FULL ARTICLE

Predicted distribution and habitat loss for the endangered Black-faced black spider monkey (*Ateles chamek*) in the Amazon

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ABSTRACT

Amazonian deforestation is on the rise. Predictive models estimate that agriculture expansion will soon reduce 40% of forests, diminishing habitat of forest-dwelling species, such as the endangered black-faced black spider monkey (*Ateles chamek*). This species has been losing much of its habitat, particularly along the arc of deforestation in the Brazilian Amazon. In this study we used species distribution modelling (SDM) to (i) estimate the species distribution according to environmental predictors; (ii) quantified species' distribution area covered by protected areas network; and (iii) quantified species habitat loss, according to future scenarios of deforestation. We found that the species occupies only ~28% of its extent of occurrence (model accuracy: TSS = 0.56 ± 0.06). Only 32% of the species' area of occupancy is legally covered by protected areas, and the species is expected to lose 31 to 40% of its habitat until 2050. We indicate three unprotected regions, with a considerable amount of current forest cover, that are expected to become severely deforested in the next decades, as the priority regions for expanding protected area network. We also propose three human-modified regions as areas for landscape management and restoration. Our study provides a useful example of how SDM can be applied to assess threats to species and for supporting decision-makers to implement conservation actions.

KEYWORDS

Deforestation, landscape planning, Maxent, primates, protected areas, reserve design

INTRODUCTION

Over the past few decades, Amazonian forests have been undergoing unprecedented disturbances mainly due to the intensification of extensive single-crop agriculture, cattle ranching, logging and urban footprints (Davidson et al., 2012). Predictive models of deforestation estimate that, by 2050, agriculture expansion will reduce 40% of forests, and about one-quarter of mammal species may lose more than 40% of their habitats in the Amazon (Soares-Filho et al., 2006).

Deforestation is obviously harmful to forest-dwelling species, such as Neotropical primates, which spend all their lives on trees, rarely coming down to the forest floor or crossing open areas. Not surprisingly, habitat loss and fragmentation have been considered the main direct threat to primates (Estrada et al., 2017). Neotropical primates often occupy important trophic positions in forest food webs (Terborgh, 1983) and usually play an important role as seed dispersers (Hawes & Peres, 2014), which means that their demise is likely to produce cascading ecological effects. The Black-faced black spider monkey (*Ateles chamek*) is an Amazonian primate species that is listed as Endangered by the IUCN (Wallace et al., 2008). The forests in the southern portion of its range are among the hardest-hit areas by deforestation due to expanding Brazilian agriculture frontier – a region that has been nicknamed as the 'arc of deforestation'.

Species distributional data are essential to indicate priority regions for establishing conservation actions (Brooks et al., 2006). Species distribution models (SDMs) have been widely recognised as valuable tools in species/habitat conservation plans, reserve design and habitat management and restoration (Franklin, 2009). These models evaluate the relationships between occurrences of a target species and a set of spatially-explicit environmental variables in order to estimate the species' environmental requirements, and project them in geographical space. SDMs have been widely applied in conservation science and practice, which make them usefull for supporting decision-making to inform conservation actions (Villero et al., 2017).

Here we use SDM to predict the distribution of the black-faced black spider monkey (*Ateles chamek*). Our objective is to quantify the areas with highest habitat suitability that are protected by protected areas and indigenous lands. In addition, we estimate current and future habitat loss for the species, using two scenarios of deforestation across Amazon Basin (Soares-Filho et al., 2006). Finally, we propose priority areas for the conservation of this species, through the implementation of new protected areas, and to the restoration of the forest landscape connectivity.

METHODS

Species Distribution Modelling

We used the maximum entropy algorithm, in MAXENT 3.3.3, to map habitat suitability for the species and estimate its potential distribution (Phillips & Dudík, 2008). This algorithm seeks non-random relationships between species' occurrences and environmental variables, building a model that estimates the species potential distribution according to relevant variables.

We gathered data on species occurrence from the literature, online datasets (such as the Global Biodiversity Information Facility – GBIF [www.gbif.org]; speciesLink [splink.cria.org.br]; and Macaulay Library at the Cornell Lab of Ornithology [www.macaulaylibrary.org]) and personal observation. Age of occurrence records varied from 1979 to 2017 (Table S1). We inspected all records, excluding those with uncertain species identification, inaccurate geographic location or located on areas already deforested. We only used old records if they were located in areas with current pristine forests, assuming that the species is still likely to be present and/or that we would model the habitat suitability for the species at a broader time-frame. After excluding those records, we randomly removed duplicate records within a 30-km radius, in order to control for the sampling bias (Boria et al., 2014), as the species' records in the Amazon are commonly spatially clustered in long-term and well-studied sites. We obtained a total of 172 occurrence records of *A. chamek*, from which 99 were used in the model, after the records filtering (Tab. S1, Appendix 1). Then, we plotted all records into a GIS environment and created a polygon layer that included all records. As the range of Amazonian primates are usually limited by large rivers (e.g., Boubli et al., 2015), we drew the boundaries of this polygon following the rivers, comprising the entire interfluvial region that included species' records (see Fig. 1). This polygon was defined as the species' 'extent of occurrence' (*sensu* IUCN, 2012), and it was used to parameterize the model and to project the species distribution.

