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The jaguar in South America – status review and strategy

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For joining the Friends of the Cat Group please contact Christine Breitenmoser at ch.breitenmoser@kora.ch

Original contributions and short notes about wild cats are welcome
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Editors: Christine & Urs Breitenmoser
Co-chairs IUCN/SSC
Cat Specialist Group
KORA, Talgut-Centrum 5, 3063 Ittigen, Switzerland
Tel ++41(31) 951 90 20
Fax ++41(31) 951 90 40
<u.breitenmoser@kora.ch>
<ch.breitenmoser@kora.ch>

Associate editors: Luke Hunter
Stacey Johnson

Cover Photo: Jaguar in the Pantanal
Photo: Patrick Meier

JEFFREY J. THOMPSON[1,2,3*#], AGUSTÍN PAVIOLO[4,5#], RONALDO G. MORATO[6], WŁODZIMIERZ JĘDRZEJEWSKI[7], FERNANDO TORTATO[8], SOLEDAD DE BUSTOS[9,10], JUAN REPPUCCI[10,11,12], PABLO PEROVIC[10,11], NUNO NEGRÕES[13], ALFREDO ROMERO-MUÑOZ[14], DAMIÁN RUMIZ[15], PAULA CRUZ[4,5], CARLOS DE ANGELO[4,5,16], VERÓNICA QUIROGA[17,18], YARA BARROS[19], VANIA FOSTER[19], MARIANELA VELILLA[1,2,3,20], ANA C. SRBEK-ARAUJO[21], CLAUDIA BUENO DE CAMPOS[22], URS BREITENMOSER[23] AND CHRISTINE BREITENMOSER[23]

Jaguar status, distribution, and conservation in south-eastern South America

The jaguar *Panthera onca* has experienced a significant reduction in its global distribution, particularly in south-eastern South America. This chapter conducts an extensive assessment of the jaguar's distribution, population status, and threats in this region, encompassing Argentina, Paraguay, Uruguay, southern and eastern Bolivia, and south-eastern Brazil. Spanning 8.3 million km², this area contains diverse ecosystems, including tropical forests, grasslands, and wetlands, making it of global conservation significance. To assess jaguar distribution and population size, we employed a comprehensive dataset, expert opinions, and ecological models, categorising jaguar population status into four classes: Extinct, Possibly Extinct, Possibly Extant, and Extant. We estimated that jaguars are extant in 20% of their historical range, with potential existence in an additional 14%, primarily located in fragmented habitat patches. The Pantanal, Northern Chaco, and Chiquitano together emerge as a population stronghold, while the Atlantic Forest, Caatinga, and Eastern Cerrado exhibit lower jaguar occurrence. Country-level assessments indicate that the jaguar is extinct in Uruguay and has decreased extensively in distribution in Argentina and Paraguay. Bolivia retains substantial jaguar populations, particularly in the Chaco, Chiquitano, and Pantanal regions. South-eastern Brazil, despite extensive historic range loss, harbours a significant jaguar population, especially in the Pantanal and Cerrado. Our study underscores the importance of evaluating under-researched regions like the Bolivian Andes, Chiquitano Forest, Humid Chaco, Caatinga, and the Cerrado. Additionally, it highlights the need for conservation efforts in the Pantanal, northern Chaco, and the Chiquitano for the jaguar's conservation. Moreover, our findings emphasise the urgency to restore populations and connectivity in the Atlantic Forest, Caatinga, and southern Chaco. Conservation priorities are habitat preservation, the maintenance of prey availability and landscape connectivity, and the reduction of hunting to secure jaguar populations in south-eastern South America.

Although the jaguar's global distribution has been reduced by about 50% (de la Torre et al. 2018, Quigley et al. 2017, Sanderson et al. 2002), this reduction has been considerably greater at the northern and southern extremes of its distribution where most of its populations are highly threatened (de la Torre et al. 2018, Sanderson et al. 2002). In this chapter we evaluate the distribution, population status, and threats to jaguar populations in south-eastern South America, including Argentina, Paraguay, Uruguay, and south-eastern Bolivia and south-eastern Brazil delimited by ecoregional limits and the jaguar's historic distribution (see methods). This focal area covers about half of South America (8.3 million km²) and 7.2 million km² of the southern historical distribution of the jaguar.

The climate and topography of our focal region is highly variable, including extremes for the distribution of the jaguar in terms of altitude, temperature, and precipitation. The interactions of climate and topography result in a high diversity of ecosystems with large variations in productivity and vegetational structure. These include humid tropical and subtropical forest (Atlantic Forest, Yungas), dryland forest, scrubland, and savanna systems (Chiquitanía, Dry Chaco, Cerrado, Caatinga), grasslands (Pampas) and large wetlands (Pantanal, Humid Chaco). Our focal region not only harbours a great diversity of ecosystems, but also includes global biodiversity hotspots (Atlantic Forest, Cerrado, Tropical Andes) and other ecoregions of high conservation value (Gran Chaco and Chiquitano), and is consequently of broader global conservation relevance (Kareiva & Marvier 2003, Myers et al. 2000, Redford et al. 1990).

