Is reintroduction a tool for the conservation of the jaguar *Panthera onca*? A case study in the Brazilian Pantanal

Rose Lilian Gasparini-Morato, Leonardo Sartorello, Lilian Rampim Carlos Eduardo Fragoso, Joares Adenilson May Jr, Pedro Teles Mario Haberfeld, Rogério Cunha de Paula and Ronaldo Gonçalves Morato

Abstract To evaluate the feasibility of reintroduction as a tool for conservation of the jaguar *Panthera onca*, we adapted the IUCN soft release protocol to reintroduce two jaguars in the southern Pantanal, Brazil. After being kept at rescue centres for 13 months, the jaguars were moved to a 1-ha enclosure with native vegetation on a 53,000 ha ranch in the Pantanal, where hunting is not allowed and prey is abundant. In the enclosure, the animals were fed with meat, dead animals (roadkill) and then, progressively, live wild prey. After 11 months, the jaguars were fitted with collars equipped with GPS/VHF (recording one location per hour) and accelerometers, and released in the same area. The animals established residence near the enclosure, with home ranges, movement parameters, daily activity patterns and prey consumption similar to that recorded in previous studies. Social interaction and reproduction indicated the reintroduction was successful, and that it can be a tool for the species' survival in areas where the jaguar population is in decline.

Keywords Brazil, home range, jaguar, Pantanal, *Panthera onca*, reintroduction

The historical range of the jaguar *Panthera onca* has contracted and many populations are now threatened (De la Torre et al., 2017), including the subpopulations in the Atlantic Forest (Morato et al., 2013). The last c. 300 individuals in this forest occur in seven subpopulations, and the survival of the species in this biome will depend on reducing jaguar mortality and reconnecting the subpopulations (Paviolo et al., 2016). However, some of these are isolated and the cost of establishment of suitable corridors may be prohibitive (Paviolo et al., 2016), and alternative strategies, such as supplementation and reintroduction, may be required (Galetti et al., 2013).

Reintroductions of apex predators, including the few attempts to reintroduce jaguars, have generally been poorly documented and measurement of failure or success has been hampered by the lack of prior definition of expected outcomes (Breitenmoser et al., 2001). To evaluate reintroduction as a tool for conservation of the jaguar, we adapted the IUCN (2013) soft release protocol to reintroduce two rescued jaguars in the southern Pantanal, Brazil (Fig. 1). We chose this area based on five criteria: (1) rescued animals were from the same region, (2) knowledge of the species' biology in the Pantanal was available, including for the release site (Cavalcanti & Gese, 2010), (3) availability of suitable habitat (de Paula et al., 2012), (4) prey availability (Perilli et al., 2016), and (5) acceptance by the local community.

Our expected outcomes were that the two jaguars would: (1) prey on wild species (to evaluate this, we compared the species preyed upon with the reported feeding habits of jaguars in the same area; Perilli et al., 2016), (2) establish residence (establishment of residence may be an indicator of acclimation, and jaguars have resident ranges; Rabinowitz & Nottingham, 1986), (3) have similar home ranges and movement to those reported for jaguars in the Pantanal (Morato et al., 2016), (4) have daily activity patterns comparable to that of resident jaguars, (5) exhibit social interactions (Kanda et al., 2019), and (6) reproduce.

In June 2014, during the flood season, a female jaguar and her two 3-month old female cubs were forced to seek refuge in an urban area of Corumbá, in the state of Mato Grosso do Sul, in the southern Brazilian Pantanal, climbing a tree c. 2 m from a house. An attempt to capture the jaguars resulted in the accidental death of the mother. The two orphans were moved to a wildlife rescue centre in Campo Grande, where they spent 9 months. We then moved them to a new facility in São Paulo state, with better infrastructure and minimum contact with people, where they stayed for 4 months.

