Jaguar Conservation in Brazil: The Role of Protected Areas

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Brazil holds 50% of the jaguar's current range, much of it centring in the Amazon basin, which has long been considered the species' stronghold. Jaguars also range across four other biomes of Brazil (Cerrado, Caatinga, Pantanal and Atlantic Forest). We estimated jaguar population size for reserves and indigenous lands > 100km² using biome-specific density estimates. These results informed a population viability analysis (PVA) to assess the potential of the protected areas system for jaguar conservation in the five biomes. Mean protected area and jaguar population size varied significantly among biomes: the Atlantic Forest biome had the smallest and the Amazon forest biome the largest mean area and mean population sizes (431 km² and 10 individuals, and 10,993 km² and 311 individuals, respectively). Based on the PVA, jaguar populations >85 individuals were viable for > 200 years. These populations accounted for 90% of all protected jaguars, but are mostly restricted to the Amazon biome. In the other biomes, ≥ 50 % of populations were viable for up to 10 years only. Only in the Amazon are protected areas alone large enough to have the potential for long-term jaguar conservation. In other more fragmented biomes, landscape-scale conservation will be essential to sustain jaguar populations over the long term.

As the largest predator in the tropical Americas, the jaguar *Panthera onca* faces threats typical for large carnivores worldwide: Habitat loss and persecution. Large-scale habitat conversion (Fig. 1) collapses the range and fragments the landscape, constraining jaguar populations to protected areas. Where cattle ranching overlaps with jaguar range (Fig. 2), hunting as retaliation for domestic livestock predation can drive the species to local extinction (IUCN/SSC Cat Specialist Group 1996). As a result, the jaguar's entire range has been reduced by more than 50% since 1900 (Sanderson *et al.* 2002), and the species is thought to be extirpated in two of the 21 countries in which it originally occurred (Cat Specialist Group 2002). Listed as *Near Threatened* on the IUCN Red List (Cat Specialist Group 2002), the species' major stronghold is the 6,915,000-km² Amazon basin, although significant populations are also thought to exist in the Paraguayan Chaco and the Pantanal wetlands shared by Brazil and Paraguay (Sanderson *et al.* 2002).

According to a recent range-wide assessment, 50% of the jaguar's distribution lies within Brazil (Sanderson *et al.* 2002). Brazil gains even more importance for the species' range-wide conservation because half of the Amazon basin is located in Brazil and provides the large un-fragmented block of habitat essential for the survival of this area-sensitive top predator. In addition to the Amazon forest, jaguars occur in four other Brazilian biomes: the savannah-like Cerrado, the semi-arid Caatinga, the coastal Atlantic Forest, and the Pantanal wetlands. Ecological conditions, as well as the socio-economical situation of the human population vary widely among these biomes, so the jaguar's conservation status is likely to vary accordingly. Nationally, the species is listed as threatened (IBAMA 2003). The protection of threatened species such as the jaguar on a regional and national level is an explicit objective of the Brazilian National System of Conservation Units (Sistema Nacional de Unidades de Conservação – SNUC, IBAMA 2000). In an ever changing and developing human landscape, protected areas are one of the most important tools for conservation in any biome and should be cornerstones for regional conservation planning (Noss *et al.* 1996, Margules & Pressey 2000, Rylands & Brandon 2005).

The purpose of this study was to classify the potential of the Brazilian protected areas for the jaguar's long-term survival in the five biomes, utilizing estimates of jaguar population size in protected areas in a Population Viability Analysis (PVA). Comparing results between biomes, we give the first systematic assessment of differences in jaguar protection status within major regions of Brazil.

Fig. 1. Large-scale agriculture in central Brazil is one of the main activities responsible for the fragmentation of jaguar populations (Photo Jaguar Conservation Fund/Instituto Onça-Pintada).

Fig. 2. Extensive cattle ranching requires deforestation and induces jaguars to prey on the domestic livestock. Hunting in retaliation to cattle predation poses a major threat to jaguar populations on ranchland (Photo Jaguar Conservation Fund/Instituto Onça-Pintada).

