of ~90 m; available at <http://www.cnpm.embrapa.br/projetos/relevobr>) to identify continuous highland patches.

To characterise the spatial structure of the sky-islands from a landscape perspective, we measured the following metrics: size, isolation (shortest distance to the nearest neighbouring sky island), protected area coverage (proportion of area overlapping any conservation unit in an integral protection category – *proteção integral sensu* MMA 2011), the shape index (shape complexity, indicating how much the shape differs from a standard square shape), and the core area index (quantifying the percentage of the patch that consists of the core area, i.e. the areas less influenced by the edge) (McGarigal *et al.* 2002). We calculated the patch metrics with R version 3.6.0 (R Core Team 2019) and the SDMTools version 1.1-221.1 package (VanDerWal *et al.* 2014).

Species distribution modelling (SDM)

We used statistical modelling to predict species distribution (Gaston and Fuller 2009) within sky island areas with the addition of a 1-km buffer. We used the MaxEnt algorithm to build a model based on presence-only locality records and 22 environmental variables, including 19 bioclimatic variables (Fick and Hijmans 2017), elevation (same as above), slope (derived from altitude layer), and the normalized difference vegetation index (NDVI). We used the NDVI to represent the vegetation cover and was calculated from CBERS 2B satellite images (available at <http://www.dgi.inpe.br/CDSR>). All layers were rescaled to a coarse resolution (~1 km), and recorded locations were filtered for only one occurrence in each raster pixel ($n = 71$ presences). We randomly generated 1,000 pseudo-absence points from the background and used the block method to partition occurrence and background points into four bins for training and testing of the models. We built the models using different regularisation multipliers and feature classes with the R package ENMeval version 0.3.0 (Muscarella *et al.* 2018), which we used to run MaxEnt version 3.4.1 (Phillips *et al.* 2019) via the ‘dismo’ version 1.1-4 package (Hijmans *et al.* 2017).

We used the lowest value of Akaike’s information criterion corrected for small sample size (AICc) to select the optimal model. We assessed the model performance on the basis of the area under the curve (AUC) of receiver operating characteristics curves. We evaluated how much the model discriminates Cipo Canastero occurrences from background localities by the mean difference between the training and testing AUC averaged across k bins based on testing data (mean AUC), and evaluated the degree of overfitting by the mean omission rates expected by excluding the 10% of training localities with the lowest predicted suitability (OR10) or the minimum training presence (MTP). We transformed the output predicted geographic values of the optimal model

into a binary presence/absence map using the maximum training sensitivity plus the specificity threshold (Liu *et al.* 2016).

Extent of occurrence (EOO) and area of occupancy (AOO)

We used the R package 'ecospat' version 3.0 (Di Cola *et al.* 2017) to measure EOO and AOO following the standard IUCN guidelines for threat assessment under criterion B – geographic range (IUCN 2019). EOO was calculated as the area within the minimum convex polygon (MCP) constructed with the occurrence data points. AOO was measured as the sum of occupied cells in a uniform grid scaled to a 4 km² (2 x 2 km) cell size.

Additionally, we calculated the upper limit values for EOO and AOO using the predicted area of presence from SDM calculated as described above (Freitas *et al.* 2019a). The MCP around the outermost limits of the modelled presence was the upper EOO (EOO_{up}), and the modelled area of presence within EOO was the upper AOO (AOO_{up}).

We calculated the areas according to the Universal Transverse Mercator (UTM) projected coordinate system (datum WGS84). We performed the geoprocessing procedures with QGIS version 3.6 (available at <http://www.qgis.org>) and the R package raster version 2.9-5 (Hijmans *et al.* 2019).

Results

We compiled 88 Cipo Canastero presence localities (Table S1 in the online supplementary materials), with 72 (82%) new records added in this study (detailed descriptions of the new records and absence localities are provided in Appendix S1). All records could be grouped into 33 overall locations (i.e. mountain or microregion; Table S1, Figures S3–S5). We only found the species in rocky outcrop agglomerations in the highlands of the Espinhaço Range, especially along the high tops of escarpments that face west (Figure 2, Figure S1). The average elevation of the records was 1,430 m (SD = 176; range = 1,100–2,002 m; Figure S2). Using a cut-off value of 1,100 m elevation, we delimited nine Cipo Canastero sky islands (Figure 1), with a total area equal to 6,865.08 km², of which 21.4% was included in protected areas (Table 1). The sky islands are distributed in three main sectors: South (Figures S3 and S4), Central, and North (Figure S5).