Our focal region has witnessed an increase in the human footprint over the last several decades (Venter et al. 2016), a range of habitat conversion, as well as of socio-economic activities. Regions such as the Atlantic Forest and the Pampas have undergone centuries of habitat transformation and support most of the human population of Argentina, Brazil, Paraguay, and Uruguay. For example, the Brazilian Atlantic Forest has been reduced by 88%, with most remnants being degraded (Ribeiro et al. 2011). Conversely, regions such as the Caatinga and Pantanal have a long history of relatively low-intensity habitat conversion and low human population density, while the Gran Chaco, Cerrado, and Chiquitano have undergone a more recent, but extensive and intensive habitat conversion (Beuchle et al. 2015, Da Ponte et al. 2021, Hansen et al. 2013, Pinto-Ledezma & Rivero Mamani 2014, Ribeiro et al. 2011, Vallejos et al. 2015, Viglizzo 1997), This pattern is illustrated in the Gran Chaco where annual deforestation rates accelerated to about 4% starting during the 2000s (Da Ponte et al. 2022, Vallejos et al. 2015).

Using a large dataset on occurrence and various analyses presented in other chapters of this Special Issue (Jędrzejewski et al. 2023a, 2023b, Morato et al. 2023, Payán et al. 2023, Polisar et al. 2023), in combination with regional expert opinion and the literature, we updated the state of knowledge on jaguar distribution, population status, and threats in south-eastern South America while accounting for the high variability of ecological and anthropogenic determinants of habitat suitability across this region.

Methods

We estimated the current distribution of jaguars based on the analysis performed for the whole of South America by Jędrzejewski et al. (2023a). Our focal region (Fig. 1) was delimited by the estimated historic distribution of the jaguar (Sanderson et al. 2002) and the ecoregional limits used in the analysis (see below). For our focal region we compiled jaguar presence and absence data between 2000 and 2020, including data from published sources and monitoring projects (Fig. 1). To facilitate this process the coauthors completed a standardised questionnaire developed by the IUCN SSC Cat Specialist Group (Supplementary Online Material SOM Questionnaire).

Most data came from camera trapping, telemetry, record of tracks, and field interviews. To avoid bias from spatial autocorrelation, we reduced clustered data points to a maximum of one record per 100 km² (De Angelo et al. 2011, Dormann et al. 2007). We used 585 jaguar presence records from 2000–2009 and 415 records from 2010–2020. We also compiled 30 jaguar non-detection points collected from within the jaguar's current distribution and randomly selected 1641 points within the historic distribution of the jaguar where individuals have not been recently recorded (Fig. 1).

To estimate ecoregion-specific occurrence probability for jaguars and understand the factors that determine its distribution we used logistic regression models with a set of 21 predictive variables (see Jędrzejewski et al. 2023a). We then combined the results of these models with a kriging interpolation to estimate the current jaguar status and distribution (Jędrzejewski et al. 2017, 2023a). We defined ecoregions by combining the Level I and Level II ecoregions of Griffith et al. (1998) to broadly represent the ecological characteristics of geographic regions within the historic and current distribution of the jaguar. While this categorisation loses intra-ecoregional variation (e.g. Gran Chaco includes Dry Chaco, Humid Chaco, and temperate Espinal Forest, while southwestern Cerrado also encompasses Chiquitano Forest; Olson et al. 2001), it permits a more tractable geographic assessment of jaguar status in our focal area.

Following the IUCN guidelines for mapping species distribution (IUCN Red List Technical Working Group 2021), we classified jaguar status in four categories based on our estimated occurrence probability: Extinct (0.0–0.25), Possibly Extinct (>0.25–0.49), Possibly Extant (>0.49–0.75), and Extant (>0.75–1.0). In our classification the class 'Extinct' corresponds to low habitat suitability and no jaguar records; 'Possibly Extinct' to low or medium habitat suitability and no or few jaguar records, 'Possibly Extant' to high habitat suitability and few records or low/medium habitat suitability but several records, and 'Extant' to high habitat suitability and several jaguar records. We defined the current (2020) jaguar range as the combined area of the classes 'Extant' and 'Possibly Extant'. Additionally, we estimated the jaguar population size by country and ecoregion for the focal region by multiplying the potential jaguar population densities and their 95% credibility intervals (Jędrzejewski et al. 2018) by the probabilities of jaguar occurrence inside the current (2020) jaguar range within our focal region, following the methodological approach of Jędrzejewski et al. (2018).

Results

Range-wide distribution

The historical range of the jaguar in south-eastern South America covered 7.2 million km² that was 86% of the focal region, with the remainder corresponding to the portions of the Andes and Patagonia ecoregions (Sanderson et al. 2002, Fig. 1, Table 1). A large portion of the jaguar's range was converted to unsuitable habitat through increases in agriculture, infrastructure, and exploitation of jaguar and their prey as the human population grew (Quigley et al. 2017). We estimated that jaguars are extant in 799,000 km² (11% of the historical range) and possibly extant in an additional 633,000 km² (9% of the historical range), for a total of 1,432,000 km² for the current (2020) jaguar range in our focal region (Fig. 2, Table 1). Most of the remaining jaguar distribution in the focal region is fragmented in relatively small habitat patches that are often surrounded by unsuitable habitat for jaguars (Fig. 2). The exception is a large patch of relatively continuous habitat located in the northern Chaco in Bolivia and Paraguay, the Chiquitano, and the Pantanal where jaguars are contiguously present throughout most of these ecoregions (Fig. 2).