Rose Lilian Gasparini-Morato* (Corresponding author, orcid.org/0000-0003-2885-0034), Rogério Cunha de Paula (orcid.org/0000-0003-1943-8320) and Ronaldo Gonçalves Morato (orcid.org/0000-0002-8304-9779) Instituto Chico Mendes de Conservação da Biodiversidade – Centro Nacional de Pesquisa e Conservação de Mamíferos Carnívoros, Estrada Municipal Hisaichi Takebayashi 8600, 12952-011, Atibaia, São Paulo, Brazil
E-mail rose.morato@icmbio.gov.br

Leonardo Sartorello* (orcid.org/0000-0001-7607-9577), Lilian Rampim (orcid.org/0000-0001-8121-3152), Carlos Eduardo Fragoso (orcid.org/0000-0001-8971-2896), Joares Adenilson May Jr (orcid.org/0000-0002-0007-9690), Pedro Teles (orcid.org/0000-0003-0754-2470) and Mario Haberfeld (orcid.org/0000-0001-9360-6658) Associação Onçafari, São Paulo, Brazil

*Contributed equally

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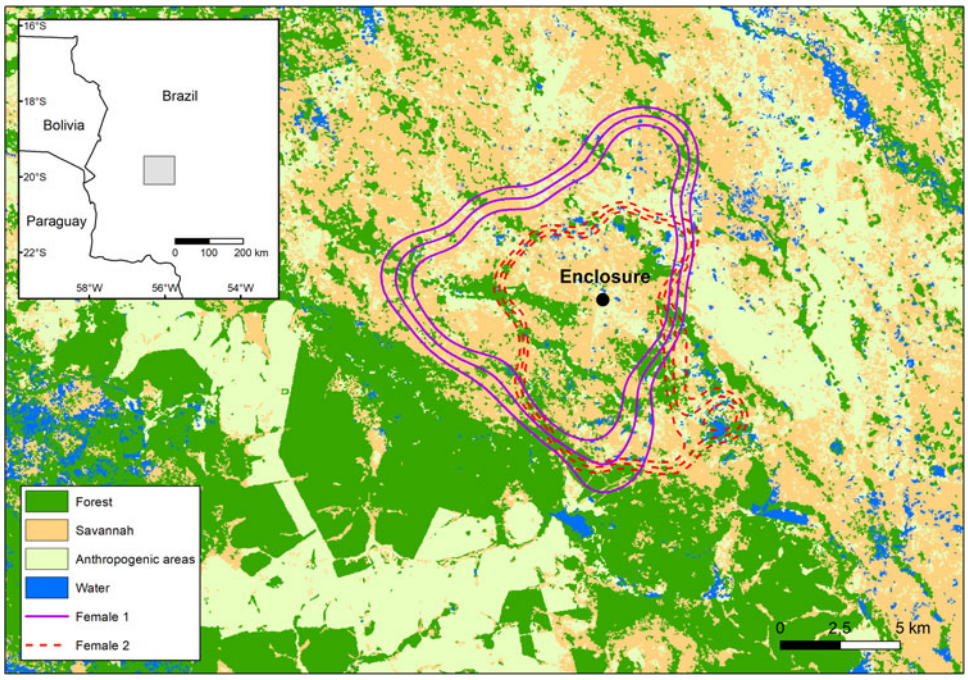

FIG. 1 The estimated home range (with 95% CI bands) of jaguars *Panthera onca* 1 and 2 in the southern Pantanal, Brazil. Note the high overlap in their home ranges.

