A conservation assessment of Brazil's iconic and threatened Araucaria Forest-Campos mosaic

Article

Supplemental Material

Supplementary information: A conservation assessment of Brazil's iconic and threatened Araucaria Forest-Campos mosaic

Mosaic definitions

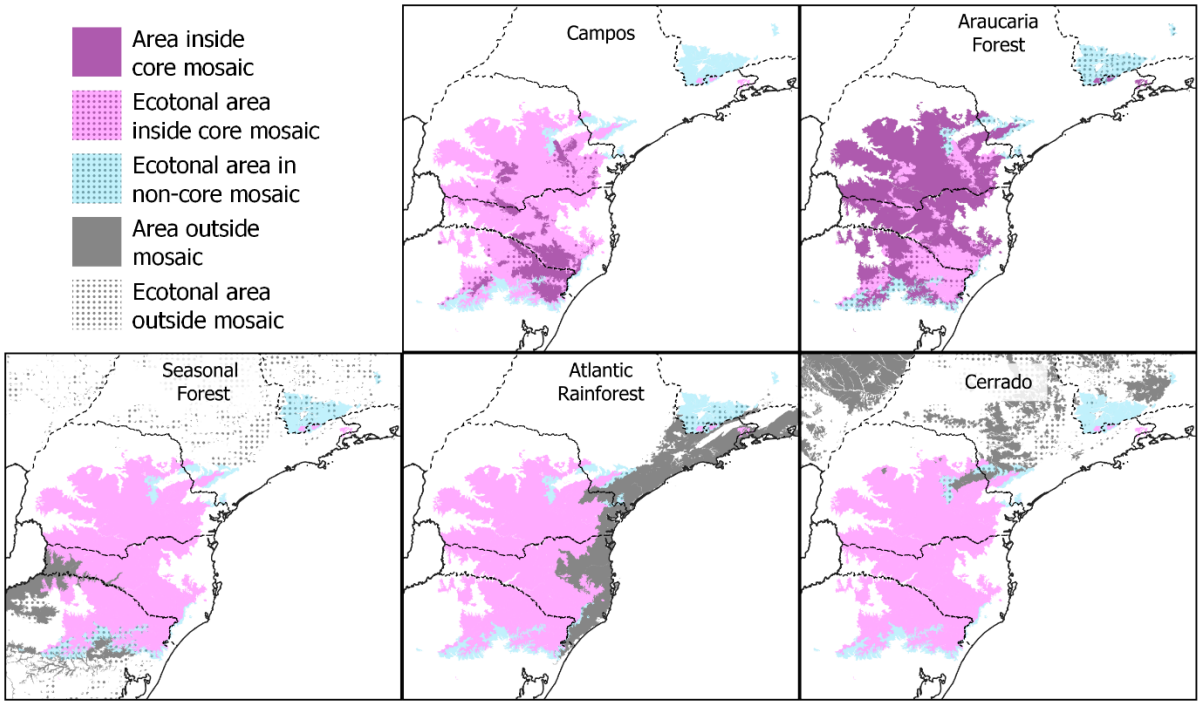

Figure S1: maps showing the locations of the studied vegetation zones in relation to the whole and core mosaic area.

Mapeamento de Recurso Naturais do Brasil (MRNB) analysis

The MRNB dataset is described in detail in two references (IBGE - Instituto Brasileiro de Geografia e Estatística, 2012, 2018); in this study, the 2021 version of the data, at 1:250,000 scale, is used. As a vector dataset, MRNB includes a considerable amount of information about each area of the landscape and its coverage. A tiered approach to this data provides insights into the state of the highlands' natural remnants, progressively refining the area selected and measured:

1. Tier 1: predominantly natural areas (natural vegetation cover types listed in 'legenda_2' of the dataset)
2. Tier 2: purely natural areas (areas which did not have any anthropic vegetation cover listed under 'leg_carga')
3. Tier 3: purely natural areas with no secondary vegetation (as in (2) but also excluding secondary vegetation).

The natural land cover categories used in tier 1 were: Estepe Gramíneo-Lenhosa (termed Campos); Floresta Ombrófila Mista Alto-Montana and Floresta Ombrófila Mista Montana (together termed Araucaria Forest); Formação Pioneira com influência fluvial e/ou lacustre, Refúgio Vegetacional Alto-Montano, Refúgio Vegetacional Montano, Floresta Ombrófila Densa Alto-Montana, and Floresta Ombrófila Densa Montana (together termed Other Natural Vegetation); and Vegetação Secundária (termed Secondary Vegetation).

The anthropic land cover types excluded in tier 2 were: Ag (Agropecuária), Ac (Agricultura), Acp (Agricultura com culturas permanentes), Acc (Agricultura com culturas cíclicas), Ap (Pecuária (pastagem)), R (Florestamento/Reflorestamento), Re (Florestamento/Reflorestamento com Eucaliptos), Rp (Florestamento/Reflorestamento com Pinus), Ra (Florestamento/Reflorestamento com Acácias), Rg (Florestamento/Reflorestamento com Algarobas), Rs (Florestamento/Reflorestamento com Seringueiras), Rf (Florestamento/Reflorestamento com Frutíferas), Iu (Influência urbana), and Ai (Indiscriminadas). For tier 3, Vss (Vegetação Secundária sem palmeiras) was added to this list.

More information on these vegetation cover types can be found in the Manual Técnico da Vegetação Brasileira (IBGE - Instituto Brasileiro de Geografia e Estatística, 2012).