At the ecoregional level the Pantanal retained the highest estimated proportion of jaguar occurrence compared to the historical extent (90%), whereas in the Pampas ecoregion the jaguar has been extirpated from

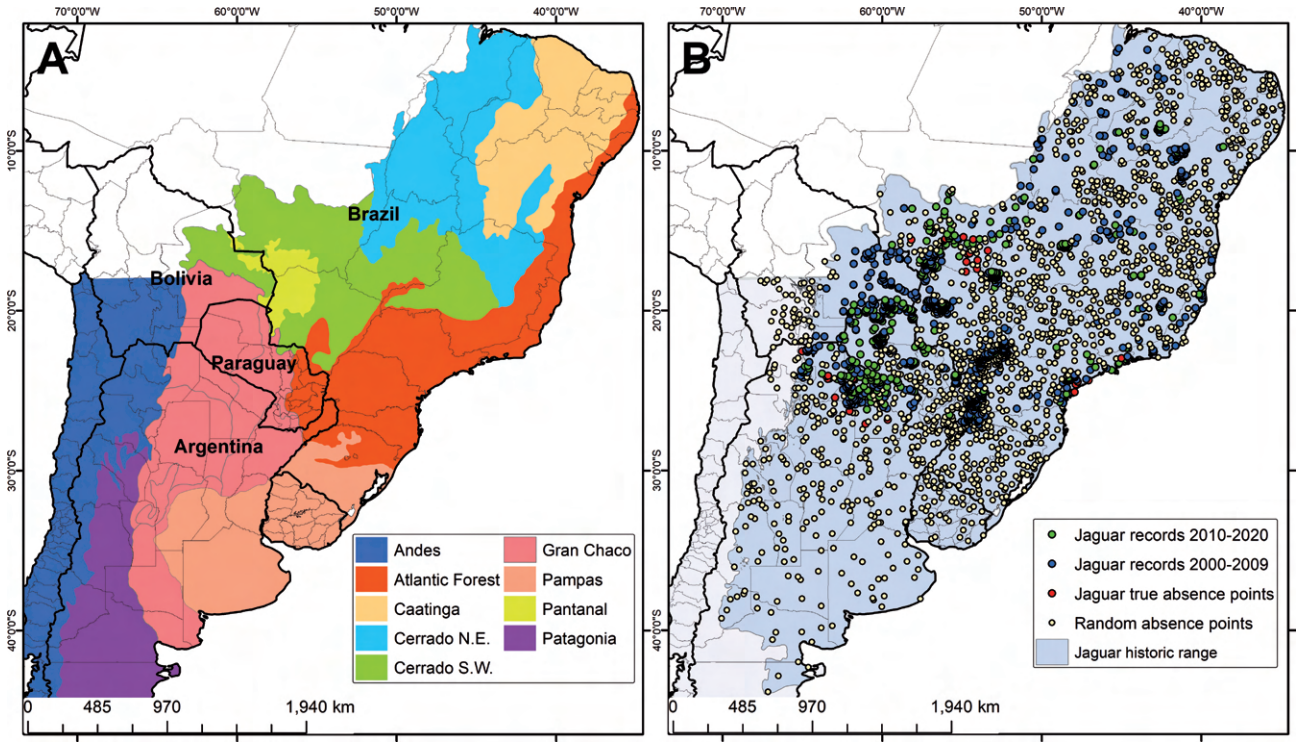

Fig. 1. Figure 1. A) Ecoregions within the analysis focal area in south-eastern South America and B) the jaguar;s historic range (after Sanderson 2002; darker grey) and the distribution of data points within the focal area used in the analysis.

Table 1. Area of the jaguar historic range (after Sanderson et al. 2002), area of the estimated 2020 jaguar distribution by country (Jędrzejewski et al. 2023a, Chapter 6 this volume), extrapolated country-level population and density and their 95% credibility intervals CRI in south-eastern South America. The estimated 2020 distribution is the sum of the estimated Extant and Possibly Extant categories.