Material and Methods

Data for this study were derived from an ongoing jaguar distribution project undertaken by the Jaguar Conservation Fund (JCF), in which a systematic mapping of the species' occurrence in Brazil is in process. Although JCF's database includes jaguar occurrence in protected and non-protected areas, for this analysis we only considered state and federal reserves, as well as indigenous lands. This last category – areas traditionally occupied by Indians and used by them permanently - was included because they contribute significantly to habitat protection throughout Brazil (Rylands & Brandon 2005). To design the sampling method across the country we adopted the mapping system by the Brazilian Institute for Geography and Statistics (IBGE), in which Brazil is divided into 3,055 quadrants of approximately 50 x 50 km. Throughout Brazil, we compiled jaguar records from the existing scientific literature, JCF initiated surveys and other research, and interviews with locals. The current jaguar distribution analysis we created considers records from 1997 to the present. Quadrants with jaguar records were classified as "with jaguar presence." An entire protected area (PA) was classified as "with jaguar presence" if the PA had at least one jaguar record within its boundaries. PAs were also classified as "with jaguar presence" if jaguars had been registered in a quadrant adjacent to the PA. We will refer to these PAs with jaguar presence as Protected Jaguar Areas (PJAs). Data on protected areas came from the following sources: IBAMA (Brazilian government agency for the environment), MMA (ministry for the environment), FUNAI (Brazilian government agency for indigenous affairs).

To estimate the size of jaguar populations in PJAs, we used biome-specific jaguar density estimates based on camera-trapping data from the existing literature (Table 1), and multiplied density with PJA size. We only considered areas >100 km², as any fragments smaller than this threshold failed to support a pair of jaguars. (Table 1). We excluded APA (Areas of Environmental Protection) and RPPN (Private Reserves) from our analysis due to weak protection for the former and the lack of precise geo-referenced information for the latter. Several PJAs that are directly connected to each other are considered as a single area with a contiguous jaguar population.

Table 1. Jaguar density estimates for each Brazilian biome based on camera-trapping data.

Biome	Jaguar density (individuals/100km²)	Reference
Amazon	2.84	Silver *et al.* 2004
Cerrado	2.00	Silveira 2004
Caatinga	2.65	JCF, unpublished data
Atlantic Forest	2.22	Cullen *et al.* 2005
Pantanal	10.3	Soisalo & Cavalcanti 2006

In order to group protected jaguar populations into categories of viability, we performed a population viability analysis (PVA) using the computer program VORTEX 9.3 (Lacy *et al.* 2007). As demographic data for the species is incomplete, we used an existing Vortex model for the jaguar (Eizirik *et al.* 2002) and adjusted some of the demographic parameters based on empirical data from ongoing Jaguar Conservation Fund field studies of jaguar populations in four different Brazilian biomes (input parameters of the model can be requested from the lead author). We ran this model several times with varying initial population sizes and determined the time of population persistence with a 0.95 probability (TP95). With these values, we then performed a piecewise linear regression using the software package STATISTICA 7 (StatSoft, Inc. 2005) to determine minimum and maximum population size for the following viability categories: TP95 of up to 10 years (1), from 11 to 50 years (2), from 51 to 100 years (3), from 101 to 150 years (4), from 151 to 200 years (5) and longer than 200 years (6). We considered the last category as long-term viability. We then compared the mean PJA size and respective population size among biomes using a Kruskal-Wallis test for *k* independent samples, and the distribution of viability categories among biomes using a Chi² test, both implemented in the software package SPSS 13.0 for Windows (SPSS Inc., Chicago IL).

Results should be understood comparatively: In estimating size of jaguar populations in PAs using a single biome-specific density estimate, we do not consider the specific vegetation of each PA, nor differences in their level of protection. In addition, the idea of estimating minimum viable populations in general has received considerable critique (reviewed by Beissinger 2002), and it is recommended to interpret results comparatively. Specifically, our PVA model does not consider biome-specific differences in vital rates or external influencing factors due to a

lack of quantitative information and the scope of this study. Also, the surroundings of any reserve play a major role for the performance of any protected population within a reserve (Woodroffe & Ginsberg 1998; Ranganathan *et al*. 2008). Nevertheless, we are confident that even within these limitations, this analysis gives an overview of how well the jaguar is protected within 50% of its global range.

Results

We counted 1,166 PAs in Brazil, the majority located in the Amazon (42%), followed by the Atlantic Forest (31%), Cerrado (21 %), Caatinga (5 %), and the Pantanal (1%). From this reserve network, we identified 298 PJAs (individual areas or blocks of adjacent areas) > 100 km². Combined, PJAs covered an area of 1,969,374 km², or about 25% of Brazil's land area.