We chose 19 freely-available environmental variables that we would expect to somehow influence species distribution (Tab. S2). These variables consisted of climatic (10), topographic (4), edaphic (2) and vegetation (3) layers at 10-km resolution. We used the species' extent of occurrence polygon to crop the environmental variables and then we performed a pair-wise correlation test (Tab. S3). We removed all highly correlated variables ($r > |0.8|$) to avoid collinearity problems (Carvalho et al., 2017). We ended up using nine predictor variables in the model: (i) temperature seasonality; (ii) minimum temperature of coldest month; (iii) annual precipitation; (iv) precipitation seasonality; (v) annual potential evapotranspiration; (vi) flooded areas, (vii) compound topographic index, which is a measure of soil wetness; (viii) high above nearest drainage; and (ix) net primary productivity.

We used 5,000 random background records and divided the occurrences in 10 subsets (1 training, 9 testing), using the cross-validation technique to validate the model (Phillips & Dudík, 2008) (see Appendix 2 for further details of model parametrization). We converted the continuous prediction of habitat suitability into a binary prediction, by setting a threshold of habitat suitability, above which we considered that habitat is occupied (i.e., species' 'area of occupancy', *sensu* IUCN, 2012). We accomplished this task by choosing the threshold with equal sensitive (rate of true presences) and specificity (rate of true absences). We evaluated model accuracy with the True Skill Statistic (TSS), an effective and well-accepted measure of accuracy for binary predictions (Allouche et al., 2006). All procedures were performed on R software version 3.3.3 (R Development Core Team, 2016).

Threats assessment and priority regions for conservation

We used QGIS 2.14 (QGIS Development Team, 2015) to overlay the prediction of species distribution, the protected areas and indigenous lands (UNEP-WCMC, 2016), and the current and future scenarios of forest cover modelled by Soares-Filho et al. (2006). These authors modelled the future patterns of deforestation across the Amazon Basin, from 2002 to 2050, for two scenarios: (i) a "Business-as-Usual" (BAU) scenario, which considers that current deforestation trends will continue, highways scheduled for paving will be paved, compliance with legislation requiring forest reserves on private land will remain low, and new protected areas will not be implemented; and (ii) a "Governance" scenario, that also considers the current deforestation trends, but assumes a 50% limit imposed for deforested land within each basin's sub-region, and that existing and proposed protected areas play a determinant role in hindering deforestation. We calculated the extent of areas currently covered by protected areas and indigenous lands, as well as current and future forested, deforested and non-forest areas within the species' area of occupancy.

Finally, we used these overlaid layers to indicate priority regions for the conservation of species. We indicated regions for expanding protected area network those regions (i) with high habitat suitability for the species (> 40 %); (ii) considerably covered by forests (> 75 % of forest cover); (iii) expected to become severely deforested by 2050 (> 50 % of deforested area by 2050) because they are not under any protection; and (iv) that are adjacent to existing protected areas/indigenous lands. Also, we indicated human-modified regions with (i) high habitat suitability for the species (> 40 %); (ii) that have already become deforested but are about to become even more devastated (> 70 % of deforested area by 2050); and (iii) are adjacent to existing protected areas/indigenous lands (i.e., forest continuums), as potential areas for landscape planning, management and/or restoration.

RESULTS

The habitat suitability and predicted species distribution are shown in Figure 1. According to our model, the species has a considerably reduced occupied area within its extent of occurrence, being expected to occupy an area of 927,754 km^2 (only 28% of the extent of occurrence). We found that the species is more likely to occur in the central-southern region of its range, where the habitat suitability is higher (Fig. 1). We also found suitable habitats for the species in the north-western part of its range, in the Amazonas-Javary interfluviual region, in Peru; and in the Lower-Jutaí and Juruá rivers, in Brazil.

The most important variables in the model were temperature seasonality, net primary productivity and potential evapotranspiration, which jointly contributed with 57 % to the model gain in all iterations (24 %, 21 %, and 12%, respectively; Tab. S4). According to our model, higher forest productivity and higher temperature variation are associated with higher habitat suitability for the species. On the other hand, the higher the potential evapotranspiration (i.e., dryer environments), the lower the habitat suitability for the species. The mean threshold of equal sensitivity-specificity was 35.75 %, above which we considered that the species is present. Model averaged TSS score was 0.56 ± 0.05 (mean ± S.D.), which gave us a good confidence about the accuracy of our prediction (Appendix 2).

We found that only 297,603 km^2 (32% of the species' area of occupancy), fall within protected areas (231,009 km^2 – 24%) and indigenous lands (81,489 km^2 – 8%). Based on the deforestation estimates (Soares-Filho et al., 2006), until 2002, the species had already lost 15% (~127,306 km^2) of the forest cover within its predicted occupied area (Fig. 2). Most of the forest loss occurred in the Rondônia state, in Brazil. According to the future scenarios of deforestation, the species may lose 31% (273,287 km^2) of its high suitable habitat in the 'Governance' scenario, and up to 40% (377,951 km^2) in the 'BAU' scenario (Fig. 2).

We indicated six priority regions for the conservation of species (Fig. 3; Tab. 1). Three of these priority regions consisted of areas indicated for implementation of new protected areas (Fig. 3a-c). One of these regions encompasses three South American countries – Peru, Bolivia and Brazil (Fig. 3a). The other two regions are entirely located Brazil (Fig. 3b) and Bolivia (Fig. 3c). We indicated another three human-modified regions as areas for landscape planning, involving protection of forest remnants, as well as landscape management (Fig 3d-f). Two of them are located in Rondônia state in Brazil (Fig. 3d and 3e) and one in Santa Cruz department, in Bolivia (3f).

