Translocation as a tool for the conservation of the jaguar *Panthera onca*: a case study in the Brazilian Atlantic Forest

Fernando C.C. Azevedo, Pedro H. Nobre, Giovanne A. Ferreira Ronaldo Morato, Rogério C. de Paula, Paulo R. Amaral, Eduardo Eizirik Caroline C. Sartor and Artur Andriolo

Abstract The success of translocation as a management tool is based on reversing the factors that led to a population becoming threatened or locally extinct. We assessed whether translocating a jaguar *Panthera onca* into the surroundings of a protected area in the Brazilian Atlantic Forest with a resident jaguar population was effective. We captured a male jaguar in an urban area where there were no substantiated previous records of jaguars. In the capture area only one predation event had been recorded, when the jaguar killed several chickens a few days before capture. After capture we translocated the jaguar to a forested area 240 km from the capture site, adjacent to the Rio Doce State Park. To investigate whether the potential geographical origin of the individual was any nearby fragment of the Atlantic Forest or nearby fragments of the Cerrado ecoregion, we genotyped it for 12 microsatellite loci and compared the results to a database developed previously. We fitted the jaguar with a GPS/VHF collar from which we recovered 2.5 months of data. Post-release monitoring with camera traps indicated the jaguar established residence within the region of the Park and we recorded no events of predation on livestock. The genetic analysis indicated that the jaguar resembled individuals from the Inner Atlantic Forest, Cerrado and Amazon. Translocation was an important tool for avoiding potentially negative interactions between the jaguar and local people, and may have benefitted the jaguar population at the release site.

Keywords Brazil, jaguar, *Panthera onca*, predation, survival, telemetry, translocation, wildlife management

The supplementary material for this article is available at doi.org/10.1017/S0030605323000662

Fernando C. C. Azevedo* (Corresponding author, orcid.org/0000-0001-9831-6692, fazevedo@ufsj.edu.br) Departamento de Ciências Naturais, Universidade Federal de São João del Rei, 36301-160, São João del Rei, Minas Gerais, Brazil.

Pedro H. Nobre (orcid.org/0000-0001-6702-227X) Departamento de Ciências Naturais, Universidade Federal de Juiz de Fora, Juiz de Fora, Brazil

Giovanne A. Ferreira (orcid.org/0000-0001-5507-7206) Instituto de Pesquisas Cananéia, Cananéia, Brazil

Ronaldo Morato (orcid.org/0000-0002-8304-9779), Rogério C. de Paula (orcid.org/0000-0003-1943-8320) and Paulo R. Amaral Instituto Chico Mendes de Conservação da Biodiversidade, Atibaia, Brazil

Eduardo Eizirik (orcid.org/0000-0002-9658-0999) and Caroline C. Sartor (orcid.org/0000-0002-3552-0140) Laboratório de Biologia Genômica e Molecular, Escola de Ciências da Saúde e da Vida, Pontifícia Universidade Católica do Rio Grande do Sul, Porto Alegre, Brazil

Artur Andriolo (orcid.org/0000-0002-5582-0183) Departamento de Zoologia, Laboratório de Ecologia Comportamental e Bioacústica, Universidade Federal de Juiz de Fora, Juiz de Fora, Brazil

*Also at: Instituto Pró-Carnívoros, Atibaia, Brazil

Received 03 November 2022. Revision requested 1 February 2023. Accepted 19 May 2023.

Jaguar *Panthera onca* populations are becoming threatened or locally extinct in the Atlantic Forest (Paviolo et al., 2016). The level of isolation of some populations and the increasing human encroachment into their habitats could prevent the establishment of suitable corridors to reconnect populations, thus compromising the long-term persistence of jaguars across the Atlantic Forest (Paviolo et al., 2016). Translocations could promote the long-term persistence of these small and isolated jaguar populations (Massei et al., 2010). Translocation is widely used for apex carnivores involved in human–wildlife conflicts but without a consensus on its effectiveness (Fontúrbel & Simonetti, 2011). We assessed whether translocating a jaguar into the surroundings of an Atlantic Forest protected area with resident conspecifics was effective. The presence and behaviour of this jaguar in an urban area led to public pressure for its capture and translocation. The jaguar population at the protected area had an estimated density of 1.61 ± SE 0.6 individuals/100 km² (Azevedo et al., 2022). We adopted the IUCN (2013) guidelines for conservation translocations, which require a feasibility study, a preparation phase, a release phase and a monitoring phase.