The South sector contains most of the sky islands, is the largest in total area and contains the closest sky islands (except for Serra do Ambrósio). In this sector, the Diamantina Plateau is the largest sky island, constituting 55% of the species' range, and has the most complex shape (Table 1). The most isolated sector is the North, which is 112 km from the nearest sky island (Table 1). The isolation distance is also great (53 km) between the Central and the South sectors of the distribution (between Itacambira and the Diamantina Plateau). The most isolated Cipo Canastero subpopulations are those living in Itacambira and Botumirim, which are 22.7 km from each other in the Central sector. Botumirim exhibits the least complex shape, followed by Serra da Formosa and both of the Serra do Cipó patches, whose shapes are close to square. Serra do Cipó North exhibits the highest proportion of core area, followed by the Diamantina Plateau, while Serra do Ambrósio presents a smaller proportion of core area.

The optimal model (AIC_c = 1131.42, AUC = 0.898) showed a good fit to the data (mean AUC = 0.863) without any indication of high level of overfitting (OR₁₀ = 0.186, MTP = 0.042). The optimal model was built by combining linear and quadratic feature classes and a regularisation multiplier of one. The variables with the greatest permutation importance in this model were the minimum temperature of coldest month (23.8%; negatively related), precipitation of the warmest quarter (22.2%; negatively related), elevation (18.8%; positively related), precipitation of the wettest month (15.9%; positively related), and isothermality (15.3%; negatively related). The area of predicted species presence based on SDM (threshold = 0.162) covered 2,225.21 km². The sky islands with the greatest amount of modelled habitat were Serra do Cipó South and North and Itambé-Gavião (Figures 3 and S6). Although a relatively high proportion of the areas of

