Modelling 21st century refugia and impact of climate change on Amazonia's largest primates

Short running title:

Climate change impacts on Amazonian primates

Thiago Cavalcante[1]*, Adrian A. Barnett[2,3], Jasper Van doninck[4], Hanna Tuomisto[5]

[1] Programa de Pós-Graduação em Ecologia, Instituto Nacional de Pesquisas da Amazônia, INPA, Manaus, Brazil

[2] Departamento de Zoologia, Universidade Federal do Amazonas, Manaus, Brazil

[3] Departamento de Zoologia, Universidade Federal de Pernambuco, Recife, Brazil

[4] Department of Geography and Geology, University of Turku, Turku, Finland

[5] Department of Biology, University of Turku, Turku, Finland

*Corresponding author: thiagocav.ferreira@gmail.com, +55 (82) 988224704; Instituto Nacional de Pesquisas da Amazônia, Av. André Araújo, 2936, 69067-375, Manaus, Amazonas, Brazil.

Abstract

Aim: Unsuitable edaphic and vegetation conditions can render climatically suitable sites inadequate for a species to persist, constraining both the amount of suitable habitat and the possibilities of tracking their preferred climatic niche under future climate change. We combined climatic and remotely sensed environmental data to estimate current and future distributions of nine extant lineages of ateline primates across the whole Amazon basin. We used these estimations to identify and quantify range changes and potential refugia at taxon and complex levels up until the mid-21st century (2041-2070) under two different climate change scenarios.

Location: Amazonia.

Taxon: Atelinae (Primates).

Methods: We used an ensemble forecasting approach for species distribution models combining occurrence data from online sources and scientific literature, bioclimatic layers from Climatologies at High Resolution for the Earth's Land Surface Areas (CHELSA), and reflectance data from a basin-wide Landsat TM/ETM+ image composite.

38 **Results:** We found that all taxa are likely to experience pronounced range losses
39 irrespective of climate change scenarios. Modelled ateline richness exhibited a broadly
40 similar spatial pattern under both climate change scenarios with a visual decrease in
41 areas with higher predicted richness, and a possible redistribution/migration along the
42 northernmost parts of western Amazonia. Refugia from 21st century climate change for
43 the conservation of the whole complex were mostly concentrated in the western part of
44 the Amazon basin, especially in the southern region.

45 **Main conclusions:** We were able to identify hotspots of vulnerability to climate change
46 and 21st century refugia for all Amazonian atelines while accounting for habitat
47 characteristics that must remain coupled with climatic conditions to guarantee the
48 continued existence of colonizable habitats for these strictly arboreal forest-dwelling
49 taxa. Increasing the understanding of reactions to climate change for this climate-
50 sensitive group can help to spatially-inform conservation planning decisions and
51 management to sustain forest-dwelling biodiversity over large areas such as Amazonia.