DISCUSSION

Here we compiled the largest ever published dataset to date on *A. chamek* occurrence records. We found that the species occurs beyond the extent proposed by IUCN (Wallace et al., 2008) (Fig. A1), as it has been previously notified (Palminteri et al., 2011; Rabelo et al., 2014; Santos-Filho et al., 2017). However, according to our model, the species occupies only about 28 % of its extent of occurrence, which is an empirically-based information that we consider relevant and that should be taken into account for a species of conservation concern.

Following Soberón & Nakamura's (2009) definitions, which are also adopted by the IUCN criteria (IUCN, 2012), the species' extent of occurrence is the area that is/has been accessible to the species given its dispersal ability, during a given time-frame. However, it is not expected that a species occupies its entire extent of occurrence uniformly because of biotic or environmental limitations. In this context, after having set the threshold of habitat suitability, above which we expect the species is present, we may assume that: (i) the filled areas within extent of occurrence (Fig. 1, right map) correspond to the species' area of occupancy; (ii) species records located within filled areas correspond to populations occurring on highly-suitable habitats; and (iii) records located on unfilled areas represent populations occurring on habitat with environmental constraints.

It may be argued that our model did not predict suitable areas for the species in the Central-North and Eastern portions of the species' extent of occurrence because the absence of records in these regions. However, there have been exhaustive and long-term primate surveys in those regions that did not record the species or recorded at very low densities (Peres, 1997; Haugaasen and Peres, 2005; Kasecker, 2006; Bastos, 2012; Gonçalves et al, in review). Therefore, we do not believe that our model was biased by the absence of records in these regions. Instead, we believe that these regions were predicted to be unoccupied due to unsuitable environmental conditions.

According to our model, temperature variation and high net primary productivity were the most important variables for predicting species distribution (Table S4). Trees in seasonal and highly-diverse forests tends to produce fruits asynchronously (van Schaik et al., 1993), and forests with high primary productivity generally have high fruit production (Clark et al., 2001). Spider monkeys are primary consumers and have been consistently identified to be among the most frugivorous Neotropical primates (Di Fiore et al., 2008). Thus, we could expect that areas with higher temperature seasonality and primary productivity would represent areas with high habitat suitability for the species.

We found that most of the species' area of occupancy is outside protected areas (68%). As the habitat loss advances in tropical forests, protected areas become essential refuges for wildlife. Gray et al. (2016) recently showed that protected areas harbour higher species richness and abundance than unprotected areas, reinforcing that they are the cornerstone of *in situ* conservation of viable populations in natural ecosystems worldwide. Thus, once studies have consistently shown the role of protected areas and indigenous lands in safeguarding Amazonian forests (Nepstad et al., 2006; Dobrovolski et al., 2011; Blackman et al., 2017), we believe that they still are an effective tool for conservation spider monkeys and many other species.

Although expanding protected area network would help to inhibit habitat loss, this may not be enough for the conservation of the black-faced black spider monkey. Even under the most conservative scenario of deforestation (the governance scenario), the deforested area within species distribution in 2050 is expected to be twice as large as it was in 2002. It is worth noting that the governance scenario assumes effective implementation of environmental legislation across the Amazon basin through the enforcement of mandatory forest reserves on private properties, agro-ecological zoning of land use and the expansion of PA network (Nepstad et al., 2002), requiring even some international conservation policies. However, it is very unlikely that these experiments in frontier governance are going to be refined and multiplied, especially after the controversial changes in Brazilian legislation regulating land use on private properties (Soares-filho et al., 2014). Therefore, the BAU is a more realistic scenario, which will result in a loss of 40% of the forested area within the black-faced black spider monkey distribution.

We identify six priority regions for the conservation of the black-faced black spider monkey, all of them currently outside protected areas. Three of these priority regions still have a considerable amount of forest cover (Fig. 3; Tab. 1), but according to the deforestation scenarios, these areas are about to become severely deforested because they are not under protection. Spider monkeys are known for their long daily journeys (460–5,690 m), large home-ranges (153 – 340 ha), which scarcely overlap with other groups' home-ranges, often show a preference for using tall forest types and may avoid edge habitats (Wallace, 2008). Additionally, they are particularly vulnerable to habitat loss and fragmentation, which means that large amounts of continuous forest (or at least large forest patches) are more likely to sustain viable populations of the species (Ramos-Fernández & Wallace, 2008). Therefore, we suggest these three regions as priority areas for implementation of new protected areas in order to conserve these large forest tracts.

We also point out three priority regions where conservation measures for regulating land-use and management of private lands would help to protect forest remnants and conserve the species outside reserves. It is worth noting that, due to the scale of our analysis (10-km resolution), we are targeting wide-scale human-modified regions, where infrastructure development and large-scale farming have caused severe habitat loss and fragmentation. Forest-dwelling species, such as spider monkeys, may potentially persist in human-modified regions if forest connectivity is managed at the landscape scale (Pardini et al., 2010), specially because we found a high habitat suitability for the species in these regions. The restoration of forest connectivity could be planned by the implementation of environmental legislation that regulates vegetation loss and restoration within private properties, especially in riparian zones. However, further fine-scale studies must be conducted to base landscape management within these regions.