Most PJAs are located in the Amazon (n = 167), corresponding to 42.9 % of the entire biome's area, followed by the Cerrado (n = 60, 5.6 %), Atlantic Forest (n = 49, 2 %), Caatinga (n = 16, 1.6 %), and Pantanal (n = 6, 2.7 %).

Mean PJA size varied among biomes (H = 52.224, df = 4, $p > 0.001$), ranging from 431 km² in the Atlantic Forest to 10,993 km² in the Amazon (Table 2). Mean population size also differed among biomes (H = 64.942, df = 4, p < 0.001), ranging from 10 individuals (SD = 12) in the Atlantic Forest to 311 (SD = 1137) in the Amazon (Table 2). We estimated that all Brazilian PJAs hold about 55,500 jaguars. Of those, 93.6 % occupy Amazonian PJAs, followed by 4.2 % in the Cerrado, and only 0.9 %, 0.8, and 0.6% Atlantic Forest, Pantanal and Caatinga, respectively (Table 2).

Based on our population model, a minimum population with TP95 of 200 years was 85 individuals. We calculated population size for the six viability categories as: 1 (TP95 up to 10 years) ≤ 18, 2 (TP95 up to 50 years) ≤ 41, 3 (TP95 up to 100 years) ≤ 59, 4 (TP95 up to 150 years) ≤ 73, 5 (TP95 up to 200 years) ≤ 85, and 6 (TP95 over 200 years) > 85.

Fifty-one percent of all estimated jaguar populations (n = 153) fall into viability category 1 (Table 3), accounting for about 2 % of all protected jaguars, while populations in viability category 6 (19 %, n = 56) account for 90% of protected jaguars Brazil-wide. The distribution of viability categories (Fig. 3) differs significantly between biomes (Chi² = 55.693, df = 20, p < 0.001). With 29% (n=48) of its populations falling into the highest viability category with a TP95 more than 200 years, the Amazon is the only biome that holds more long term viable populations (category 6) than expected. In contrast, the Atlantic Forest holds none, the highest category being 4 (TP95 up to 150 years; Table 3). Apart from the Amazon, all biomes have >50% of their protected jaguar populations in the lowest viability category.

Discussion

The jaguar can be found throughout most of Brazil, but our analyses show that its conservation status differs widely across the five Brazilian biomes. Our results corroborate that the Amazon is unique among Brazilian biomes with respect to jaguar conservation: It is the biome with the largest percentage and absolute area of PAs that hold jaguars, and, consequently, harbours the vast majority of the country's protected jaguar population. Mean population size of more than 300 individuals implies that a considerable proportion of all populations has a high probability of long-term survival. While the agricultural frontier is moving into the Amazon, bringing a predicted habitat loss of 50% over the next decades (Costa *et al.* 2005), the extensive system of large and often connected PAs in the Brazilian part of the Amazon plays a key role for long-term conservation of the jaguar Brazil-wide and range-wide.

Cited as another stronghold for the species (Sanderson *et al.* 2002), the Brazilian Pantanal shows a very small number of PJAs and protected jaguars (Table 2). However, due to its environmental characteristics – the seasonal flooding of most of its area – 87 % (MMA 2007[a]) is still covered by native vegetation. Extensive cattle ranching, the primary human activity in the

Table 2. Statistics (number, size and estimated protected jaguar population (PJP)) of protected areas > 100km² with jaguars (Protected Jaguar Areas - PJA) in the five Brazilian biomes the species occurs in.

Biome	No. PJA	Mean size of PJA (SD) km²	Total area of PJAs km²	Mean PJP (SD)	Total protected jaguars
Amazon	167	10,993 (40,057)	1,816,302	311 (1,137)	51,920
Cerrado	60	1,936 (3,592)	116,156	39 (73)	2,332
Caatinga	16	734 (1,269)	11,749	20 (34)	327
Atlantic Forest	49	431 (530)	21,093	10 (12)	479
Pantanal	6	679 (971)	4,073	70 (100)	420
TOTAL Brazil	298	6,674 (30,391)	1,969,374	186 (862)	55,477

Table 3. Distribution of protected areas > 100km² with jaguars (Protected Jaguar Areas - PJAs) in the five Brazilian biomes the species occurs in, ranked in six viability categories (1 – 6), based on different time of population persistence wit 0.95 probability (TP95).