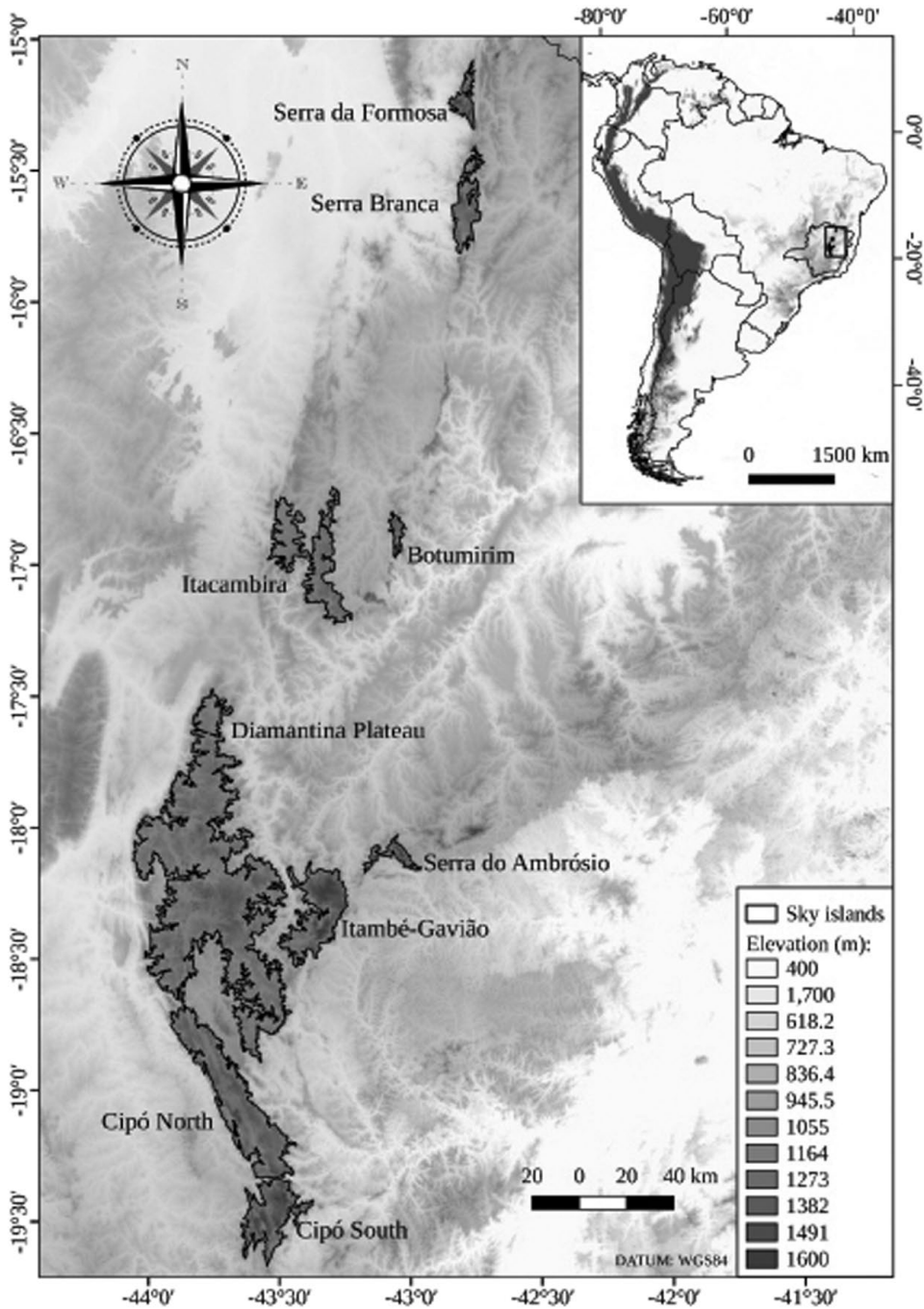


Figure 1. Cipo Canastero range within the Espinhaço Range, state of Minas Gerais, south-eastern Brazil (region within South America indicated by the rectangle in the inset map). The sky islands are continuous areas above 1,100 m where Cipo Canastero occurs. All localities with species records are presented in Table S1 and detailed maps are shown in Figures S3-S5.

Table 1. Landscape metrics and conservation of the nine sky islands of Cipo Canastero distribution in the Espinhaço Range, south-eastern Brazil. Sky islands are continuous areas above 1,100 m where species' recorded locations overlap, and they were grouped into three sectors: South, Central, and North. The isolation refers to the shortest distance to the nearest neighbouring sky island or between the sectors. The % of protected areas is the proportion of the sky island overlapping conservation units of integral protection categories (*sensu* MMA 2011) (see Figures S3-S5). The shape index and core area index were calculated according to McGarigal *et al.* (2002). % SDM corresponds to the amount of the area of predicted species presence based on species distribution modelling within each sky island.

Sky Island	Size (km ²)	% of total range	Isolation (km)	% of protected areas	Shape index	Core area index	% SDM
SOUTH SECTOR							
A. Cipó South	436.22	6.35	0.30	39.69	4.59	0.92	90.40
B. Cipó North	998.66	14.55	0.80	14.81	5.03	0.94	69.74
C. Diamantina Plateau	3,773.60	54.97	0.80	21.02	12.37	0.93	12.63
D. Itambém-Gavião	553.11	8.06	2.80	23.86	5.25	0.92	48.68
E. Serra do Ambrósio	90.36	1.32	9.40	0.00	4.68	0.83	48.49
Total South:	5,851.96	85.24	53.00	21.30			32.13
CENTRAL SECTOR							
F. Itacambira	603.50	8.79	22.70	0.00	7.97	0.89	20.56
G. Botumirim	53.34	0.78	22.70	0.00	3.30	0.85	60.29
Total Centre:	656.84	9.57	53.00	0.00			23.79
NORTH SECTOR							
H. Serra Branca	249.97	3.64	7.13	89.52	4.62	0.90	42.44
I. Serra da Formosa	106.30	1.55	7.13	0.00	3.79	0.87	24.09
Total North:	356.27	5.19	112.03	62.81			36.96
Total:	6,865.08			21.41			31.59