Here we provided key information for the conservation of threatened species, required by the IUCN and the Brazilian National Action Plans: an update of the species extent of occurrence, the predicted species' area of occupancy, the protection status of suitable areas for the species and a recommendation of priority regions for establishing protected areas and for enhancing habitat connectivity (e.g., Jerusalinksy et al., 2011). The black-faced black spider monkey is only one of thousands of species that are being threatened by the land-cover changes in the arc of deforestation region in the Amazon. This species could be endorsed by conservation organisations as a flagship species to motivate public support for conservation actions (e.g., Home et al., 2009). Our findings will help in the assessment of the conservation status of the species in red lists, and also in the establishment of goals in National Action Plans for the conservation of the species. We will pass our recommendations to relevant stakeholders to facilitate this process.

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AUTHOR CONTRIBUTIONS

RMR designed the study, collected the data, performed analysis, wrote and revised the manuscript. JRG, FES and DGR collected the data, contributed to results interpretation and assisted with manuscript edition and revision. GRC, CSSB and JPB helped with study design, contributed to results interpretation and assisted with manuscript edition and revision.

REFERENCES

ALLOUCHE, O., TSOAR, A. & KADMON, R. (2006) Assessing the accuracy of species distribution models: Prevalence, kappa and the true skill statistic (TSS). *Journal of Applied Ecology*, 43, 1223–1232.

Bastos, A.N. (2012) O efeito da estrutura do habitat na abundância de populações de macaco-barrigudo (Lagothrix cana) no interflúvio purus-madeira, Amazônia Central. Master Dissertation. Instituto Nacional de Pesquisas da Amazônia, Manaus.

Blackman, A., Corral, L., Lima, E.S. & Asner, G.P. (2017) Titling indigenous communities protects forests in the Peruvian Amazon. *Proceedings of the National Academy of Sciences*, 201603290.

Boria, R.A., Olson, L.E., Goodman, S.M. & Anderson, R.P. (2014) Spatial filtering to reduce sampling bias can improve the performance of ecological niche models. *Ecological Modelling*, 275:73–77.

Boubli, J.P., Ribas, C., Lynch Alfaro, J.W., Alfaro, M.E., da Silva, M.N.F., Pinho, G.M. & Farias, I.P. (2015) Spatial and temporal patterns of diversification on the Amazon: A test of the riverine hypothesis for all diurnal primates of Rio Negro and Rio Branco in Brazil. *Molecular Phylogenetics and Evolution*, 82, 400–412.

Brooks, T.M., A, M.R., Da Fonseca, G.A.B., Gerlach, J., Hoffmann, M., Lamoreux, J.F., et al. (2006) Global Biodiversity Conservation Priorities. *Sciences*, 313, 58–61.

Clark, D. a, Brown, S., Kicklighter, D.W., Chambers, J.Q., Thomlinson, J.R. & Ni, J. (2001) Measuring net primary production in forest concepts and field methods. *Ecological Applications*, 11, 356–370.

Davidson, E. a., de Araújo, A.C., Artaxo, P., Balch, J.K., Brown, I.F., C. Bustamante, M.M., et al. (2012) The Amazon basin in transition. *Nature*, 481, 321–328.

Di Fiore, A., Link, A. & Dew, J.L. (2008) Diets of wild spider monkeys. In *Spider Monkeys Behavior, Ecology and Evolution of the Genus Ateles* (ed C. Campbell), pp. 81–137. Cambridge University Press, Cambridge.

Dobrovolski, R., Diniz-Filho, J.A.F., Loyola, R.D. & De Marco Júnior, P. (2011) Agricultural expansion and the fate of global conservation priorities. *Biodiversity and Conservation*, 20, 2445–2459.

Estrada, A., Garber, P.A., Rylands, A.B., Roos, C., Fernandez-duque, E., Fiore, A. Di, et al. (2017) Impending extinction crisis of the world' s primates : Why primates matter. *Science Advances*, 3, 1–16.

Franklin, J. (2009) Mapping species distributions: spatial inference and prediction. Cambridge University Press, New York.

Gray, C.L., Hill, S.L.L., Newbold, T., Hudson, L.N., Börger, L., Contu, S., et al. (2016) Local biodiversity is higher inside than outside terrestrial protected areas worldwide. *Nature Communications*, 7, 12306.

Haugaasen, T. & Peres, C.A. (2005) Primate assemblage structure in Amazonian flooded and unflooded forests. *American Journal of Primatology*, 67, 243–258.

Hawes, J.E. & Peres, C.A. (2014) Ecological correlates of trophic status and frugivory in neotropical primates. *Oikos*, 123, 365–377.

Home, R., Keller, C., Nagel, P., Bauer, N. & Hunziker, M. (2009) Selection criteria for flagship species by conservation organizations. *Environmental Conservation*, 36, 139.

IUCN (2012) IUCN Red List Categories and Criteria., version 3.1, second edition. IUCN, Gland, Switzerland and Cambridge.

Jerusalinksy, L., Talebi, M. & Melo, F. (2011) Plano de Ação Nacional para a Conservação dos Muriquis. ICMBio, Brasília.

Kasecker, T.P. (2006) Efeito da estrutura do hábitat sobre a riqueza e composição de comunidades de primatas da RDS Piagaçu-Purus, Amazônia Central, Brasil. Master

Dissertation. Instituto Nacional de Pesquisas da Amazônia / Universidade Federal do Amazonas, Manaus.

