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The highly threatened and little known Amazonian savannahs

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Methods

Spatial data

It has long been recognised that within the Amazon rainforest region, savanna islands exist²⁰. To locate and quantify these areas, we conducted spatial analyses in Quantum GIS version 2.16.1²¹. The extent of the Amazon biome was defined based on World Wildlife Fund maps (e.g. http://wwf.panda.org/what_we_do/where_we_work/amazon/about_the_amazon/) using the Terrestrial Ecoregions of the World shapefile, version 2.0²². Within South America, areas of Tropical Savanna were identified in two shapefiles. Firstly, from the Terrestrial Ecoregions of the World shapefile²², we selected areas classified as biome 7 – “Tropical & Subtropical Grasslands, Savannas & Shrublands”. Within the Amazon region, these areas consist of two ecoregions: 1) the “Beni savanna” in Bolivia, and 2) the “Guianan savanna” which consists of three areas in the north of the Amazon region, and which here we refer to separately as the “Savannas of Guyana”, the “Sipaliwini-Paru” savanna and the “Cerrado of Amapá”.

Ecoregions are areas that represent a distinct biota, and are considered appropriate units for conservation priority setting in relation to biodiversity features²². However, most ecoregions contain habitats that differ from their assigned biomes, and various further areas of savanna habitat exist within the other Amazonian ecoregions. Therefore, within Brazil, additional areas of tropical savanna were identified as those which are predominated by one of eight classes of savanna and savanna steppe habitat, as classified in the Brazilian Biomes Vegetation Cover map for the Brazilian Amazon²³. These areas were added to our analysis because many known areas of Amazonian savanna, for example the highly studied savanna close to the village of Alter do Chão in the Central Brazilian Amazon, were not captured by the Terrestrial Ecoregions of the World shapefile for the reasons stated above. From these Tropical Savannas, Amazonian savannas were defined as areas within the Amazon biome

that 1) did not intersect with the Cerrado of Brazil and Bolivia or the Llanos of Venezuela and Colombia, 2) did not intersect with the transition zone between the Brazilian Cerrado and the Amazon biome, as defined by WWF and IBAMA²⁴, and 3) were not immediately adjacent to the Cerrado (and transition zone), Llanos or any other biome – i.e. we selected areas contained wholly within the geographic extent of the Amazon biome. It is also important to note that patches of Amazonian savanna can be very small and difficult to detect within the forest using satellite imagery, and can be mixed with or grade in to white sand ecosystems²⁵. There is therefore uncertainty associated with the area estimates presented in this paper, and depending on how Amazonian savannas are defined, their total area may have been over- or under-estimated.

To map the distribution of different protected area types we used data from the World Database of Protected Areas²⁶. We separated all nationally designated protected areas in the study region in to three categories: Strictly Protected (correspondent to IUCN categories I - IV), Multiple Use (correspondent to IUCN categories V - VI), and Indigenous Lands. When the IUCN category was not reported, we assigned the areas to one of the three broad categories (SP, MU, or IL) based on national protected area classifications, where available. Otherwise the areas were placed in the closest category based on the stated objectives of the protected area, and the IUCN guidelines for classification²⁷. This applied to 8 SP areas and 5 MU areas in Bolivia, and to 4 MU areas and the 64 ILs in Brazil. We assumed that the degree of protection declines from Strictly Protected areas, to Indigenous Lands, to Multiple Use areas. As such, where protected areas of different categories overlap spatially, we classified the area according to the highest level of protection afforded.

Area calculations

We overlaid our shape of Amazonian savannas with a shapefile of the countries of South America, and calculated the area of Amazonian savanna in each country, in square kilometres. These data were intersected with the protected areas shapefile to calculate the total area of Amazonian savanna in each protection type in: 1) each country, and 2) each of the four largest complexes of Amazonian savannas.