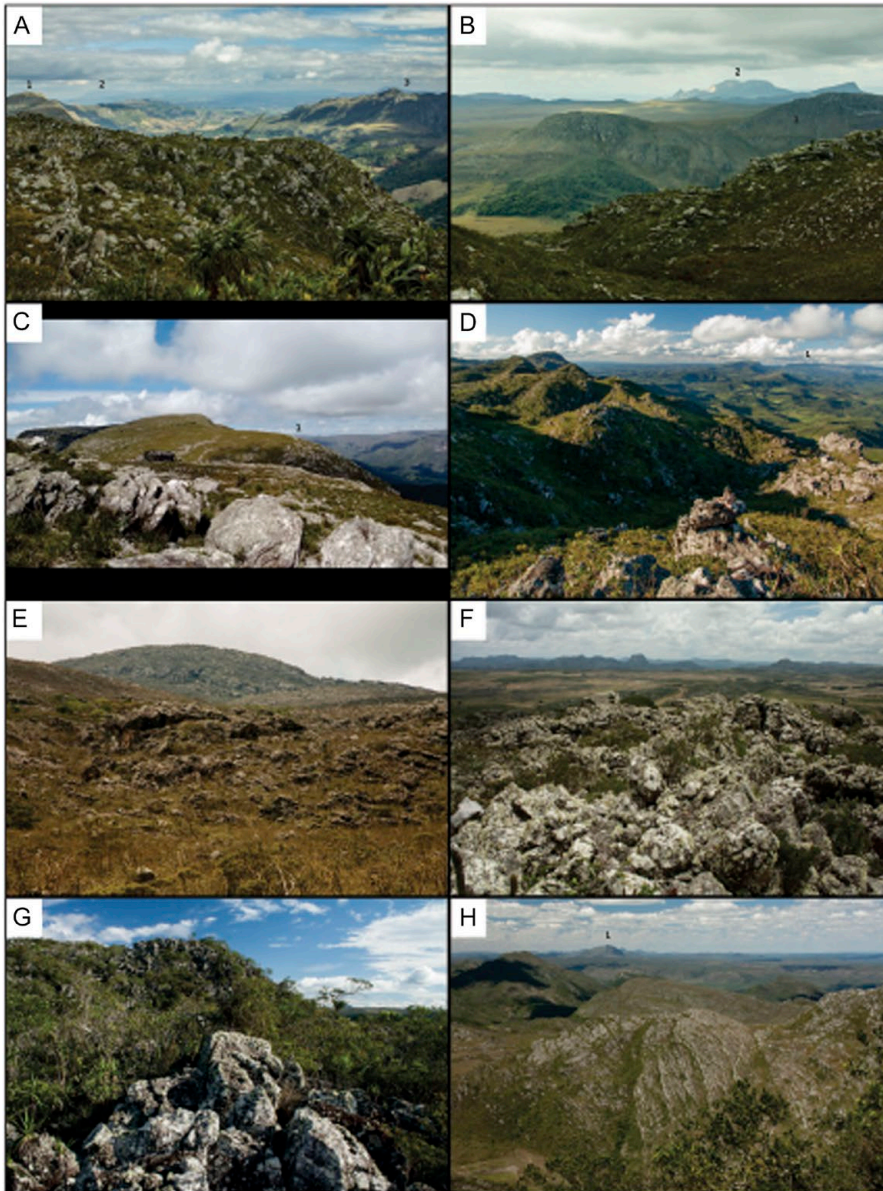


Figure 2. The Cipo Canastero habitat throughout its distribution (see localities on the map in Figure S3-S5): A) from Serra da Mutuca (first plane) looking south, Serra Altamira (1) and High Ribeirão da Prata (3) are within the species range, while further south, Serra do Caraça (2) and Serra da Piedade (same direction as 3), are outside of the species range; B) from Serra da Mutuca (first plane) looking east to the highest point (east) in the Bandeirinha stream (1) and Serra do Lobo (2); C) from Serra do Lobo looking south-west to Serra da Mutuca on the most distant plane (1); D) from Serra do Gavião (first plane) looking north-east to Serra do Ambrósio (1); E) Serra do Ambrósio; F) Parque Nacional das Sempres-Vivas; G) Serra dos Ferreiras; H) from the northernmost location of Serra da Formosa (Serra Montevideu) looking north-east to Serra do Pau D'Arco (1), at the outer limit of the species range. Photos by GHSF (A-B, D-H) and JCS (C).