Pre-release, the two jaguars were tested for all relevant infectious and parasitic diseases. At c. 16 months old, having been confirmed healthy, they were moved on 27 July 2015 to a 1 ha enclosure with native vegetation (Plate 1) in the Caiman Ecological Refuge, a 53,000 ha private ranch in Miranda, Mato Grosso do Sul (Fig. 1). The ranch is a mixed enterprise, with cattle ranching and ecotourism. It follows jaguar-friendly best practices (Rampim et al., 2020), and hunting is not allowed on the property. As a result, potential prey is abundant and the estimated density of jaguars is c. 7 per 100 km² (Soisalo & Cavalcanti, 2006). In the first 2 months in the enclosure the jaguars were fed meat and dead animals (roadkill), to facilitate acclimation. After this, live wild prey was captured and presented, one animal at a time. Prey was released into the enclosure through one of six guillotine gates. These gates were covered with wooden plates to prevent the jaguars associating the arrival of food with people. We observed that hunting was better after 7 days without food. After 11 months the two jaguars were able to chase, surprise and kill all the animals offered. On a few occasions we offered two prey, of the same species, simultaneously, to evaluate hunting behaviour. In total, the jaguars captured and consumed 46 prey, including white-lipped peccaries *Tayassu pecari*, capybaras *Hydrochoerus hydrochaeris*, caimans *Caiman yacare* and feral pigs *Sus scrofa scrofa* (Table 1). After fitting collars equipped with GPS/VHF, recording one location per hour, and accelerometers, the jaguars were monitored for 30 days inside the enclosure, to provide baseline data on activity patterns and social behaviour.

The two jaguars were released at c. 27 months old, on 9 June 2016. To evaluate movement behaviour and estimate home range and spatial overlap, we used 16 months of telemetry data (June 2016–September 2017). We also performed visual appraisals using images captured by a c. 200 km² grid of 60 camera traps. We observed that jaguar no. 2 suffered initial loss of weight but recovered 20 days after release. The enclosure door remained open for 3 months and both jaguars returned several times. We fitted a continuous-time stochastic movement model (*ctmm*; Calabrese et al., 2016) in *R 3.5.1* (R Core Team, 2018) to evaluate movement behaviour and estimate home range. This method accounts for the inherent serial autocorrelation of our data and could handle irregularities in the sample schedule (Fleming et al., 2015). Range residence behaviour was checked by visual inspection of a semi-variogram (function *variogram* in *R*). Movement models were fit with maximum likelihood (function *ctmm.fit*) and ranked based on the Aikake information criteria (function *ctmm.select*). We estimated home range conditional on the fitted model for both individuals using the *akde* function (autocorrelated kernel density estimator). We estimated spatial overlap using the *overlap* function. Daily activity patterns were evaluated using *Activity Pattern Software* (Lotek, Newmarket, Canada) after recovering the accelerometer data from the GPS collars.

We adapted the method described by Cavalcanti & Gese (2010) to identify prey consumed. When >4 consecutive locations were found <100 m from each other this was classified as a kill site, where we then searched for prey remains to identify the species. Social behaviour, interactions and reproduction were investigated by observation and camera-trap images. Range residence was confirmed after visual inspection of a semi-variogram, 2 months post release (Morato et al., 2016). Home range estimates were 97.6 km²

TABLE 1 Total amount of meat consumed and dead and live prey offered to the two female jaguars *Panthera onca* during 238 days in an enclosure in the Caiman Ecological Refuge, in Miranda, Mato Grosso do Sul, Brazil.

	kg (no. of carcasses/individuals)
Meat	
Beef	137
Chicken	118
Pig	13
Dead prey	
Capybara *Hydrochoerus hydrochaeris*	55 (2)
Giant anteater *Myrmecophaga trydactila*	30 (1)
Caiman *Caiman yacare*	23 (1)
Live prey	
Capybara	400 (15)
White-lipped peccary *Tayassu pecari*	345 (16)
Caiman	185 (8)
Pig	110 (6)
Feral pig *Sus scrofa scrofa*	5 (1)

TABLE 2 Details of the 52 and 32 prey killed by female jaguars 1 and 2, respectively, after release (January 2017–December 2017) and, for comparison, the mean per cent of total prey killed by jaguars in an earlier study in the southern Pantanal.

Prey	Female 1 (% of total)	Female 2 (% of total)	Mean % of kills (range)[1]
Caiman	32 (61)	18 (56)	36 (10–52)
Capybara	1 (2)	4 (12)	3 (0–17)
White-lipped peccary	9 (17)	3 (10)	30 (0–57)
Armadillo *Dasypus novemcinctus*	1 (2)	3 (10)	2 (0–15)
Coati *Nasua nasua*	5 (10)	2 (6)	2 (0–11)
Raccoon *Procyon cancrivorus*		1 (3)	1 (0–4)
Crab eating fox *Cerdocyon thous*		1 (3)	1 (0–3)
Giant anteater	2 (4)		4 (0–17)
Deer *Mazama* sp.	1 (2)		2 (0–5)
Bird	1 (2)		1 (0–3)

[1]From Cavalcanti & Gese (2010).