Literature search

In order to identify studies carried out in areas of Amazonian savanna, we conducted literature searches using combinations of the following keywords in Google Scholar: Amazonian savanna*, cerrado, llanos, Amazon, Brazil, Bolivia, Venezuela, Suriname, Guyana, Llanos de Moxos, Llanos de Mochos, Savannas of Guyana, Cerrado of Amapá, Sipaliwini-Parú savannas, lavrados, Roraima, Pará, Amapá, Rondônia, Acre, Amazonas, Beni, Pampas del Heath, mammal/s, bird/s, invertebrate/s, amphibian/s, reptile/s, vegetation, fish, plant/s and bat/s. From the studies returned by these searches, we filtered out studies conducted in the Amazonian savannas, excluding any studies conducted in the transition zone between the Cerrado and Amazon biomes. We further checked the reference lists of included studies, and papers citing included studies. Here we considered only peer-reviewed literature, and have not included grey literature (e.g. theses, dissertations and reports), to avoid introducing potential geographic biases based on familiarity with certain regions and languages. As such, the review cannot be considered exhaustive, but rather indicative of the total number of studies carried out in these ecosystems, and their geographic spread. We then classified each study based on where the work took place and on which taxonomic groups were studied: plants, amphibians, reptiles, birds, small mammals, medium and large bodied mammals, fish and bats.

Table S1 – Studies conducted in Amazonian savannas. The 136 references returned using our search criteria and filters (see methods), grouped by taxonomic group and specifying the country/ies in which the studies were conducted.

Reference	Location
Plants	
Myers ²⁸	Guyana
Takeuchi ²⁹	Brazil
Egler ³⁰	Brazil
Gottsberger ³¹	Brazil
Branch & Silva ³²	Brazil
Bastos ³³	Brazil
Beck ³⁴	Bolivia
Janssen ³⁵	Brazil
Gottsberger & Morawetz ³⁶	Brazil
Miranda ³⁷	Brazil
Gottsberger & Morawetz ³⁸	Brazil
Sanaïotti & Magnusson ³⁹	Brazil
Desjardins et al. ⁴⁰	Brazil
Sanaïotti et al. ⁴¹	Brazil
Magnusson et al. ⁴²	Brazil
Miranda & Absy ⁴³	Brazil
Sanaïotti et al. ⁴⁴	Brazil
Magnusson et al. ⁴⁵	Brazil
Vieira et al. ⁴⁶	Brazil
Barbosa & Fearnside ⁴⁷	Brazil
Barbosa & Fearnside ⁴⁸	Brazil
Barbosa & Fearnside ⁴⁹	Brazil
Barbosa et al. ⁵⁰	Brazil
Benezar & Pessoni ⁵¹	Brazil
Araújo & Barbosa ⁵²	Brazil
Toledo & Bush ⁵³	Brazil
Batista et al. ⁵⁴	Brazil
Magnusson et al. ⁵⁵	Brazil

Fadini et al. ⁵⁶	Brazil
Flores & Rodrigues ⁵⁷	Brazil
Barbosa et al. ⁵⁸	Brazil
Rossetti et al. ⁵⁹	Brazil
Fadini ⁶⁰	Brazil
Fadini & Lima ⁶¹	Brazil
Rocha & Miranda ⁶²	Brazil
Boudouris & Queenborough ⁶³	Brazil
Santos et al. ⁶⁴	Brazil
Jati et al. ⁶⁵	Brazil
Rocha et al. ⁶⁶	Brazil
Sebastiani & Mamede ⁶⁷	Brazil
Feitosa et al. ⁶⁸	Brazil

Invertebrate

Bührnheim & Aguiar ⁶⁹	Brazil
Flint ⁷⁰	Brazil
Rafael ⁷¹	Brazil
Hamada & Adler ⁷²	Brazil and Venezuela
Franklin et al. ⁷³	Brazil
Póvoa et al. ⁷⁴	Brazil
Vasconcelos & Vilhena ⁷⁵	Brazil
Vasconcelos et al. ⁷⁶	Brazil
Matavelli & Louzada ⁷⁷	Brazil
Santos et al. ⁷⁸	Brazil
Vasconcelos et al. ⁷⁹	Brazil
Vulinec ⁸⁰	Brazil
Louzada et al. ⁸¹	Brazil
França et al. ⁸²	Brazil

Fishes

Lowe-McConnell ⁸³	Guyana
Gottsberger ³¹	Brazil
Pouilly et al. ⁸⁴	Bolivia
Watkins et al. ⁸⁵	Guyana
Montag et al. ⁸⁶	Brazil