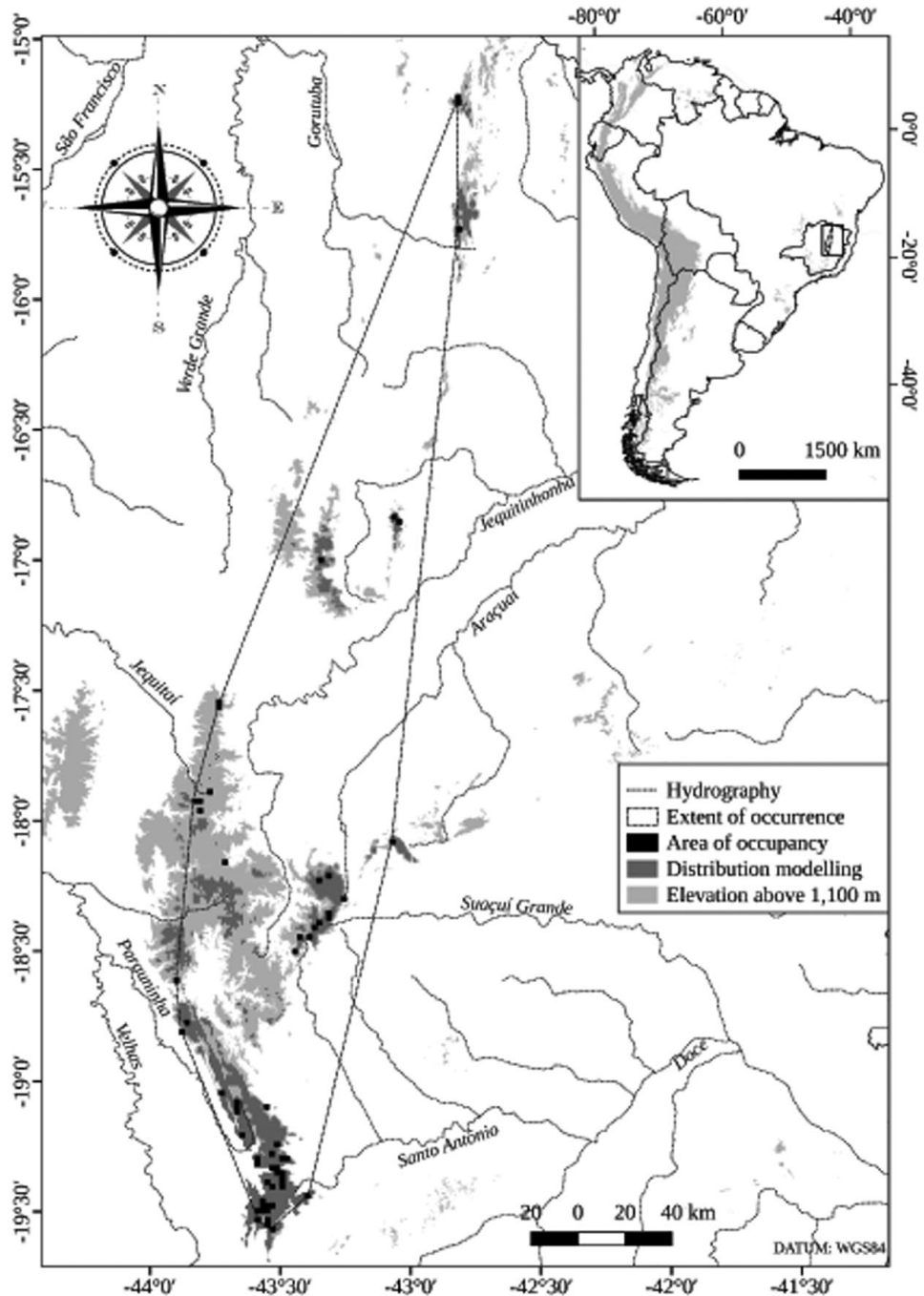


Figure 3. Distribution of Cipo Canastero in Minas Gerais, south-eastern Brazil (rectangle in the inset map) expressed as the extent of occurrence (EOO), area of occupancy (AOO), and predicted species presence based on species distribution modelling (SDM; see MaxEnt cloglog output in Fig. S6). All localities with species records are shown in Table S1 and detailed maps are in Figures S3–S5.

Botumirim and Serra do Ambrósio was also covered by the SDM, their representativeness in the total species range was minimal (Table 1). The calculated EOO was 24,555.85 km² and EOOup was 30,697.58 km². AOO was 228.0 km², while AOOup covered 1,827.39 km² (Figure 3).