Muscarella, R., Galante, P.J., Soley-Guardia, M., Boria, R.A., Kass, J.M., Uriarte, M. & Anderson, R.P. (2014) ENMeval: An R package for conducting spatially independent evaluations and estimating optimal model complexity for Maxent ecological niche models. *Methods in Ecology and Evolution*, 5, 1198–1205.

Nepstad, D., Mcgrath, D., Alencar, A., Barros, A.C., Carvalho, G., Santilli, M. & Vera Diaz, M. del C. (2002) Frontier governance in Amazonia. *Science*, 295, 629–630.

Nepstad, D., Schwartzman, S., Bamberger, B., Santilli, M., Ray, D., Schlesinger, P., et al. (2006) Inhibition of Amazon deforestation and fire by parks and indigenous lands. *Conservation Biology*, 20, 65–73.

Palminteri, S., Powell, G.V.N. & Peres, C. a. (2011) Regional-scale heterogeneity in primate community structure at multiple undisturbed forest sites across south-eastern Peru. *Journal of Tropical Ecology*, 27, 181–194.

Pardini, R., de Bueno, A.A., Gardner, T.A., Prado, P.I. & Metzger, J.P. (2010) Beyond the fragmentation threshold hypothesis: Regime shifts in biodiversity across fragmented landscapes. *PLoS ONE*, 5, e13666.

Peres, C.A. (1997) Primate community structure at twenty western Amazonian flooded and unflooded forests. *Journal of Tropical Ecology*, 13, 381–405.

Phillips, S.J. & Dudík, M. (2008) Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography*, 31, 161–175.

QGIS Development Team (2015) QGIS Geographical Information System. Open Source Geospatial Foundation Project.

R DEVELOPMENT CORE TEAM (2015) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

RABELO, R.M., SILVA, F.E., VIEIRA, T., FERREIRA-FERREIRA, J., PAIM, F.P., DUTRA, W., ET AL. (2014) Extension of the geographic range of Ateles chamek (Primates, Atelidae): evidence of river-barrier crossing by an amazonian primate. *Primates*, 55, 167–171.

RAMOS-FERNÁNDEZ, G. & WALLACE, R. (2008) Spider monkey conservation in the twenty-first century: recognizing risks and opportunities. In *Spider monkeys: behavior, ecology and evolution of the genus Ateles* (ed C.J. Campbell), pp. 351–356, 1st edition. Cambridge University Press, Cambridge.

SANTOS-FILHO, M., BERNARDO, C.S.S., BARBOSA, H.W.V. DER L., GUSMÃO, A.C., JERUSALINSKY, L. & CANALE, G.R. (2017) A new distribution range of Ateles chamek (Humboldt 1812) in an ecotone of three biomes in the Paraguay River Basin. *Primates*, 58, 441–448.

SOARES-FILHO, B., RAJÃO, R., MACEDO, M., CARNEIRO, A., COSTA, W., COE, M., ET AL. (2014) Cracking Brazil's Forest Code. *Science*, 344, 363–364.

SOARES-FILHO, B.S., NEPSTAD, D.C., CURRAN, L.M., CERQUEIRA, G.C., GARCIA, R.A., RAMOS, C.A., ET AL. (2006) Modelling conservation in the Amazon basin. *Nature*, 440, 520–523.

SOBERÓN, J. & NAKAMURA, M. (2009) Niches and distributional areas: Concepts, methods, and assumptions. *Proceedings of the National Academy of Sciences*, 106, 19644–19650.

TERBORGH, J. (1983) Five new world primates: a study in comparative ecology. Princenton University Press, Princenton.

UNEP-WCMC (2016) World Database on Protected Areas User Manual 1.3. *Cambridge, UK*. Http://wcmc.io/WDPA_Manual.

VAN SCHAIK, C.P., TERBORGH, J. & WRIGHT, S.J. (1993) The phenology of tropical forests: adaptative significance and consequences for primary consumers. *Annual Review of Ecology Evolution and Systematics*, 24, 353–377.

VILLERO, D., PLA, M., CAMPS, D., RUIZ-OLMO, J. & BROTONS, L. (2017) Integrating species distribution modelling into decision-making to inform conservation actions. *Biodiversity and Conservation*, 26, 251–271.

WALLACE, R.B. (2008) Factors influencing spider monkey habitat use and ranging patterns. In *Spider monkeys: behavior, ecology and evolution of the genus Ateles* (ed C. Campbell), pp. 138–154. Cambridge University Press, Cambridge.

WALLACE, R.B., MITTERMEIER, R.A., CORNEJO, F. & BOUBLI, J.P. (2008) Ateles chamek. *The IUCN Red List of Threatened Species*.

BIOGRAPHICAL SKETCHES

RAFAEL RABELO is interested in modelling approaches to understand the distribution patterns of species across environmental gradients, with application to conservation. JONAS GONÇALVES, FELIPE SILVA and JEAN BOUBLI are experienced field primatologists interested in biogeography, ecology and conservation. DANIEL ROCHA works with ecology and conservation of wild mammals in the Southern Brazilian Amazonia. GUSTAVO CANALE is interested in ecology and conservation of mid- to large-sized mammals. CHRISTINE BERNARDO has experience with species distribution modelling and population viability analysis of birds and mammals.

Table 1. Forest cover in the priority regions for the conservation of the black-faced black spider monkey (*A. chamek*) according to the future scenarios of deforestation in the Amazon basin (Soares-Fillho et al., 2006). Forest, deforested and non-forest areas are in km².