Country	Area with current jaguar status (x 1000 km²)							2020 range as % of historic range	2020 Jaguar population estimate (95% CCI)	Mean jaguar population density (95% CRI) (jaguars/ 100 km²)
	Study focal area	Historic jaguar range	Extinct	Possibly Extinct	Possibly Extant	Extant	2020 Jaguar distribution			
Argentina	2,780	1,900	1,689	80	89	42	131	6.9	464 (158–813)	0.35 (0.12–0.62)
SE Bolivia	550	340	50	31	46	213	259	76.2	3,875 (3,095–4,661)	1.50 (1.20–1.80)
Paraguay	407	399	105	63	57	174	231	57.9	2,181 (0,972–3,427)	0.94 (0.42–1.48)
SE Brazil	4,421	4,380	2,700	869	441	370	811	18.5	8,809 (6,783–10,764)	1.09 (0.84–1.33)
Uruguay	176	176	176	0	0	0	0	0.0	0.0	0.00
Total	**8,334**	**7,195**	**4,720**	**1,043**	**633**	**799**	**1,432**	**19.9**	**15,329 (11,008–19,665)**	**1.07 (0.77–1.37)**

all of its original distribution (Table 2). The other ecoregions have all witnessed large-scale reductions in the distribution of the jaguar with only 7.8–35.7% of the original distribution being estimated to be occupied or potentially occupied (Table 2). Of these ecoregions, the Atlantic Forest, Caatinga, and Eastern Cerrado had the greatest estimated reductions, with only 7.8–19.0% of the historical distribution estimated to be occupied by jaguars (Table 2).

Country-level jaguar status

Uruguay

The jaguar was extirpated from Uruguay in the beginning of the 20th century (Pereira-Garbero & Sappa 2016). The historical jaguar range covered all the country where the species inhabited grasslands and riparian forests. The extinction of the species was driven by persecution related to the expansion of ranching activities and for the commercialisation of its skins, as well as the reduction of main prey species (Pereira-Garbero & Sappa 2016).

Argentina

The historical distribution of the jaguar in Argentina covered approximately 1.9 million km² (Table 1), including most of the northern and central regions of the country, north of the province of Río Negro (Di Bitetti et al. 2016, Perovic & Herrán 1998). Historically, the species' distribution included the Gran Chaco, Andean forests (which corresponds to Yungas Forest within our focal region), Atlantic Forest, Pampas grasslands, and northern Patagonia (Table 2). According to our analysis, the species is estimated to be Extinct in 1.69 million km² (89% of the historical range of the country; Table 1), and is Possibly Extinct in an additional 80,000 km² (4.2% of the historical range; Table 1). The disappearance of the species occurred from south to north during the last 150 years, becoming extinct in northern Patagonia and the Pampas region, then in most of the Gran Chaco region (Di Bitetti et al. 2016, Perovic & Herrán 1998; Table 2). The rapid contraction of the species' range coincided with economic and demographic growth, driven by the colonisation of much of the territory (Di Bitetti et al. 2016, Romero 1978).

We estimated the jaguar to be Extant across 42,000 km² (2.2% of the historical range) of Argentina and Possibly Extant across 89,000 km² (4.7% of the historical range; Table 1). However, a previous analysis estimated that the jaguar occurs in only 85,000 km² (Paviolo et al. 2019). Within Argentina the remaining jaguar population is divided into three subpopulations in the Atlantic Forest of the Misiones province, the Andean Forest of Salta and Jujuy, and the northern Gran Chaco (Paviolo et al. 2019). Additionally, restoration efforts are underway to restore jaguars in the Ibera marshland in the eastern Chaco region (Donadio et al. 2022). There is genetic evidence that the Atlantic Forest population is isolated from other populations in Argentina (De Angelo et al. 2011, Robino 2022), and it is likely that the Yungas and Chaco populations have recently become isolated from each other but not yet at the genetic level (Robino 2022) The three populations are, however, connected to varying degrees with other populations in neighboring countries, the Andean Forest population with Bolivia, the Gran Chaco population with Bolivia and Paraguay, and the Atlantic Forest population with Brazil (Paviolo et al. 2019).

Based upon previous modeling (Jędrzejewski et al. 2018) and that of this study, we estimated mean jaguar density of 0.35/100 km² and the total jaguar population within Argentina at 464 individuals (95% credibility interval of 158–813; Table 1). However, systematic camera-trap surveys in Argentina estimated a population between 200 and 300 animals (Paviolo et al. 2019). All the subpopulations are highly threatened, with the largest population in the Andean Forest with previous estimates of between 100 and 200 individuals (Di Bitetti et al. 2016, Paviolo et al. 2019, Perovic et al. 2015) which is consistent with our estimate of 33–171 individuals (Table 2).

For the Atlantic Forest of Argentina, we estimated between 34 and 172 individuals (Table 2) which is similar to recent estimates of between 72 and 123 obtained with camera trap surveys (A. Paviolo et al., unpubl. data). However, our estimate of 90–464 individuals in the Gran Chaco is much greater than field-based estimates of <20 jaguars (Paviolo et al. 2019, Quiroga et al. 2014). This discrepancy is likely the result of the very low human tol-