(95% CI 79.1–118.1) for jaguar 1, and 64.2 km² (95% CI 55.5–73.7) for jaguar 2 (Fig. 1). Both individuals anchored their home range around the enclosure and showed high spatial overlap with each other (85%, 95% CI 74–94%; Fig. 1). The home ranges included areas with ecotourism and cattle ranching activities, areas with wild prey, and well-preserved natural vegetation. Directionality in movement paths, represented by the velocity autocorrelation timescale (h), were 0.45 (95% CI 0.42–0.46) and 0.45 (95% CI 0.42–0.48) for jaguar 1 and 2, respectively. Mean distances travelled per day were 9.6 and 10.3 km for jaguar 1 and 2, respectively. Daily

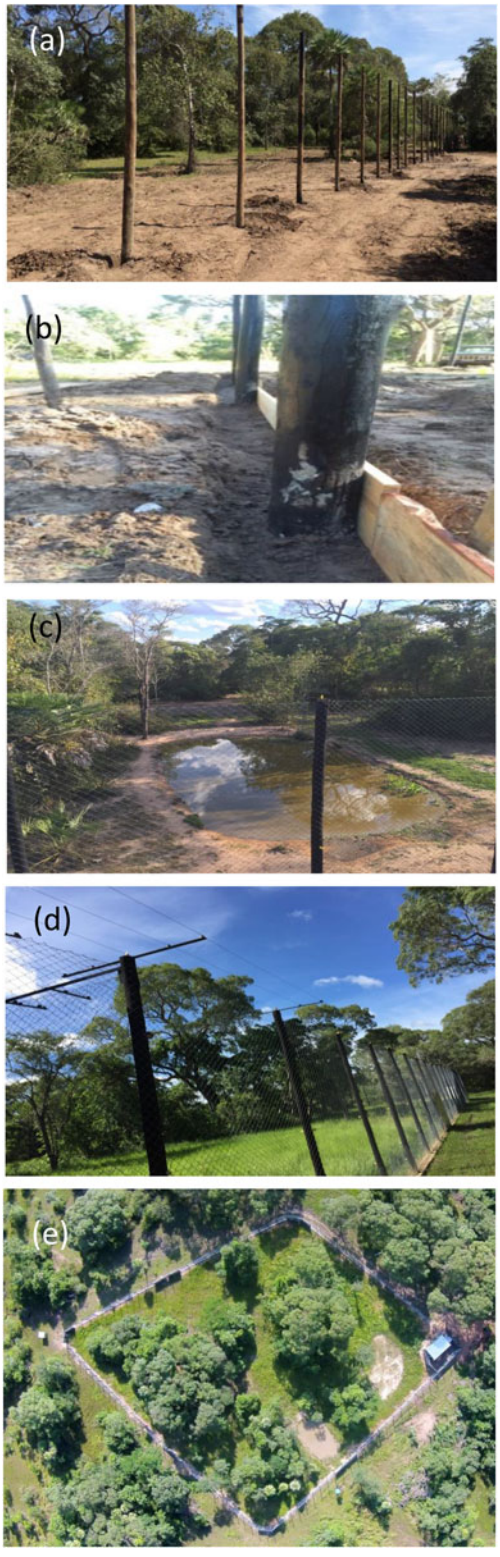

PLATE 1 The 1 ha enclosure in the Caiman Ecological Refuge (Fig. 1): (a) 4.5 m high eucalyptus posts, 3 m apart; (b) 40 cm deep trench excavated around the perimeter of the enclosure and filled with cement, to prevent any animal digging into or out of the enclosure; (c) c. 2 m deep, 60 m² pond; (d) galvanized wire perimeter fence of 2.2 mm gauge and 6 × 6 cm mesh, with electric wires at 40, 100 and 200 cm, both inside and outside and on the top of the fence; (e) aerial view.