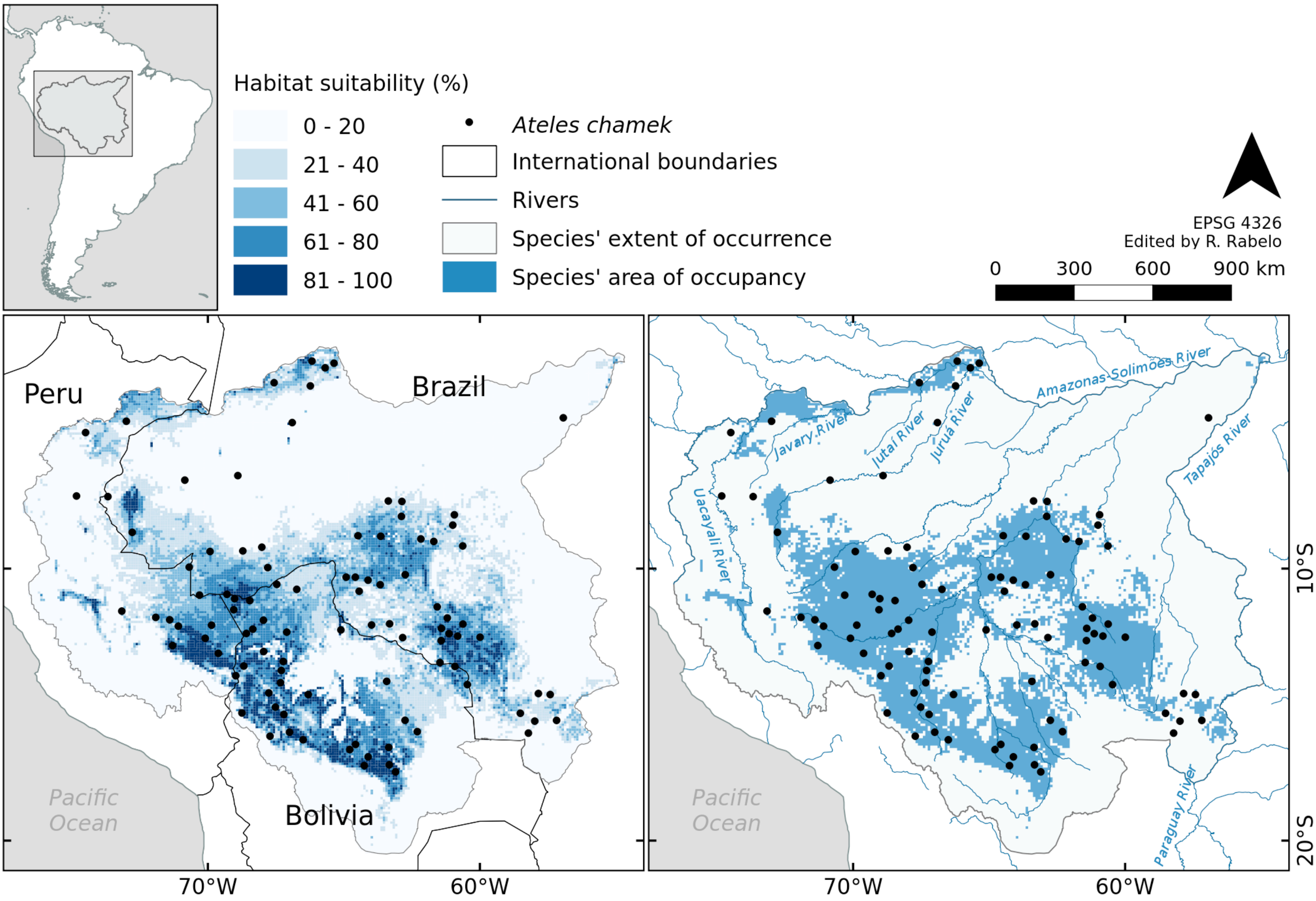
			2002	2050 (GOV)	2050 (BAU)
Conservation action	Region	Land cover	Area (%)	Area (%)	Area (%)
Expansion of PA network	Cruzeiro	forest	15618.96 (88.0)	8639.23 (49.5)	1882.73 (10.8)
		deforested	1841.24 (10.4)	8522.67 (48.8)	15279.16 (87.5)
		non-forest	296.34 (1.7)	296.34 (1.7)	296.34 (1.7)
	Assis Brasil	forest	60835.13 (91.7)	35579.27 (53.6)	26040.17 (39.3)
		deforested	4940.93 (7.4)	30196.79 (45.5)	39735.90 (59.9)
		non-forest	547.24 (0.8)	547.24 (0.8)	547.24 (0.8)
Landscape management	La Paz	forest	16694.67 (74.3)	7849.98 (34.9)	4223.80 (18.8)
		deforested	1590.34 (7.1)	10435.03 (46.4)	14061.22 (62.6)
		non-forest	4186.26 (18.6)	4186.26 (18.6)	4186.26 (18.6)
	Porto Velho	forest	18251.43 (47.3)	3406.89 (8.8)	387.21 (1.0)
		deforested	20105.51 (52.1)	34950.05 (90.6)	38187.04 (98.5)
		non-forest	209.41 (0.5)	209.41 (0.5)	209.41 (0.5)
	Vilhena	forest	9545.03 (36.4)	3965.00 (15.0)	573.91 (2.2)
		deforested	13633.50 (51.9)	19318.24 (73.2)	22630.31 (86.0)
		non-forest	3076.97 (11.7)	3108.58 (11.8)	3108.58 (11.8)
	Santa Cruz	forest	32108.17 (53.8)	13600.90 (22.8)	8030.75 (13.4)
		deforested	18990.30 (31.8)	37497.56 (62.8)	43067.72 (72.1)
		non-forest	8622.43 (14.4)	8622.43 (14.4)	8622.43 (14.4)