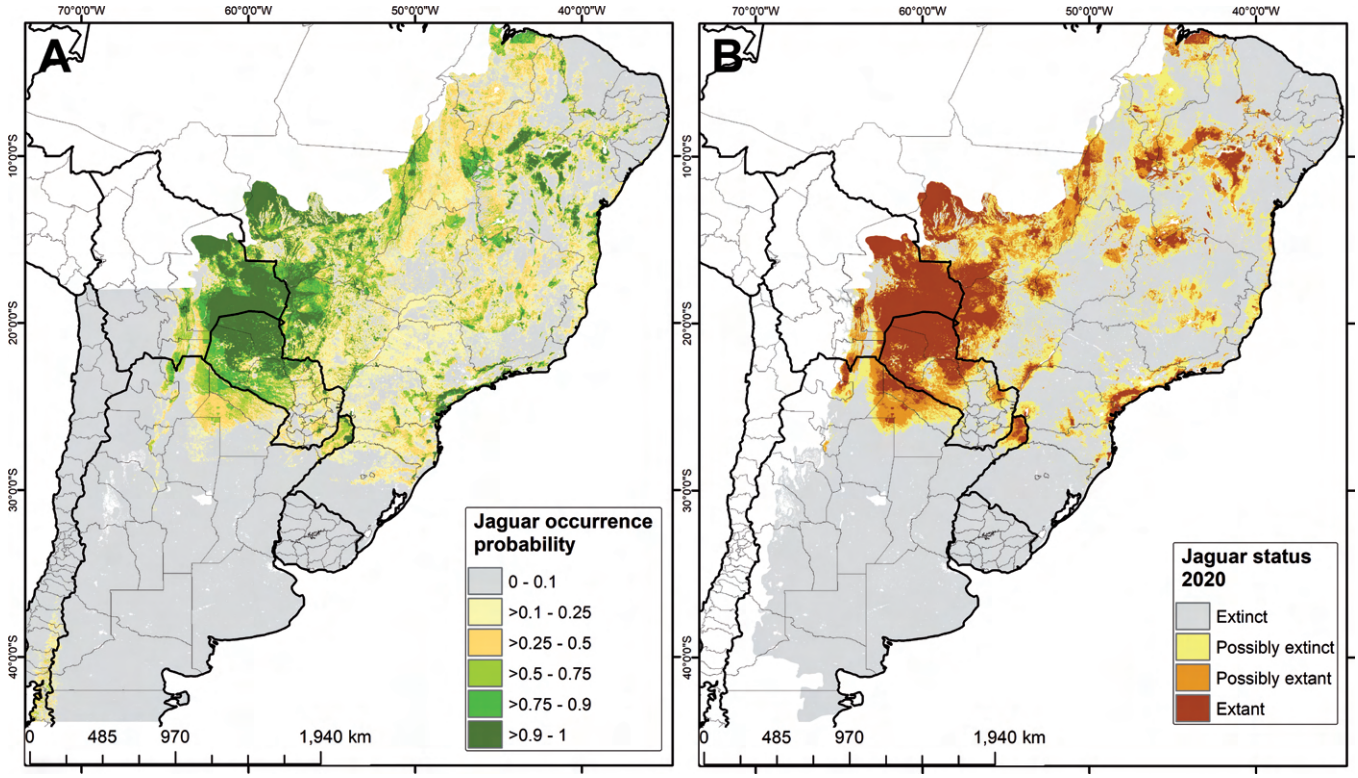

Fig. 2. A) Estimated probability of jaguar occurrence resulting from the logistic regression model of jaguar presence and absence and B) the estimated current status classified into four categories within the study's focal area based upon the jaguar occurrence probability estimated with the combined logistic regression and kriging interpolation models; Extinct (0.0–0.25), Possibly Extinct (>0.25–0.49), Possibly Extant (>0.49–0.75), and Extant (>0.75–1.0). Brown (Extant) and orange (Possibly Extant) indicate the current jaguar distribution, while yellow (Possibly Extinct) and grey (Extinct) indicate an extent of the historical jaguar range (Sanderson et al. 2002) outside the current jaguar range. For methodological details see Jędrzejewski et al. (2023a).

erance of the species in the region and the consequent high anthropogenic mortality that suppresses the population below potential levels (Fig. 3; Quiroga et al. 2014, Thompson et al. 2020).

Paraguay

The historical distribution of the jaguar covered nearly all of Paraguay including areas of the Atlantic Forest, Gran Chaco, Cerrado, and Pantanal (Fig. 1, Table 2). However, agricultural expansion and infrastructure development have greatly reduced the availability of jaguar habitat (Da Ponte et al. 2017, 2021, Hansen et al. 2013, Venter et al. 2016). We estimated that the jaguar is Extinct or Possibly Extinct in 43% of its original distribution within the country (Table 1). The most impacted ecoregion is the Atlantic Forest where most of the area has become unsuitable (Fig. 2, Table 2) with the remaining populations located in two small and isolated areas (De Angelo et al. 2013, López Duré 2021, McBride & Thompson 2019).

We estimated the jaguar to be Possibly Extant in 14% of the country and Extant in 43% of the historical range (Table 1). Jaguars remain in large portions of the Gran Chaco (Table 2), but since 2000 the Chaco forests have undergone rapid and extensive conversion for cattle pasture and row crops (Baumann et al. 2017, 2022, Romero-Muñoz et al. 2019, Vallejos et al. 2015). This activity not only is affecting the habitat availability for the species, but also resulting in high levels of persecution in response to real or perceived livestock predation (McBride and Thompson 2018, Romero-Muñoz et al. 2019).