Discussion

Cipo Canastero range limits

Cipo Canastero is patchily distributed along hilltops above 1,100 m elevation in the mountains of the Espinhaço Range in the state of Minas Gerais, Brazil. The Cipo Canastero range is interrupted by several geographic barriers (discontinuities in the mountain range formed by lowland areas) (Chaves *et al.* 2015), which isolate the sky islands identified in this study. From the perspective of three geographic scales, the species range could be divided into three sectors (South, Central, and North), or nine sky islands (Serra do Cipó South to Formosa, or A to I of Table S1), or 33 overall locations (Serra do Bicudo to Serra da Formosa, or A.I to I.I of Table S1).

The South sector is limited to the south by a decreasing elevation and narrowing of the mountain range (see Figure 2A) that separates the southern Espinhaço Range from the Quadrilátero Ferrífero (barrier 'O' of Chaves *et al.* 2015). That valley acts as a barrier to gene flow for many *campo rupestre* plants, promoting genetic differentiation in local subpopulations (Lousada *et al.* 2013). It is limited in the east by a decrease in the ridges extending to the north-east in the Doce / Jequitinhonha River watershed, next to Ambrósio sky island (barrier 'M' of Chaves *et al.* 2015). It is limited in the west by the lowlands that isolate the Diamantina Plateau unit from Serra do Cabral (barrier 'K' of Chaves *et al.* 2015). It is limited to the north by the lowlands of headwaters of the Jequitinhonha River, which separate the South and Central sectors. The Central and the North sectors are separated by an extension in which only small patches of *campos rupestres* occur, which apparently do not support a Cipo Canastero population. The North sector is limited in the west by a barrier ('H' of Chaves *et al.* 2015) that isolates it from the Caminho dos Gerais mountains. Finally, in the north, the Cipo Canastero range is limited by a barrier ('I' of Chaves *et al.* 2015) that isolates the North sector from the Serra do Pau D'Arco (Figure 2H) and other small mountains distributed in the southernmost part of the state of Bahia.

Other discontinuities isolate some Cipo Canastero subpopulations at the sky island scale, which partly overlaps with areas of plant endemism (Echternacht *et al.* 2011). Serra do Cipó South is isolated from the Serra do Cipó North by a deep transverse depression in the relief at the centre of the Parque Nacional da Serra do Cipó, a region known as Travessão, which is an important barrier to some *campo rupestre* plants (Lousada *et al.* 2011). At the north of Serra do Cipó, there is a large geological depression in the Gouveia municipality forming the Paraúna valley (close to barrier 'N' of Chaves *et al.* 2015), which separates the Serra do Cipó North and Diamantina Plateau sky islands. The Jequitinhonha and Araçuaí River valleys isolate the sky islands Itambé-Gavião and Serra do Ambrósio, respectively. The Congonhas River valley separates the Itacambira and Botumirim sky islands, and between Serra Branca and Serra da Formosa a depression is formed by the headwaters of the Tracabal and Tabuleiro rivers which isolate these sky islands.

The ecosystem of the Cipo Canastero range

The south-north axis of the Cipo Canastero's distribution encompasses a latitudinal gradient that reflects distinct *campo rupestre* types from climatic, geomorphological, botanical and ornithological perspectives. The overall climate of the Espinhaço Range is marked by dry winters and wet summers, with a notable tendency of increasing mean monthly temperatures and decreasing total rainfall towards the north (Silveira *et al.* 2016). Locally, the geographic position, elevation and other complex topographic factors produce diverse local microclimates, such as those derived from cold air pooling effects or the higher humidity on summits and east-facing slopes receiving the moister Atlantic winds (Ribeiro *et al.* 2009, Barbosa *et al.* 2015).

Geomorphologically, the mountains at Serra do Cipó occur within a narrow width of 30 km from east to west, where impressive rock walls are arranged in parallel in an approximate north-south direction (Magalhães Junior *et al.* 2015). In the Diamantina Plateau region, the Espinhaço is much wider, reaching 90 km, and rocky outcrops occur in numerous quartzite monadnocks (Magalhães Junior *et al.* 2015), with large blocks grouped in a disorganized manner or distributed on scattered hills across an open field (see Figure 2F). In the Central and North sectors of the species range, rocky outcrops are highly isolated in smaller highland areas.