The capture site is within the Botanical Garden of the Federal University of Juiz de Fora in the municipality of Juiz de Fora, Minas Gerais state, Brazil (Fig. 1), within a remaining fragment of semi-deciduous Atlantic Forest that, together with other preserved remnants, totals c. 3.74 km² (Rabelo & Magalhães, 2011). The forest fragments are surrounded by an urban area (McKinney, 2006). The release site is a forested area adjacent to the c. 360 km² Rio Doce State Park (Fig. 2) in south-eastern Brazil, the largest continuous protected remnant of Atlantic Forest in Minas Gerais state (Gontijo & Britto, 1997). On 25 April 2019, an adult jaguar appeared within the Botanical Garden and

was filmed by a night watchman using a mobile phone. A committee of experts comprising representatives of the Federal University of Juiz de Fora, the City Hall of Juiz de Fora, local military police, the fire department, the local Brazilian army, the Centro Nacional de Pesquisa e Conservação de Mamíferos Carnívoros and the Instituto Estadual de Florestas began to monitor its presence and movements. On 27 April 2019, seven camera traps (Bushnell Trophy HD, Bushnell, Overland Park, USA) were installed within the Botanical Garden, and the next day the jaguar was recorded in various places (Fig. 1; Plate 1). During the following days, information about the presence of the jaguar (Plate 1) was disseminated widely in the media. In late April 2019, the jaguar was recorded in the parking lot of a hotel, in a residential neighbourhood square, in the parking lot of a church and in urban residential areas (Fig. 1). Two attacks on domestic fowl were recorded at point 5 of Fig. 1. The committee of experts then decided to capture and remove the jaguar to a safer location.

On 3 May 2019, five leg-hold traps and four box traps were set within the Botanical Garden. The jaguar was captured on 12 May in one of the box traps. We immobilized the jaguar (hereafter called Juiz), sexed and weighed it and took blood and hair samples and biometric measurements. Juiz was an adult male, c. 4–5 years old based on tooth wear. He weighed 51.6 kg, was 1.80 m in length and had no marks that indicated injuries or aggressive encounters with other males, no ectoparasites or any other signs of weakness or disease. We fitted Juiz with a GPS/VHF collar (Lotek, Iridium Track M 2D, Newmarket, Canada) programmed to record his location every hour, and transported him by vehicle. We estimated his home range and evaluated his movement behaviour at the release site using autocorrelated kernel density estimation in continuous-time movement models in package *ctmm* (Calabrese et al., 2016) in *R 4.1.0* (R Core Team, 2021) with 95% confidence levels. We visually inspected a semi-variogram to check his range residence behaviour. We used a camera-trap grid in Rio Doce State Park to evaluate his behaviour at the release site, and linear regression to investigate any potential spatial or temporal association between his movements and nearby urban areas. Specifically, we examined whether Juiz was more attracted to anthropogenic areas or to areas covered predominantly by native vegetation, and whether any relationship changed with time after translocation. We used the number of days after release as the predictive variable and distances to nearby urban areas and to the Park limits as the response variables.

There are no previous confirmed records of jaguars in Juiz de Fora. To investigate whether the potential geographical origin of Juiz was a nearby fragment of the Atlantic Forest or of the Cerrado, we genotyped Juiz for 12 microsatellite loci and compared the results to a comprehensive database developed previously (Kantek et al., 2021) and to 13 new jaguar samples encompassing individuals from four Brazilian ecoregions. We used the Bayesian clustering implemented in *structure 2.3.4* (Pritchard et al., 2000) to assess which regional population had the highest assignment probability for Juiz (Supplementary Material 1).