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2 Methods

2.1 Occurrence data

55 Considering recent molecular systematic studies (Botero, Stevenson, & Di Fiore, 2015;
56 Di Fiore et al., 2014; Morales-Jimenez, Disotell, & Di Fiore, 2015), we focused on the
57 nine extant lineages within six Amazonian species of the *Ateles*/*Lagothrix* complex
58 (spider and woolly monkeys, respectively): *Ateles belzebuth*, *A. chamek*, *A. marginatus*,
59 *A. paniscus*, *Lagothrix flavicauda*, *L. lagotricha cana*, *L. l. lagotricha*, *L. l. lugens* and
60 *L. l. poeppigii*. We compiled geo-referenced occurrence data from online sources
61 (Global Biodiversity Information Facility [*http://www.gbif.org*]; iNaturalist
62 [https://www.inaturalist.org/]), and comprehensive peer-reviewed scientific literature. A
63 total of 3297 occurrence records were found for all evolutionary lineages combined.
64 Following standard practices (Sillero et al., 2021; Sillero & Barbosa, 2021), we
65 carefully cleaned and spatially thinned our occurrence records in three main steps. First,
66 we used an automated procedure to flag and exclude records with common
67 georeferencing problems ('CoordinateCleaner' package: Zizka et al., 2019), such as
68 occurrences assigned to open ocean, urban areas, administrative capitals or headquarters
69 of the GBIF, as well as those with zero or identical latitude and longitude. Second, we
70 carefully verified the remaining occurrences by corroborating these records with IUCN
71 distribution maps and established literature, together with a careful visual inspection
72 using interactive visualisations of spatial data. This step allowed us to identify major
73 discrepancies, such as confirmed locality data outside IUCN range maps. In such cases,
74 we retained the occurrence records after checking established peer-reviewed literature
75 (see Table S1 in Appendix S1 for raw cleaned occurrence dataset). Finally, we thinned
76 these raw occurrence records using a 5-km thinning distance to avoid spatial sampling
77 bias from highly sampled areas, and to reduce the clustering of species occurrence
78 points (Renner et al., 2015). This thinning distance was also used to match the spatial
79 resolution of the species records with climatic and satellite data pixel size (Sillero &
80 Barbosa, 2021). For subsequent analysis, we used a final dataset consisting of 596
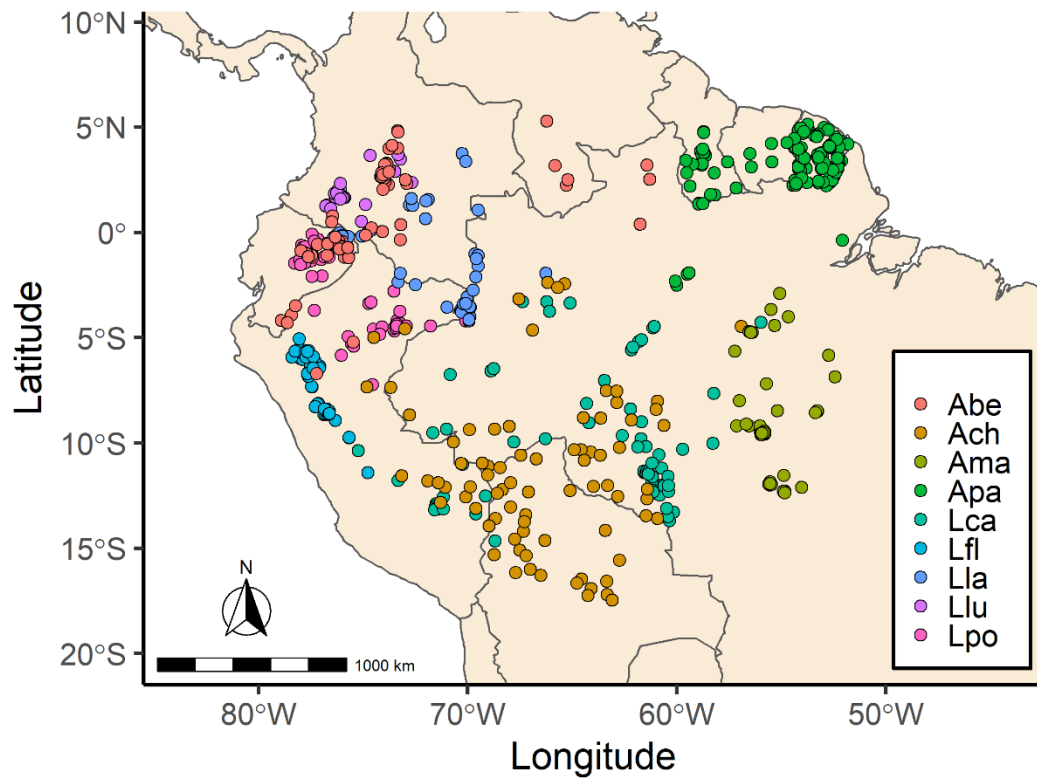81 spatially rarefied occurrences (see Figure S1.1 in Appendix S1).

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84   **Figure S1.1** Geo-referenced occurrence records used to calibrate models for nine extant

85   lineages within six Amazonian species of the *Ateles*/*Lagothrix* complex (Primates:

86   Atelidae). Taxon name abbreviations: Abe – *Ateles belzebuth* (N = 79), Ach – *Ateles*

87   *chamek* (N = 80), Ama – *Ateles marginatus* (N = 57), Apa – *Ateles paniscus* (N = 113),

88   Lca - *Lagothrix lagotricha cana* (N = 73), Lfl - *Lagothrix flavicauda* (N = 54), Lla -

89   *Lagothrix lagotricha lagotricha* (N = 52), Llu - *Lagothrix lagotricha lugens* (N = 25),

90   Llp - *L. lagotricha poeppigii* (N = 63).

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Figure 1 Adult male of *Lagothrix flavicauda* in Amazonas region, Peru. Photo by
Neotropical Primate Conservation (Almeyda Zambrano et al., 2019).

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