Figure 1. Habitat suitability and predicted distribution for *A. chamek* in Amazonia and Upper-Paraguay basins. The darker the blue, the higher the habitat suitability for the species within its extent of occurrence (left map). The species predicted distribution (i.e., areas with habitat suitability > 35.75%) is shown on the right map. The filled blue areas (i.e., species' area of occupancy) correspond to 28% of the species' extent of occurrence.

Figure 2. Habitat loss and protected area network cover within *A. chamek* predicted distribution in Amazonia, according to the 'Governance' and 'Business as usual' future scenarios of deforestation. Pie charts show the percentage of forest (green), deforested (magenta) and non-forest areas (orange) in each scenario. Data on deforestation scenarios from Soares-Filho et al. (2013).

Figure 3. Priority regions for the conservation of the black-faced black spider monkey (*A. chamek*) in the Amazon. For each region we show the habitat suitability for the species (blue gradient maps), the forest cover in 2002 and predicted forest cover for 2050 according to the "BAU" scenario of deforestation. Proposed regions for expanding protected area network: (a) "Assis Brasil" region includes international borders between Peru, Bolivia and Brazil; whereas (b) "Cruzeiro" and (c) "La Paz" are entirely located in Brazil and Bolivia, respectively. Human-modified regions for landscape planning, management and/or restoration: (d) "Porto Velho" and (e) "Vilhena" regions are entirely located within Rondônia state, in Brazil; (f) "Santa Cruz" region includes Santa Cruz and Cochabamba departments, in Bolivia. Data on deforestation scenarios from Soares-Filho et al. (2013).

Figure 1



Habitat suitability (%)
0 - 20
21 - 40
41 - 60
61 - 80
81 - 100
Ateles chamek
International boundaries
Rivers
Species' extent of occurrence
Species' area of occupancy
EPSG 4326
Edited by R. Rabelo
0
300
600
900 km
Peru
Brazil
Bolivia
Pacific Ocean
Amazonas-Solimoes River
Javary River
Jutaí River
Juruá River
Tapajós River
Uacayali River
Paraguay River
70°W
60°W
10°S
20°S