According to the jaguar density estimates of 0.94/100 km^2 from Jędrzejewski et al. (2018), and our analysis, we estimated the total jaguar population within Paraguay at 2,181 individuals (95% credibility interval 972–3427, Table 1). Most of the estimated population was distributed in the Gran Chaco region and it is believed that in the Atlantic Forest of eastern Paraguay <20 individuals remain (Paviolo et al 2016), although our estimate of 87 jaguars is considerably larger (Table 2).

South-eastern Bolivia

In our focal area in south-eastern Bolivia (hereafter SE Bolivia; 550,000 km^2) jaguars were historically distributed over 340,000 km^2 (Table 1), including in the Gran Chaco, the Chiquitano, Andean Forest, and the Pantanal. We estimated that in our focal region within Bolivia the jaguar disappeared from 15% of its historic range and is Possibly Extinct in an additional 9% (Table 2). The most negatively affected regions have been parts of the Andean Forest, the Gran Chaco, and the western Chiquitano in the department of Santa Cruz that have been modified by agricultural development (Maffei et al. 2016).

We estimated jaguars to be extant in 63% and possibly extant in 14% of the historical distribution in SE Bolivia (Table 1). The species remains in large areas of continuous habitat in the Chaco, Chiquitano, and Pantanal that are connected with contiguous blocks of suitable habitat in Brazil and Paraguay (Fig. 2). However, the Chiquitano forest has recently experience rampant deforestation which may affect the jaguar population, and important connectivity areas between the Chaco and the Amazon (Thompson et al. 2021). Furthermore, the situation in the Andean Forest is more precarious due to increasing habitat fragmentation (Table 2).

Table 2. Area of the jaguar historic range (after Sanderson et al. 2002) and area of current estimated jaguar distribution by country and ecoregion (Jędrzejewski et al. 2023a, Chapter 6 this volume) in south-eastern South America. The estimated 2020 jaguar distribution calculated as the sum of extant and possibly extant categories.

Ecoregion		x 1000 km²						Current range as % of historic range
	Country	Historic range	Extinct	Possibly Extinct	Possibly Extant	Extant	Current 2020 jaguar range	
Andes	Argentina	76	53	9	9	6	15	20.0
	Bolivia	55	16	13	17	9	27	48.6
	Total	131	68	21	26	15	42	**31.9**
Atlantic Forest	Argentina	31	7	7	9	8	16	53.7
	Brazil	1,127	871	186	45	25	70	6.2
	Paraguay	89	50	27	10	2	12	12.9
	Total	1,246	928	221	63	34	98	**7.8**
Caatinga	Brazil	779	567	104	60	49	109	**14.0**
Cerrado East	Brazil	1,143	603	324	151	66	217	**19.0**
Cerrado West	Bolivia	123	10	5	12	95	108	87.7
	Brazil	960	445	239	148	128	276	28.7
	Paraguay	7	0	1	2	3	6	82.2
	Total	1,090	455	245	163	226	389	**35.7**
Pantanal	Bolivia	23	0	1	2	20	22	96.4
	Brazil	149	5	12	33	99	132	88.9
	Paraguay	2	0	0	0	1	2	99.9
	Total	173	5	13	36	121	156	**90.0**
Gran Chaco	Argentina	895	733	62	72	28	100	11.1
	Bolivia	138	24	12	14	88	102	73.9
	Brazil	7	2	1	2	2	5	61.2
	Paraguay	299	54	34	44	167	211	70.6
	Uruguay	0	0	0	0	0	0	0.0
	Total	1,340	813	110	132	286	417	**31.1**
Pampas	Argentina	478	478	0	0	0	0	0.0
	Brazil	168	168	0	0	0	0	0.0
	Uruguay	174	174	0	0	0	0	0.0
	Total	819	819	0	0	0	0	**0.0**
Patagonia	Argentina	381	381	0	0	0	0	**0.0**
Total		**7,104**	**4,639**	**1,037**	**631**	**797**	**1,428**	**20.1**

Combining the jaguar density model (Jędrzejewski et al. 2018) and the jaguar distribution and probability of occurrence assessed in this study, we estimated the total jaguar population within the Bolivian portion of our study region at 3,875 individuals (95% credibility interval of 3,095 to 4,661; Table 1) which equated to a mean density of 1.5 jaguars/100 km² (95% credibility interval: 1.20–1.80). Most of these individuals are estimated to occur in the Gran Chaco and Chiquitano (Table 2).

South-eastern Brazil

Our focal region within Brazil (here after SE Brazil) covered 4.42 million km², of which 4.38 million km² was historic jaguar range. We estimated that of this historic distribution the jaguar is Extant or Possibly Extant in 18% of its area, while Extinct in 62% and Possibly Extinct in 20% (Table 1). The Brazilian portion of our focal region had the highest country-level estimate of the number of jaguars (8,809; 95% credibility interval: 6,783–10,764), which translated to a mean density of 1.09 jaguar/100 km² (Table 1).

Within SE Brazil the historic jaguar distribution included seven of the nine ecoregions in our study area. We estimated the jaguar to be extinct or possibly extinct in 100% of the historic range in the Pampas, 86% in the Caatinga, 85% in the Atlantic Forest, 81% in eastern Cerrado, and 71% in the western Cerrado. The ecoregions with the lowest estimated area where the jaguar is extinct or possible extinct was the

Fig. 3. The remains of a GPS collared male jaguar in the Paraguayan Dry Chaco killed in retaliation for cattle depredation (Photo: R. T. Mcbride, Jr.).