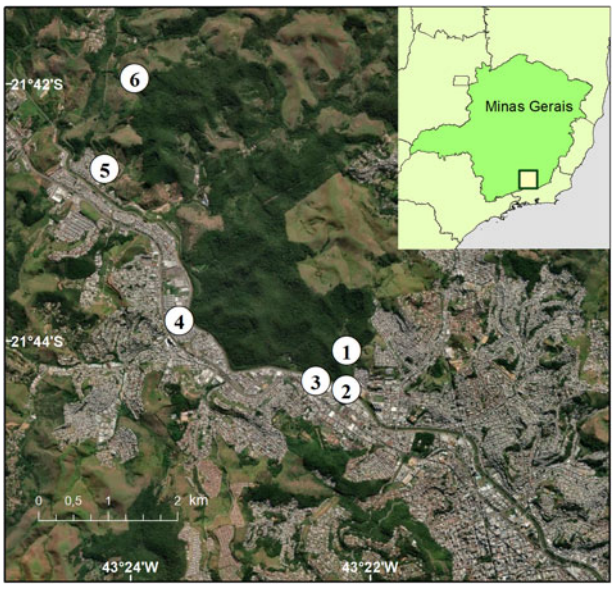

FIG. 1 Locations in which the male jaguar *Panthera onca* (Juiz) was recorded in the municipality of Juiz de Fora, Minas Gerais state, Brazil, during 27 April–12 May 2019. (1) Botanical Garden of the Federal University of Juiz de Fora, (2) parking lot of a church neighbouring the Botanical Garden, (3) hotel in São Dimas neighbourhood, near the Juiz de Fora bus station, (4) public square of an industrial neighbourhood, (5) Portal das Torres neighbourhood, and (6) a residential condominium.

On the night of capture we translocated Juiz by vehicle 240 km from the capture area, and hard-released him on 13 May 2019 in a patch of forest c. 125 m from the Rio

PLATE 1 The jaguar Juiz recorded at the Botanical Garden, Federal University of Juiz de Fora, municipality of Juiz de Fora, Minas Gerais state, Brazil, before being captured and translocated. Photo: Pedro H. Nobre.

Doce State Park border. Juiz moved in and out of the Park, moving as far as 13 km from its border and then returning on 17 July 2019. His last location (when the collar stopped functioning) was on 24 July 2019, 6.3 km from the Park border. After several unsuccessful attempts to locate Juiz, the collar was accidentally recovered on 11 May 2020 on top of the body of a recently eaten southern tamandua *Tamandua tetradactyla*, c. 1 km from the south-east border of the Park and 6.7 km from the original release site (Fig. 2).

We obtained a total of 837 GPS locations during 13 May–24 July 2019, but 2.5 months after release the semi-variogram did not confirm that the residence range of Juiz was within limits of the Park. However, 11 camera-trap records indicated that Juiz established residence in the region of the Park until July 2021 (Fig. 2). He ranged over 845.6 km² (95% CI 648.2–1,068.9 km²). There was a significant relationship ($\beta = -0.02968$, $P < 0.001$) between distance from nearby urban areas and days after release, with a decrease of 30 m in distance from nearby urban areas (villages with < 3,000 people) with every additional day after release. However, this model explained only a low proportion of the variability in distance maintained from nearby urban areas ($r^2 = 0.025$). There was also a significant relationship of distance maintained from Park limits and days after release ($\beta = 0.19918$, $P < 0.001$), with an increase of 200 m from the Park boundary every additional day after release. Similarly, this model explained a low proportion of the variability ($r^2 = 0.063$).

The genetic assignment analyses yielded consistent results amongst the several datasets (complete database vs several population subsets). For most of the datasets, when the number of assumed genetic clusters was low ($K = 3–4$), individuals of the Amazon, Cerrado and Green Corridor (Inner Atlantic Forest) formed one genetic cluster, in which Juiz was included. However, when $K \geq 5$, we could divide these individuals into two or more clusters, Juiz usually clustered with samples from the Amazon and Cerrado. However, Juiz had the highest membership coefficient ($q = 0.9664$) when we only considered individuals from the Atlantic Forest and Cerrado, clustering with individuals from the Green Corridor and Cerrado (Supplementary Table 1, Supplementary Fig. 1).

In the state of Minas Gerais records of jaguars are mostly within protected areas such as Rio Doce State Park (Azevedo et al., 2022) and Grande Sertão Veredas, Caparaó, Itatiaia, Cavernas do Peruaçu and Sempre Vivas National Parks (Morato et al., 2018). Juiz could have originated from the closest area with recent records of jaguars, which is the Serra do Mar region, c. 90 km from Juiz de Fora (the area between contains small to medium forest fragments and urban areas). Other potential sources are Itatiaia National Park, c. 150 km from Juiz de Fora, and the area of Parque Estadual da Serra do Brigadeiro, close to Caparaó National Park, also c. 150 km from Juiz de Fora. Less likely, Juiz could have come from fragments of the Cerrado ecoregion, c. 200 km from Juiz de Fora. We suggest that upon reaching sexual maturity Juiz could have begun his displacement through forest fragments and pasture areas, maintaining as temporary territory the Área de Proteção Ambiental Mata do Krambeck and its vicinities. His temporary residence in the Juiz de Fora region can be explained by the abundant occurrence of prey such as the capybara *Hydrochoerus hydrochaeris* and paca *Cuniculus paca* on the banks of the Paraibuna River in this region. Over time, with the decrease or dispersion of prey because of his presence, Juiz may have been forced to forage in urban areas. The occurrence of Juiz