Plate 2 (a) Jaguar 1 with her 6–7 month old cub, photo-trapped in December 2018, and (b) Jaguar 2 and her two 4–5 month old cubs, photo-trapped in December 2018.

activity was similar to that previously reported for jaguars, with both individuals moving (hunting and transiting) during the night and resting during the day (Kanda et al., 2019). We identified 10 species preyed upon by the two jaguars (Table 2). Social interactions were observed between the two jaguars and nine other individual jaguars), including mating, fighting and paired movement. Jaguar 1 gave birth to a cub in c. June 2018 and jaguar 2 gave birth to two cubs in c. August 2018 (Plate 2).

The two jaguars established residence near the enclosure, with home ranges, and movement and activity patterns similar to those reported for free living individuals (Morato et al., 2016), and prey consumption similar to that recorded in a previous study in the same area (Cavalcanti & Gese, 2010), including a high consumption of caimans. The exhibition of social interactions, and reproduction, indicate that the reintroduction was successful.

The main objective of a reintroduction is usually to re-establish or supplement an extinct or declining population (Cheyne, 2006). We released two individuals in an area where jaguars are not facing a high risk of extinction (Morato et al., 2013) and threats are low. Our intention was to evaluate a protocol that could be applied to other subpopulations across the species' range, and specifically for the Critically Endangered subpopulation of the Atlantic Forest (Morato et al., 2013). Despite the success of this reintroduction in the Pantanal we need to be cautious in using this tool for the species' long-term survival.

As a pre-condition for reintroduction, the highest priority must be to address the threats that are causing jaguar population declines. Firstly, some jaguar subpopulations are proximal to areas where people are active, potentially resulting in negative interactions. Jaguars involved in such interactions are often killed by members of the affected community (Inskip et al., 2013). In such areas, law enforcement to prevent killing of jaguars, and alleviation of negative interactions with ranchers, are required and should play a central role in planning any reintroduction (Caruso & Pérez, 2013). Secondly, in areas that have undergone deforestation (Ribeiro et al., 2009) or defaunation (Jorge et al., 2013), it is important to evaluate habitat quality and prey availability before establishing a reintroduction programme. Thirdly, social interaction is a key component. The absence of intersexual territoriality (Crawshaw & Quigley, 1991) suggests that reintroducing female jaguars is likely to increase the success of reintroductions in areas where male jaguars are present. Fourthly, jaguars tend to move in areas with which they are familiar, evidence of cognitive capacity and spatial memory (Kanda et al., 2019), and therefore building enclosures in the release area and keeping individuals there prior to release may facilitate acclimation. Fifthly, the cost of reintroduction needs to be compared to alternative strategies. The total cost for reintroducing the two female jaguars was c. USD 111,490, without considering the costs of previous studies of the species' behaviour in the same area. This reintroduction was in an area where spatial ecology, habitat and prey preferences were known (Cavalcanti & Gese, 2009, 2010; Morato et al., 2016). In the Atlantic Forest on the Argentina–Brazil border the main strategy for the southernmost jaguar subpopulation was to reduce persecution and poaching by means of education and law enforcement. The annual cost of the programme was c. USD 97,000 and after 10 years the jaguar population increased from an estimated 50 to 90 individuals (Paviolo et al., 2016).

In conclusion, reintroduction can be an important tool in areas where the jaguar population is in severe decline. It is the only option where the species has been extirpated and the management goal is reintroduction, residency and recovery. This study defines some of the practices and parameters that led to a successful outcome in the Pantanal.

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Ethical standards All research protocols were approved by Instituto Chico Mendes de Conservação da Biodiversidade and Sistema de Autorização e Informação em Biodiversidade (licenses 46508, 47979, 52734), and the research followed guidelines approved by the American Society of Mammalogists, and otherwise abided by the *Oryx* guidelines on ethical standards.

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