Amphibians	
Strüssmann et al. ⁸⁷	Brazil
Azevedo-Ramos & Magnusson ⁸⁸	Brazil
Azevedo-Ramos et al. ⁸⁹	Brazil
Neckel-Oliveira et al. ⁹⁰	Brazil
Garda et al. ⁹¹	Brazil
Reptiles	
Magnusson ⁹²	Brazil
Vanzolini & Carvalho ⁹³	Brazil
Magnusson & Silva ⁹⁴	Brazil
Magnusson ⁹⁵	Brazil
Avila-Pires ⁹⁶	Bolivia, Brazil, Guyana and Suriname
Vitt & Carvalho ⁹⁷	Brazil
Colli et al. ⁹⁸	Brazil
Sartorius et al. ⁹⁹	Brazil
Vitt ¹⁰⁰	Brazil
Magnusson et al. ¹⁰¹	Brazil
Mesquita & Colli ¹⁰²	Brazil
Faria et al. ¹⁰³	Brazil
Mesquita et al. ¹⁰⁴	Brazil
França et al. ¹⁰⁵	Brazil
Quijada-Mascareñas ¹⁰⁶	Brazil
Mesquita et al. ¹⁰⁷	Brazil
Carvalho Jr. et al. ¹⁰⁸	Brazil
Santos et al. ¹⁰⁹	Brazil
Werneck et al. ¹¹⁰	Guyana
Carvalho ¹¹¹	Bolivia, Brazil, Guyana and Venezuela
Birds	
Sanaïotti & Magnusson ³⁹	Brazil
Silva et al. ¹¹²	Brazil
Sanaïotti & Cintra ¹¹³	Brazil
Santos ¹¹⁴	Brazil
Ribas & Miyaki ¹¹⁵	Brazil
Cintra & Sanaïotti ¹¹⁶	Brazil

Naka et al. ¹¹⁷	Brazil
Grim & Šumbera ¹¹⁸	Bolivia
Herrera & Maillard ¹¹⁹	Bolivia
Herrera et al. ¹²⁰	Bolivia
Santos & Silva ¹²¹	Brazil
Lopes ¹²²	Brazil
Mittermeier et al. ¹⁶	Suriname
Vasconcelos et al. ¹²³	Brazil
Areta & Repenning ¹²⁴	Bolivia
Cintra et al. ¹²⁵	Brazil
Berkunsky et al. ¹²⁶	Bolivia
Davenport et al. ¹²⁷	Bolivia

Small mammals

Weksler et al. ¹²⁸	Brazil
Pontes & Chivers ¹²⁹	Brazil
Salazar-Bravo et al. ¹³⁰	Bolivia
Voss et al. ¹³¹	Bolivia
Ghizoni et al. ¹³²	Brazil
Voss et al. ¹³³	Bolivia
Cordeiro & Oliveira ¹³⁴	Brazil
Bezerra et al. ¹³⁵	Bolivia and Brazil
Terán et al. ¹³⁶	Bolivia
Bonvicino et al. ¹³⁷	Brazil
Magnusson et al. ¹³⁸	Brazil
Silva et al. ¹³⁹	Brazil

Bats

Bernard ¹⁴⁰	Brazil
Bernard ¹⁴¹	Brazil
Bernard et al. ¹⁴²	Brazil
Aguirre ¹⁴³	Bolivia
Bernard & Fenton ¹⁴⁴	Brazil
Graciolli & Bernard ¹⁴⁵	Brazil
Aguirre et al. ¹⁴⁶	Bolivia
Aguirre et al. ¹⁴⁷	Bolivia

Bernard & Fenton ¹⁴⁸	Brazil
Arteaga et al. ¹⁴⁹	Bolivia
Bernard & Fenton ¹⁵⁰	Brazil
Loayza & Loiselle ¹⁵¹	Bolivia
Martins et al. ¹⁵²	Brazil
Silva et al. ¹³⁹	Brazil
Large mammals	
Rylands ¹⁵³	Brazil
Nunes ¹⁵⁴	Brazil
Fragoso et al. ¹⁵⁵	Brazil
Silvius & Fragoso ¹⁵⁶	Brazil
Mendes-Pontes ¹⁵⁷	Brazil
Martínez ¹⁵⁸	Bolivia
Crespo ¹⁵⁹	Bolivia
Sampaio et al. ¹⁶⁰	Brazil
Silva et al. ¹³⁹	Brazil
Coelho et al. ¹⁶¹	Brazil
Guizada-Duran & Aliaga-Rossel ¹⁶²	Bolivia

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