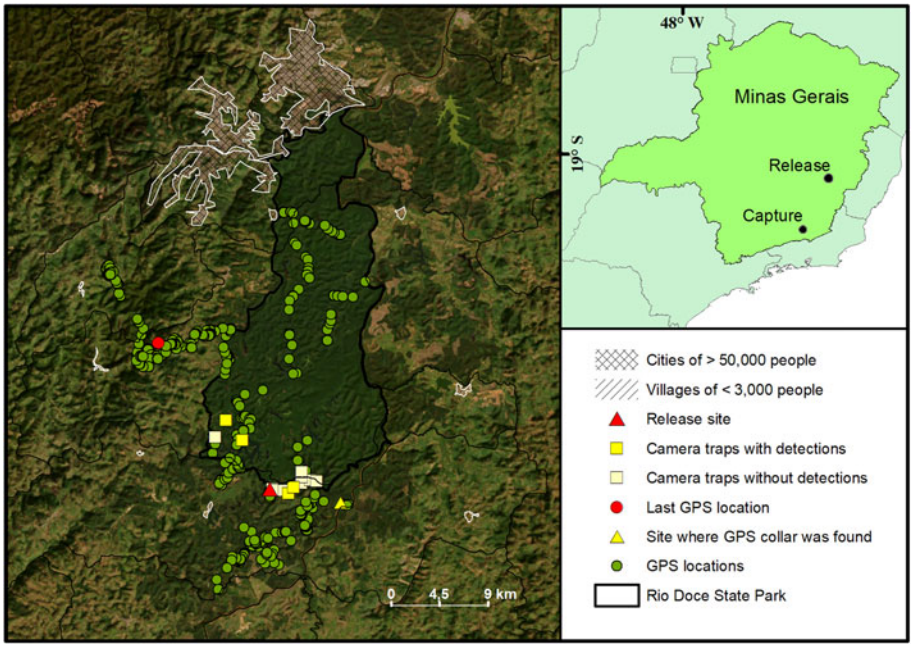

FIG. 2 Geographical locations of the male jaguar Juiz in and around Rio Doce State Park, Minas Gerais state (the release site), during 13 May 2019–December 2021, recorded on a GPS collar and by camera traps. The inset indicates the locations of both the capture site in Juiz de Fora municipality and the release site.

in the urban area could have led to situations similar to those experienced by leopards *Panthera pardus* in India (Athreya et al., 2013, 2016), in which a low density of prey increased the chances of predation upon livestock and domestic dogs *Canis lupus familiaris*, leading to illegal killings of leopards in retaliation (Athreya et al., 2016).

Attempts to translocate jaguars have provided inconclusive evidence regarding whether this technique guarantees residence at release sites, mostly because of a lack of post-release monitoring (Gasparini-Morato et al., 2021). We were able to verify that translocation fulfilled five conditions. Firstly, the risk of attacks on humans was removed. Secondly, we confirmed the survival of Juiz for >2 years at the release site. Thirdly, Juiz established residence at the release site in an area that includes Rio Doce State Park. During the short-term period of GPS monitoring, the movements of Juiz indicated some tolerance towards villages of $<3{,}000$ people, but he did not approach any towns (i.e. $>50{,}000$ people), and we found no records of his presence within villages. In addition, his GPS locations indicated no attempts to return to his capture site. Fourthly, Juiz did not appear to prey on livestock at the release site. Fifthly, local people at the capture site accepted that the process of translocation eliminated the potential risk of attacks on humans. At the release site there have been no complaints, to our knowledge, about the presence of Juiz, presumably because he did not predate livestock.