Gran Chaco (43%) and the Pantanal (11%; Table 1).

As in Argentina and Uruguay, in Brazil the jaguar has been extirpated from grassland systems (Pampas ecoregion), while also being highly negatively impacted in the easternmost ecoregions of the Atlantic Forest, eastern Cerrado, and Caatinga. The Atlantic Forest has undergone centuries of widespread land conversion resulting in extensive forest loss and fragmentation that has driven the large-scale reduction in the occurrence of the jaguar (Paviolo et al. 2016, Ribeiro et al. 2011). This process of habitat loss has resulted in a highly fragmented jaguar population that now occurs in multiple sub-populations throughout the Brazilian Atlantic Forest (Paviolo et al. 2016), resulting in reduced genetic diversity among these populations (Haag et al. 2010, Srbek-Araujo et al. 2018).

The most studied jaguar population in Brazil is in the Atlantic Forest and consequently have permitted a more detailed understanding of the regional status of the jaguar (Azevedo et al. 2016, Paviolo et al. 2016). Previous extrapolations of jaguar densities generated an estimated population of 281 jaguars in the Brazilian Atlantic Forest (Azevedo et al. 2016), which was very similar to our estimate of 271 jaguars (Table 1).

The Caatinga also has a long history of extensive land conversion and degradation whereby the jaguar population in this region is fragmented (Azevedo et al. 2016). The jaguar population in the Caatinga has previously been estimated to be 262 individuals, however it was based on a conservative constant density of 0.3 individuals/100 km^2 (Azevedo et al. 2016). Our population estimate for the Caatinga (1,017 jaguars; 95% credibility interval 783–1,243) is based on varying densities from our modeling, however, is about four times larger than those based upon a uniform density of 0.3 individuals/100 km^2.

For the Brazilian Pantanal we estimated a population of 2,177 jaguars (95% credibility interval: 1,676–2,660) which indicates that the Brazilian Pantanal remains a population stronghold for the jaguar. However, we point out that despite the common recognition of the importance of the Pantanal for jaguar conservation, relatively few studies have estimated densities in the region, generating varied estimates ranging from 3.6 to 12.4 jaguars/100 km^2 (Cavalcanti et al. 2012, Devlin et al. 2023, Eriksson et al. 2022, Soisalo & Cavalcanti 2006). Consequently, there is a conspicuous need for an ecoregion-wide assessment of jaguar densities given the relatively small proportion of protected area in the ecoregion, habitat conversion and other anthropogenic threats, and the persecution of jaguars (Azevedo et al. 2016, Cavalcanti et al. 2010, 2012, Thompson et al. 2021, Tomas et al. 2019).

The Cerrado potentially supports a large number of jaguars as it is the second largest biome in Brazil, however, large-scale land conversion in the region for agricultural production has greatly reduced the distribution of the jaguar. This is exacerbated by only 2% of the ecoregion being protected (de la Torre et al. 2018, Moraes Jr. 2012). Our estimated population of 4,863 individuals for the entire Brazilian Cerrado, equates to a mean density of 1.01 individuals/100 km^2. This is higher than a previous estimate of 0.67 individuals/100 km^2 for the entire region (Moraes Jr. 2012) and of 0.29 individuals/100 km^2 from Emas National Park (Sollmann et al. 2011), but is similar or lower than density estimates from other dryland systems in southern South America (Noss et al. 2012, Silveira et al. 2010, Sollmann et al. 2013, Thompson et al. 2022).

Conclusions

Our analysis indicates that optimistically jaguars remain Extant in about 20% of its historic distribution within our focal region in southern South America. However, at the same time, the high uncertainty of the occurrence of the jaguar in 23% of its original distribution (Possibly Extant or Possibly Extinct) points to a need for an improved quantification of the distribution and abundance of jaguar across this region. Although the status and ecology of jaguars in some ecoregions, such as the Atlantic Forest, have been well studied (Fusco-Costa et al. 2023, McBride & Thompson 2019, Paviolo et al. 2016), and others such as the Dry Chaco are gaining attention, others have received relatively little attention despite their importance for jaguar conservation.

The Bolivian Andes, Chiquitano forest, and the Humid Chaco cover relatively large areas and with the potential to support significant jaguar populations, as well as playing important roles in maintaining continent-wide connectivity (Thompson et al. 2021). However, jaguars in these ecoregions have been little studied and is a research void that needs to be addressed (Maffei et al. 2016, Maillard et al. 2020, Meißner et al. 2023, Thompson et al. 2021). Similarly, the Cerrado, despite its large size, has had jaguar research mostly confined to protected areas even though the ecoregion is dominated by working landscapes, highlighting a need for a more representative focus on quantifying the abundance and occurrence of jaguars in the Cerrado. Perhaps of most concern is the lack of a quantitative assessment of the status of the jaguar in the Pantanal given the conventional view of the ecoregion as a population stronghold for the species. The Pantanal is subject to

widespread agricultural and ranching activities, among other anthropogenic pressures (Cavalcanti et al. 2012), however, a rigorous ecoregional evaluation of the jaguar is conspicuously absent and necessary.