Biome	1 (TP95≤10 yrs)	2 (TP95≤50 yrs)	3 (TP95≤100 yrs)	4 (TP95≤150 yrs)	5 (TP95≤200 yrs)	6 (TP95>200 yrs)
Amazon	64	30	14	7	4	48
Cerrado	33	12	4	2	2	6
Caatinga	11	4	0	0	0	1
Atlantic Forest	42	6	0	1	0	0
Pantanal	3	1	0	0	1	1
TOTAL Brazil	153	54	18	10	7	56

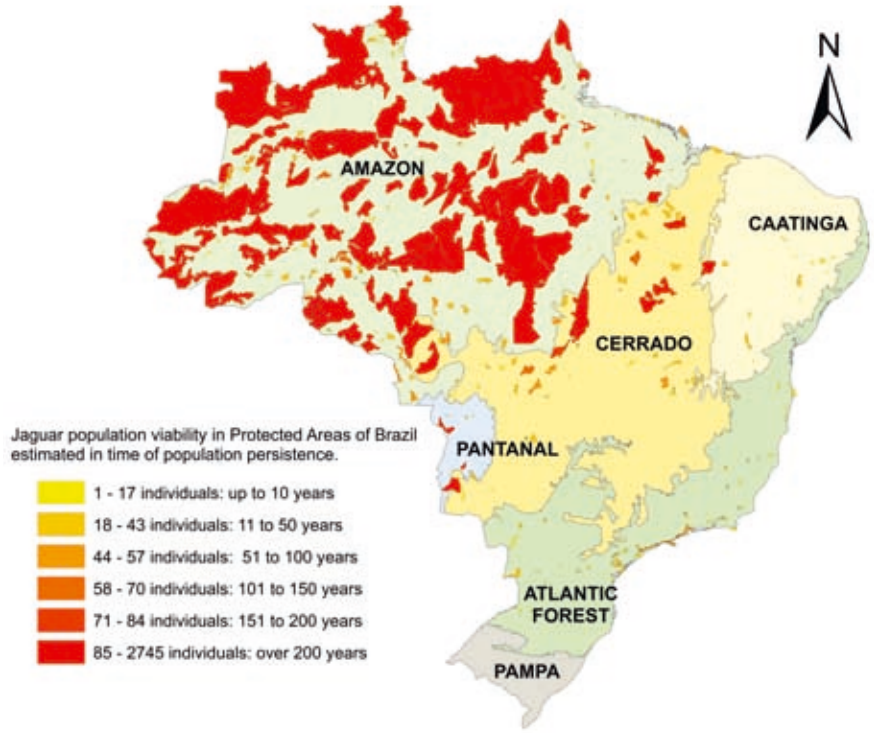

Fig. 3. Map of Brazil with protected areas and indigenous lands larger than 10,000 hectares where jaguar are known to be present (protected jaguar area - PJA); colors code for jaguar population viability derived from estimates of population size from a Population Viability Analysis. Connected PJAs were considered as a single area with a contiguous jaguar population.

Pantanal (Harris *et al.* 2005), and an extraordinarily abundant fauna (Swartz 2000) support comparatively high jaguar densities (Soisalo & Cavalcanti 2006), even in non-protected areas. In addition, private reserves (RPPNs) probably play an important role for jaguar conservation in the Pantanal, as they are integrated into a landscape that still provides large tracts of native habitat and are generally well preserved. Also, the number of private reserves > 100 km² is higher than in other biomes, for example, in the state of Mato Grosso do Sul there are four (REPAMS 2008), while we are aware of only one in the entire Amazon biome. Therefore, our analysis underestimates the current contribution of the biome to the global jaguar population and range-wide jaguar conservation. Still, the un-protected jaguars of the Pantanal face serious threats. Conflict between cattle ranchers and jaguars is omnipresent, so hunting is a major problem (Crawshaw & Quigley 2002). Also, cattle ranching practices have become more intensive and as agriculture spreads into the floodplain loss of native habitat is increasingly becoming a problem (Harris *et al.* 2005). If this trend continues, the Pantanal may diminish as a refuge for jaguars.