Although Juiz was assigned to the Amazon/Cerrado genetic groups, we cannot exclude the possibility that he came from an Atlantic Forest population. Cerrado individuals have high levels of admixture, especially with the Atlantic Forest and the Amazon, and this admixture could indicate that historically the Cerrado was a corridor for gene flow between these ecoregions. As a result of the small sample size for this ecoregion, the assessed molecular markers could not be used to reliably assign a sample to the Cerrado because of the lack of diagnostic genetic features. Moreover, most remaining Atlantic Forest jaguar populations show high genetic differentiation, low diversity and low effective sizes (Haag et al., 2010; Srbek-Araujo et al., 2018). Small and isolated populations are prone to inbreeding and loss of genetic diversity because of genetic drift (Gibbs, 2001), making individuals from such a population more similar to each other but more different from individuals of other populations. The high isolation and small size of Atlantic Forest populations could explain why Juiz had low genetic similarity with individuals from the closest sampled population, Reserva Natural Vale, and high similarity with individuals from the farthest Atlantic Forest population, the Green Corridor (Supplementary Table 1). The Green Corridor comprises the largest Atlantic Forest remnant, and its jaguar population may represent the genetic composition of Atlantic Forest jaguars prior to the severe fragmentation of this ecoregion. In addition, our database did not include some of the remnant jaguar populations from the coastal portion of the Atlantic Forest, including Rio Doce State Park. Juiz might have originated from a small, unsampled coastal Atlantic Forest population remnant with a unique genetic profile as a result of genetic drift. The other sample from Minas Gerais state, bPon-057 (Supplementary Material 1), demonstrated high levels of admixture and could not be assigned to any genetic cluster. This sample was collected within the Atlantic Forest ecoregion, c. 300 km south of where Juiz was captured, and it could indicate that other unsampled jaguar populations from the costal Atlantic Forest have distinct genetic features.

The translocation of Juiz avoided any potentially negative interactions between a wild predator and people in Juiz de Fora, and could have benefitted the local jaguar population at the release site. By investing substantial time and effort into planning the translocation, we were able to increase the chances of the survival and permanent residence of the jaguar at the release site. Continued population monitoring and genetic evaluation of the recipient population will be crucial for evaluating the long-term success of the translocation and any potential negative impacts on the local jaguar population, such as stochastic behavioural events that could have greater impact in a small population with low genetic variability. We recommend that future jaguar translocations should be based on objective and rigorous evaluation of the potential role of translocation in resolving human–wildlife conflict and benefitting the jaguar population at the release site.

Acknowledgements We thank the institutions and departments Pró-reitoria de Extensão–Jardim Botânico, Direção de Imagem Institucional, Instituto Chico Mendes de Conservação da Biodiversidade, Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, Polícia Ambiental de Juiz de Fora, Policia Militar de Juiz de Fora, Corpo de Bombeiros, Exército Brasileiro, Instituto Estadual de Floresta, Prefeitura de Juiz de Fora–Secretaria de Meio Ambiente, Procuradoria do Estado de Minas Gerais and Ministério Público de Minas Gerais, and Marcus Vinícius David, Ana Lívia de Souza Coimbra, Gustavo Soldati, Breno Moreira, Márcio Guerra, Raul Mourão, Sarah Stutz Reis, Glauber Barino, Rafael Monteiro, Elildo Alves Carvalho Junior, Ricardo Corassa Arrais, Alexandra Cumerlato, Cynthia Widmer de Azevedo, Antonio Carlos Barbosa and Luciano Mendes for their help with the translocation. This study was funded by Universidade Federal de Juiz de Fora, Instituto Chico Mendes de Conservação da Biodiversidade, Universidade Federal de São João del Rei, Instituto Estadual de Florestas de Minas Gerais and Ministério Público de Minas Gerais.

Author contributions Study design: FCCA, PHN, AA; fieldwork: FCCA, PHN, AA, RCdP, PRA; data analysis: FCCA, PHN, AA, RCdP, EE, CCS; writing: FCCA, PHN, AA, GAF, EE, CCS, RM; revision: FCCA, PHN, AA, PRA, GAF, EE, CCS, RM.

Conflicts of interest None.

Ethical standards Animal handling procedures followed research permit 34284-8 of Instituto Chico Mendes de Conservação da

Biodiversidade, Ministério do Meio Ambiente, Brazil, and this research otherwise abided by the *Oryx* guidelines on ethical standards.

Data availability The data that support the findings of this study are available from the corresponding author, FCCA, upon reasonable request.