438 **Figure 2**

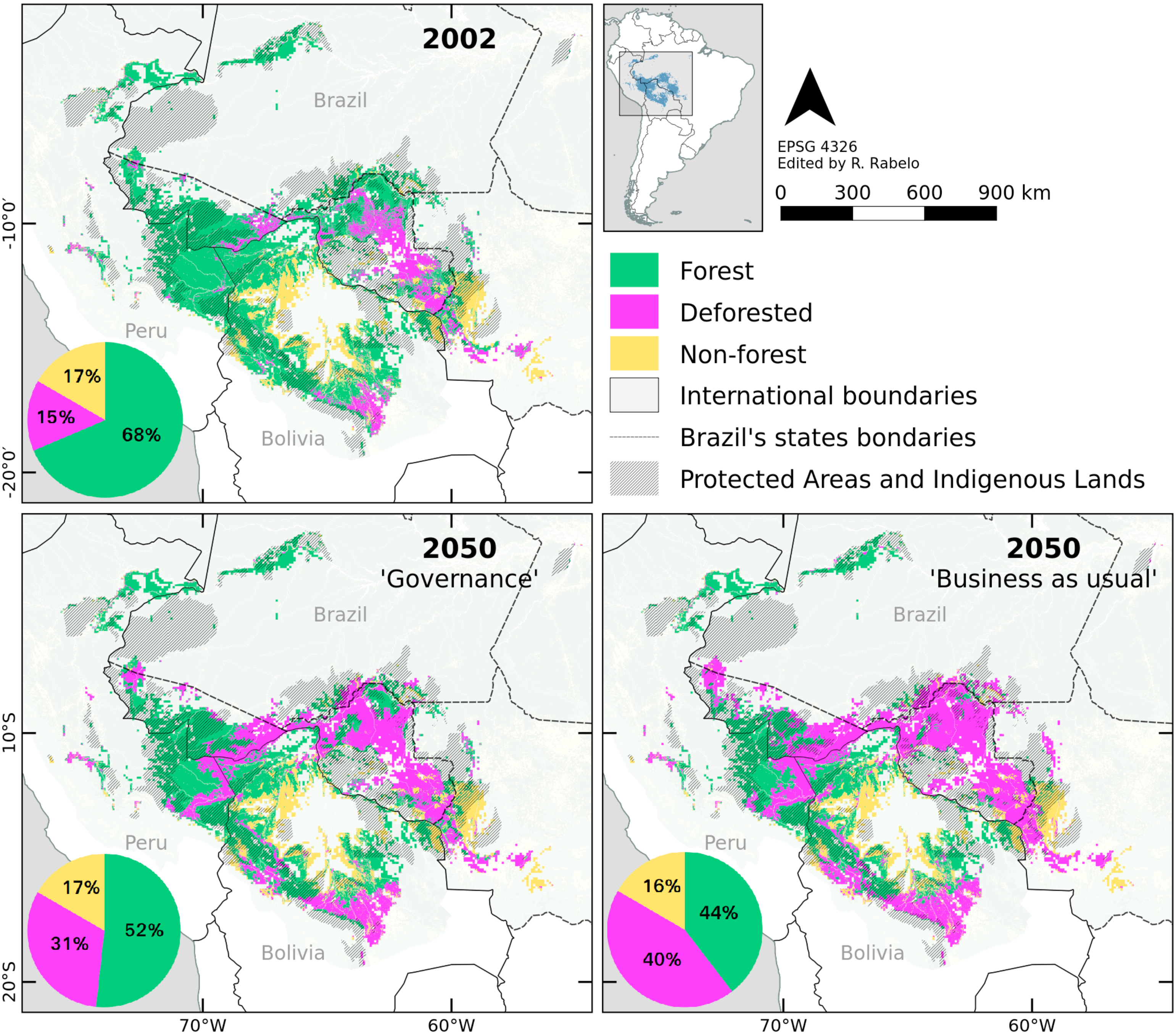


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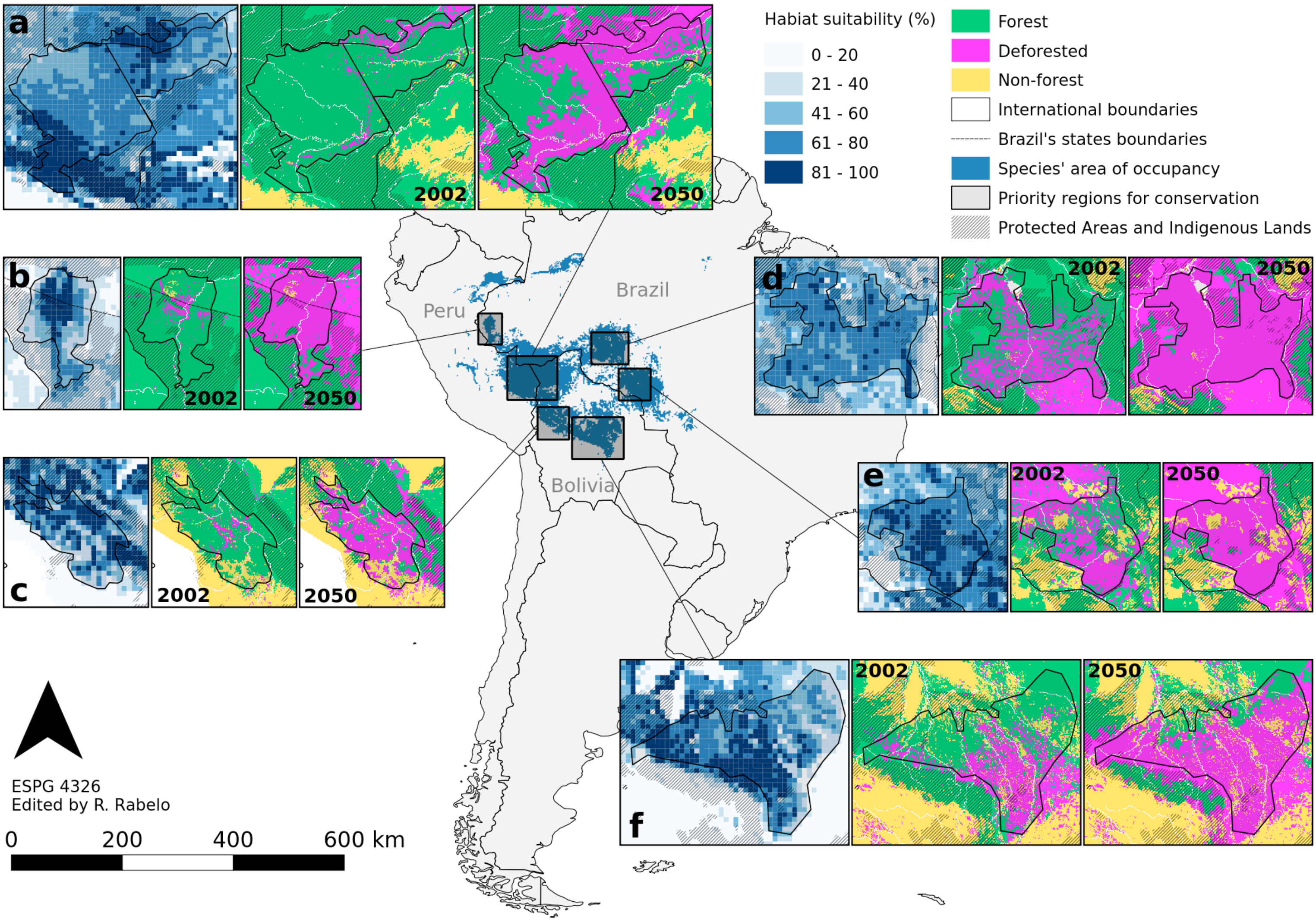
Figure 3



Habiat suitability (%)
0 - 20
21 - 40
41 - 60
61 - 80
81 - 100
Forest
Deforested
Non-forest
International boundaries
Brazil's states boundaries
Species' area of occupancy
Priority regions for conservation
Protected Areas and Indigenous Lands
a
b
c
d
e
f
2002
2050
Peru
Brazil
Bolivia
ESPG 4326
Edited by R. Rabelo
0
200
400
600 km