From a botanical perspective, there is a complex plant community in the Espinhaço Range, with very high alpha and beta diversity (Giulietti *et al.* 1987, Martinelli 2007, Alves *et al.* 2014, Silveira *et al.* 2016, Neves *et al.* 2018). Along the rocky outcrops of Cipo Canastero's area of occupancy, the vegetation is often dominated by small shrubs, as observed on the higher summits that are more exposed to cold and wind, or by tall (c. 5 m) Cerrado trees (also known as *cerrado rupestre*), as we observed on the Diamantina Plateau. In the South sector of the Cipo Canastero distribution, the *campos rupestres* are influenced by Cerrado (from the west) and Atlantic Forest (from the east) domains, and towards the north, there is a more xeric Caatinga influence, which is reflected in the flora. We observed a greater presence of large cacti (Cactaceae) and *Clusia* spp. (Clusiaceae) trees primarily in the Central and North sectors.

From the perspective of bird communities, there are many unique communities along the Espinhaço Range, as previously discussed by Vasconcelos and Rodrigues (2010). In the southern part of the range, the community is influenced by Atlantic Forest birds, although most birds, such as the Large-tailed Antshrike *Mackenziaena leachii* are associated with woodland patches or dense clumps of shrubs (Vasconcelos and Rodrigues 2010, Rodrigues *et al.* 2011). Xeric influences are reflected on the Diamantina Plateau, where Caatinga birds, such as the Silvery-cheeked Antshrike *Sakesphorus cristatus*, and the Stripe-backed Antbird *Myrmorchilus strigilatus*, occur. Although these birds are sympatric in the *campos rupestres*, they are not syntopic with Cipo Canastero in the rocky outcrop habitat.

Cipo Canastero is the only bird endemic to *campos rupestres* that is restricted to rocky outcrops (Freitas *et al.* 2019b). The other endemic birds of the mountaintops of eastern Brazil use a wider range of habitat types within the *campo rupestre* complex (Hoffmann 2006, Freitas and Rodrigues 2012, authors' pers. obs.). Additionally, most of them display a broader distribution range, occupying other mountain sectors within the Espinhaço Range, as observed in the Hyacinth Visorbearer *Augastes scutatus*, or even other mountain ranges, as found for the Grey-backed Tachuri *Polystictus superciliosus* and the Pale-throated Pampa-finch *Embernagra longicauda* (Vasconcelos 2008, Chaves *et al.* 2015, Lopes *et al.* 2016). All sites where Cipo Canastero occurs are also occupied by these species (although the Grey-backed Tachuri is very rare in the northernmost sectors; authors' pers. obs.). The other endemic ovenbird, Cipo Cinclodes *Cinclodes espinhacensis*, is the only bird species with a narrower range within the Cipo Canastero distribution, being found only in some of the highest *campo rupestre* patches within the Serra do Cipó sky islands, although it also uses habitat types other than rock outcrops (Freitas *et al.* 2012, 2019a).

Conservation

The main range of Cipo Canastero falls within the South sector (85% of the total area), with the Diamantina Plateau sky island holding more than half (55%) of the total available area (but only 13% of the area of predicted species presence based on SDM). Furthermore, the Serra do Cipó sky islands are mostly composed of areas with a predicted Cipo Canastero presence (70–90%), in addition to including a considerable amount (21% of the total area) with high connectivity. These features indicate that Serra do Cipó is the main source of individuals for the global population. The sky islands are much smaller in the Central (10% of the total area) and North (5%) portions of the distribution, and the populations found in these areas may be severely threatened due to a possible small population size and high degree of isolation (> 50 km). This is especially relevant because Cipo Canasteros seems to have low dispersal ability (Costa 2015, Freitas *et al.* 2019b).

The following conservation units of integral protection are responsible for the conservation of 21.3% of the sky islands of the South sector (15.2% of the total) of Cipo Canastero's range (Figures S3 and S4): Parque Nacional da Serra do Cipó, Parque Estadual Serra do Intendente, Parque Estadual do Pico do Itambé, Parque Estadual do Rio Preto, and Parque Nacional das Sempre-Vivas. In the Parque Estadual do Biribiri and the Monumento Natural Estadual Várzea do Lageado e Serra do Raio, included in the Diamantina Plateau and Ambrósio units, respectively, we did not check for the species. In the Central sector, there are no conservation units, while more than half of the North sector is protected (62.8%) by the Parque Estadual Serra Nova e Talhado (Figure S5).