References

Athreya, V., Odden, M., Linnell, J.D.C., Krishnaswamy, J. & Karanth, U. (2013) Big cats in our backyards: persistence of large carnivores in a human dominated landscape in India. *PLOS One*, 8, e57872.

Athreya, V., Odden, M., Linnell, J.D.C., Krishnaswamy, J. & Karanth, K.U. (2016) A cat among the dogs: leopard *Panthera pardus* diet in a human-dominated landscape in western Maharashtra, India. *Oryx*, 50, 156–162.

Azevedo, F.C.C., Pasa, J.B., Arrais, R.C., Massara, R.L. & Widmer, C.E. (2022) Density and habitat use of one of the last jaguar populations of the Brazilian Atlantic Forest: is there still hope? *Ecology and Evolution*, 12, 1–15.

Calabrese, J.M., Fleming, C.H. & Gurarie, E. (2016) *ctmm*: an *R* package for analyzing animal relocation data as a continuous-time stochastic process. *Methods in Ecology and Evolution*, 7, 1124–1132.

Fontúrbel, F.E. & Simonetti, J.A. (2011) Translocations and human–carnivore conflicts: problem solving or problem creating? *Wildlife Biology*, 17, 217–224.

Gasparini-Morato, R.L., Sartorello, L., Rampim, L., Fragoso, C.E., May, J.A., Teles, P. et al. (2021) Is reintroduction a tool for the conservation of the jaguar *Panthera onca*? A case study in the Brazilian Pantanal. *Oryx*, 55, 461–465.

Gibbs, J.P. (2001) Demography versus habitat fragmentation as determinants of genetic variation in wild populations. *Biological Conservation*, 100, 15–20.

Gontijo, B.M. & Britto, C.Q. (1997) Identificação e Classificação dos Impactos Ambientais no Parque Florestal Estadual do Rio Doce – MG. *Geonomos*, 5, 43–48.

Haag, T., Santos, A.S., Sana, D.A., Morato, R.G., Cullen, Jr, L., Crawshaw, Jr, P.G. et al. (2010) The effect of habitat fragmentation on the genetic structure of a top predator: loss of diversity and high differentiation among remnant populations of Atlantic Forest jaguars (*Panthera onca*). *Molecular Ecology*, 19, 4906–4921.

IUCN (2013) *The IUCN Red List of Threatened Species*. iucnredlist.org [accessed May 2023].

Kantek, D.L.Z., Trinca, C.S., Tortato, F., Devlin, A.L., Azevedo, F.C.C. & Cavalcanti, S. et al. (2021) Jaguars from the Brazilian Pantanal: low genetic structure, male-biased dispersal, and implications for long-term conservation. *Biological Conservation*, 259, 109153.

Massei, G., Quy, R.J., Gurney, J. & Cowan, D.P. (2010) Can translocations be used to mitigate human–wildlife conflicts? *Wildlife Research*, 37, 428–439.

McKinney, M.L. (2006) Urbanization as a major cause of biotic homogenization. *Biological Conservation*, 127, 247–260.

Morato, R.G., Thompson, J.J., Paviolo, A., de La Torre, J.A., Lima, F., McBride, R.T. et al. (2018) Jaguar movement database: a GPS-based movement dataset of an apex predator in the Neotropics. *Ecology*, 99, 1691.

Paviolo, A., De Angelo, C., Ferraz, K.M.P.M.B., Morato, R.G., Martinez Pardo, J., Srbek-Araujo, A.C. et al. (2016) A biodiversity hotspot losing its top predator: the challenge of jaguar conservation in the Atlantic Forest of South America. *Scientific Reports*, 6, 37147.

Pritchard, J.K., Stephens, M., Rosenberg, N.A. & Donnelly, P. (2000) Association mapping in structured populations. *American Journal of Human Genetics*, 67, 170–181.

Rabelo, M. & Magalhães, B. (2011) Preservação e planejamento de conservação da mata do krambeck. *Revista Geográfica de América Central*, 2, 1–13.

R Core Team (2021) *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. R-project.org [accessed May 2021].

Srbek-Araujo, A.C., Haag, T., Chiarello, A.G., Salzano, F.M. & Eizirik, E. (2018) Worrisome isolation: noninvasive genetic analyses shed light on the critical status of a remnant jaguar population. *Journal of Mammalogy*, 99, 397–407.