Fig. 4. Fragmentation and isolation of native jaguar habitat by large-scale agricultural ventures in the Cerrado: One of the major threats to jaguar populations in Brazil's second largest biome (Photo Jaguar Conservation Fund/Instituto Onça-Pintada).

The other three biomes are presented below in order of descending mean size of PJAs and current challenges to managers focused on the goal of maintaining jaguars over the long term. The Cerrado, Brazil's second largest biome, covers 22% of the country's land area. In contrast to the Amazon, however, this vast savannah-like region holds only 4 % of the country's protected jaguars. Populations also show a higher degree of fragmentation, with a mean population size of only 39 individuals. While natural vegetation still constitutes about 60 % to its area (MMA 2007[b]), the majority is under some degree of human influence and the biome is characterized by a fragmented landscape (Cavalcanti & Joly 2002; Fig. 4). A major threat to the species' persistence is the isolation of populations too small to be viable over the long term. Large-scale crop plantations most likely present barriers to jaguars so that the species depends on corridors of gallery forest (Fig. 5) for movement between suitable areas; however, hydroelectric dams disrupt these corridors (Silveira & Jácomo 2002). Much remains unknown about jaguars in the Cerrado (Silveira & Jácomo 2002), but information about the species' ability to use the fragmented landscape is crucial to understand its chances for long-term persistence, as protected areas alone cannot guarantee the jaguar's future.

Although almost five times the size of the Pantanal, the Caatinga holds only about 300 protected jaguars due to the

small fraction of protected area in this biome (1.6%, MMA 2007[c]). The semi-arid climate and poor soil limit large scale agriculture and cattle ranching, and about 60% of its area still maintains the native vegetation cover (MMA 2007[c]), however, these blocks are fragmented (Castelletti *et al.* 2004). The rural population is extremely poor and poaching is common (Leal *et al.* 2005), threatening the jaguar's prey base. The protected areas fail to protect the full range of the biome's biodiversity (revised by Leal *et al.* 2005) and, with predominantly low numbers, also do not protect long-term viable jaguar populations. Both degradation and lack of an efficient protected areas system, in combination with a lack of information about distribution, ecology and status of the jaguar in the Caatinga (Oliveira 2002) indicate an alarming conservation situation of the species in this biome.

The Atlantic Forest holds a number of PJAs comparable to the Cerrado (49 and 60, respectively), but 86% are in the lowest viability class. Only one PJA (Serra do Mar) provides some longer term perspective for jaguar conservation. Overall, the biome has suffered the highest incidence of habitat loss in Brazil, with 71 % of its area under anthropogenic use (MMA 2007[d]) and the remaining native vegetation is extremely fragmented (Gascon *et al.* 2000). In addition to the lack of sufficiently large protected areas, poaching of potential prey species (Cullen Jr. *et al.* 2000, Leite & Galvão 2002) and hunting of the jaguar due to livestock predation (Azevedo & Conforti 1999, as cited in Conforti & Azevedo 2003) have been reported even from within protected areas. Simulations indicate that it might be more important to primarily address these factors, rather than the lack of connectivity between populations (Cullen Jr. 2006). Overall, the jaguar's protection status in Brazil's most troubled biome is certainly the most critical throughout the country.

Conclusion

The problem of reserves being too small to protect viable populations of wide ranging carnivores is universal and has long been acknowledged (e.g. Schoenwald-Cox 1983, Ranganathan *et al.* 2008). We show that the same principle holds true for jaguars in most of Brazil: Only in the Brazilian Amazon does the existing protected areas system alone have the potential to conserve the species over the long term. Although on the national conservation agenda (Silva 2005), the creation of new protected areas oftentimes generates conflicts with local communities and is limited by competing human demands (Margules & Pressey 2000, West *et al.* 2006). This analysis points out the major differences in protection status of the jaguar throughout the five Brazilian biomes. From a management perspective, our data show that throughout most of the national territory, long-term jaguar conservation will depend on approaches integrating non-protected landscapes. Therefore, analyses of the specific ecological, cultural, socio-economical and environmental realities at the biome and regional level identifying specific threats and opportunities for jaguar conservation are necessary to develop an efficient conservation plan for the jaguar in Brazil.

Fig. 5. Corridors of riparian forest can provide habitat for jaguars and movement paths between suitable areas (Photo Jaguar Conservation Fund/Instituto Onça-Pintada).

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