Some of our large-scale population and density estimates differ from other local studies, particularly in the Argentine Chaco, Paraguayan Atlantic Forest, and Caatinga which indicates the need for further research which takes into account both the impact of environmental and anthropogenic factors on the variability of jaguar densities (Azevedo et al. 2016, McBride & Thompson 2019, Morato et al. 2016, Romero-Muñoz et al. 2019, Thompson et al. 2020). Consequently, given the uncertainty in some of our estimates, we caution against interpreting our results as absolutes or at overly fine geographic scales, although the majority of our estimates are consistent with field-based observations. We believe that our estimates capture the general state of the distribution and population of jaguars within south-eastern South America, however, new abundance estimations from additional sites would be valuable in validating our estimates.

Based upon our analysis, jaguars likely remain in about 20% of their historic distribution in south-eastern South America (Extant or Possibly Extant), and potentially occur in an additional 14% of our focal region (possibly extinct). Consequently, at the regional level, conservation efforts must be directed towards maintaining the existing, relatively healthy, and connected populations in the Pantanal, northern Chaco, and the Chiquitano. Moreover, our findings emphasise the urgency to restore populations and connectivity in the Atlantic Forest, eastern Cerrado, Caatinga, and southern Chaco.

Concurrently, we demonstrated that there are large areas of potentially suitable, unoccupied habitat that can support jaguars in our focal region. Therefore, to ensure the conservation of existing populations, the recolonisation of jaguars into suitable unoccupied habitat, and the connectivity and genetic variability of jaguars throughout south-eastern South America and beyond, it is imperative that the country-specific management goals outlined in the national jaguar management plans for the countries in the focal region (Desbiez et al. 2013, Pinckert de Paz et al. 2020, Ramadori et al. 2016, Secretaría del Ambiente et al. 2016) are met to maintain sufficient habitat, prey availability, and landscape connectivity for jaguars, and to reduce their direct anthropogenic mortality (i.e. hunting, roadkill).

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Supporting Online Material SOM Questionnaire is available at www.catsg.org.

[1] Asociación Guyra Paraguay, Parque Ecológico Asunción Verde, Asunción, Paraguay
[2] Consejo Nacional de Ciencia y Tecnología (CONACYT), Asunción, Paraguay
[3] Instituto Saite, Asunción, Paraguay
* <jthompson.py@gmail.com>
[4] Instituto de Biología Subtropical (IBS), Universidad Nacional de Misiones - CONICET, Bertoni 85, Puerto Iguazú, Misiones, Argentina
[5] Asociación Civil Centro de Investigaciones del Bosque Atlántico, Bertoni 85, Puerto Iguazú, Misiones, Argentina
# Authors contributed equally to this work
[6] Centro Nacional de Pesquisa e Conservação de Mamíferos Carnívoros, Instituto Chico Mendes de Conservação da Biodiversidade, Atibaia, SP, Brazil
[7] Centro de Ecología, Instituto Venezolano de Investigaciones Científicas (IVIC), Caracas, Venezuela
[8] Panthera, New York, USA
[9] Delegación Regional Noroeste - Administración de Parques Nacionales, Santa Fé 23, 4400, Salta, Argentina
[10] Fundación Biodiversidad Argentina, Salta, Argentina
[11] Jaguares en el Límite, APN-DRNOA, Santa Fe 23, 4600, Salta, Argentina
[12] Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina
[13] ACEAA-Conservación Amazónica, Calacoto, Calle 16 Nro. 8230, La Paz, Bolivia
[14] Geography Department, Humboldt University Berlin, Berlin, Germany
[15] Museo de Historia Natural Noel Kempff Mercado y Fundación Simón I. Patiño, Santa Cruz de la Sierra, Bolivia
[16] Instituto de Ciencias de la Tierra, Biodiversidad y Ambiente (ICBIA), Universidad Nacional de Río Cuarto (UNRC) – CONICET, Ruta Nacional 36 Km 601, Río Cuarto, Córdoba, Argentina
[17] Universidad Nacional de Córdoba, Facultad de Ciencias Exactas, Físicas y Naturales. Centro de Zoología Aplicada. Córdoba, Argentina
[18] Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Instituto de Diversidad y Ecología Animal (IDEA). Córdoba, Argentina
[19] Projeto Onças do Iguaçu, Parque Nacional do Iguaçu, Foz do Iguaçu, Brazil
[20] School of Natural Resources, University of Arizona, Tucson, Arizona, USA
[21] Programa de Pós-Graduação em Ciência Animal e Programa de Pós-Graduação em Ecologia de Ecossistemas, Universidade Vila Velha, Vila Velha, Espírito Santo, Brazil
[22] Programa Amigos da Onça, Institute for the Conservation of Neotropical Carnivores – IPC, Atibaia, SP, Brasil
[23] Foundation KORA, Talgut-Centrum 5, Ittigen, Switzerland