The EOO area, previously calculated to cover 17,146 km² (Pena *et al.* 2014), was revised here (24,556–30,698 km²) to fall above the 'Vulnerable' threshold under subcriterion B1 (EOO < 20,000 km²). However, the AOO estimations, obtained for the first time here, fall under subcriterion B2 into either the 'Endangered' category (AOO < 500 km²) or the 'Vulnerable' category (< 2,000 km²) considering the upper limit. These findings indicate that the degree to which potential risks to the species are spread spatially (EOO) is larger enough to not threaten Cipo Canasteros, but they are in threat due to the scarce area of suitable habitat currently occupied (AOO).

Because of the very patchy distribution of the areas that are currently or potentially occupied, Pena *et al.* (2014) recommended the use of SDM for measuring the Cipo Canastero distribution, which they identified as 9,724 km² area. This area is much larger than our modelled area of 2,225 km² and is greater than the area we calculated using the sky islands approach (6,865 km²). This discrepancy probably occurred due to methodological differences regarding the initial area in which the model was built; we used a restriction based on the sky islands, while Pena *et al.* (2014) used the political boundaries of the states of Minas Gerais and Bahia. In addition, we used many more presence localities.

Cipo Canastero exhibits a severely fragmented distribution, and consequently, its global population is also severely fragmented. Such patchiness may have natural causes related to topography, soil, and geology (Wu and Loucks 1995). However, human actions are reducing the quality of the suitable habitat patches and the landscape matrix and, thus are probably interfering within metapopulation dynamics at different scales among the *campo rupestre* biota (Fernandes 2016). This human-caused fragmentation of the *campo rupestre* directly impacts the Cipo Canastero population.

Cipo Canastero has been documented to be experiencing a population decline that is probably associated with brood parasitism by the Shiny Cowbird (Costa 2015). Moreover, the population may be undergoing a decline because of the decrease in quality of *campo rupestre* habitat due to frequent anthropogenic fires (Alvarado *et al.* 2017), livestock (Kolbek and Alves 2008), invasive grasses (Barbosa *et al.* 2010), roads, mining (Pena *et al.* 2017), tourism (e.g. by intensive use of trails causing soil compaction and erosion; Figueiredo *et al.* 2010) and climate change (Bitencourt *et al.* 2016). Climate change greatly impacts montane bird species around the world, especially those with a small geographic extent, living in an isolated mountain system (limiting lateral dispersion) and with a narrow elevation range (limiting vertical dispersion) (La Sorte and Jetz 2010), as we observed in Cipo Canastero. All of these factors contribute to the argument favouring the inclusion of Cipo Canastero in at least the 'Vulnerable' category of threat (under B2ab).

Conclusion and future directions

Here we provide details that greatly improve the knowledge of Cipo Canastero's subpopulation distribution, which will be useful for future genetic and conservation studies. However, there are many places still to be checked for Cipo Canastero occurrence, such as the Parque Estadual da Serra Negra, located only c.10 km east of the Ambrósio sky island and other mountains located mainly in the Central and North sectors where there are very few available habitat patches and Cipo Canastero records. Additionally, it would be highly desirable for further studies to refine the geographic distribution of subpopulations by mapping rocky outcrop patches to better delimit the

species' habitat suitability. Furthermore, demographic studies could better quantify changes in the condition of populations, and genetic studies could elucidate the degree of isolation of these subpopulations at different spatial and temporal scales, allowing us to understand the evolutionary processes underlying this unique distribution pattern.

Supplementary Material

To view supplementary material for this article, please visit <https://doi.org/10.1017/S0959270919000418>

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GUILHERME H. S. FREITAS*, LÍLIAN M. COSTA, RONEY A. SOUZA,
MARCOS RODRIGUES

Departamento de Zoologia, Universidade Federal de Minas Gerais, CP 486, Belo Horizonte, Brazil.

ANDERSON V. CHAVES, LEONARDO C. RIBEIRO, FABRÍCIO R. SANTOS

Departamento de Genética, Ecologia e Evolução, Universidade Federal de Minas Gerais, CP 486, Belo Horizonte, Brazil.

MARCELO F. VASCONCELOS

Museu de Ciências Naturais, Pontifícia Universidade Católica de Minas Gerais, Belo Horizonte, Brazil.

JULIANO C. SILVA

Rua dos Cravos, 450, São Pedro, Itabira, Brazil.

*Author for correspondence; email: guilhermehsfreitas@gmail.com

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