Forest Landscape Integrity Index (FLII) analysis

The FLII data (Grantham et al., 2020) provide a way to evaluate the quality of the forests included by the different data sources on remaining natural vegetation (MapBiomas, SOS Mata Atlântica, and MRNB). The declining proportions of remnant natural vegetation recorded in each dataset, from MapBiomas to MRNB (main text figure 2), suggests that they progressively exclude more low-quality forest to focus on better-quality vegetation. This is borne out by comparing the FLII values of forest areas in each dataset (figure S2, Supplementary Data) – MRNB tier 1's secondary vegetation has a similar mean FLII score (45.6%) to natural forest in the 2018 MapBiomas data (43.9%), for example. Remnants' average FLII scores increase from MapBiomas (43.9%) to SOS Mata Atlântica (52.0%) to MRNB (55.9-59.4% for Araucaria Forest, 64.4-76.1% for other natural vegetation, and 45.6-62.8% for secondary vegetation). MRNB's tier 2 natural vegetation areas have higher average FLII values than tier 1 areas, but the increase is more complicated for tier 3 (figure S2).

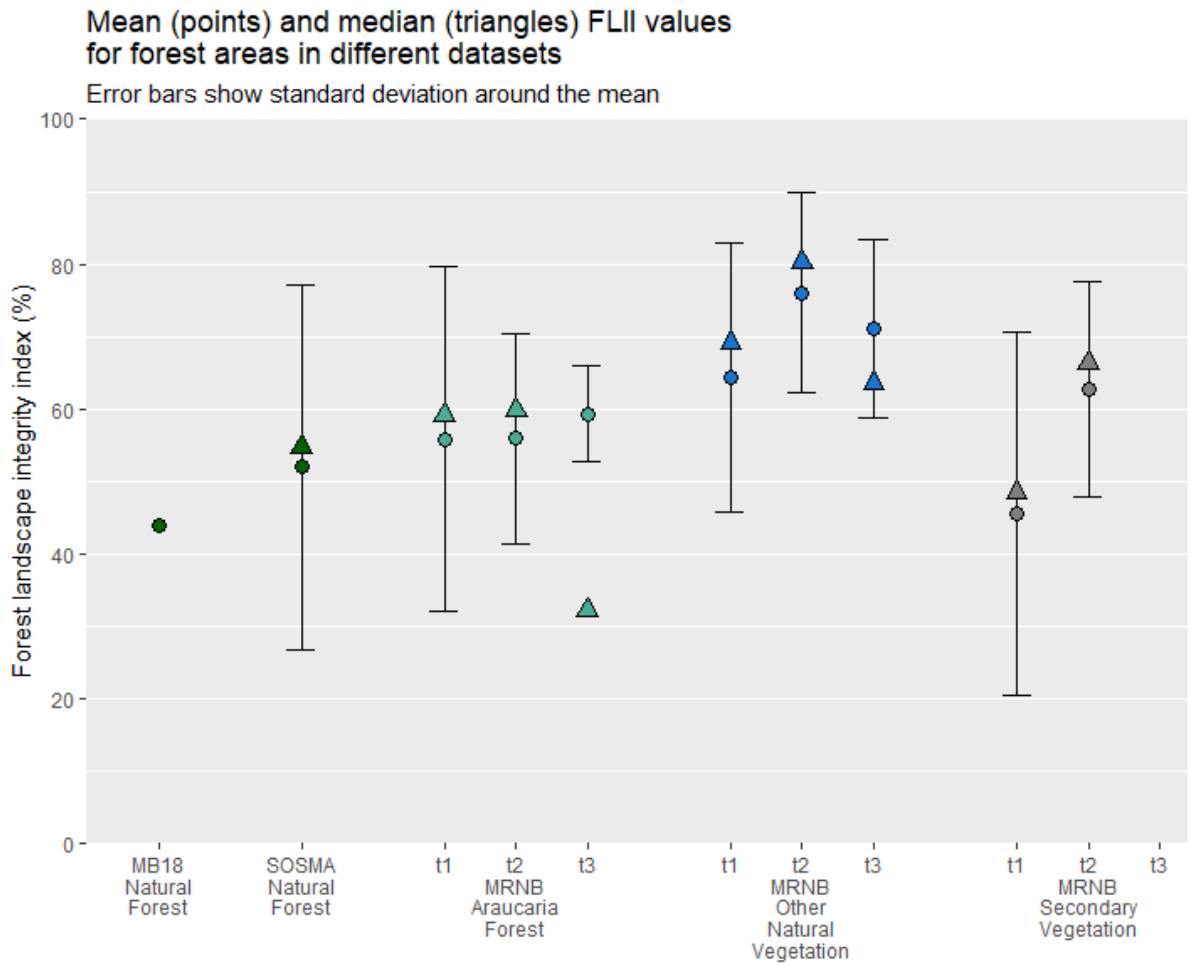

Figure S2: the mean (points), median (triangles) and standard deviation (error bars) of each dataset's natural forest areas' FLII values.

Araucaria angustifolia National Forest Inventory (NFI) analysis

The IUCN Red List assessment for *Araucaria angustifolia* uses the early satellite imagery analysis of Gantzel (1979) as the basis for "a forest reduction of over 97% within three tree generations [from 1900]" (Thomas, 2013, p. 1).[1] The claim of 97% loss specifically relates to natural forest with >50% Araucaria canopy (3.6% remaining), whereas all types of natural forest covered 18.3% of the examined region (Gantzel, 1979). The present study provides an updated analysis of the amount of natural Araucaria Forest which remains on the highlands, but the *A. angustifolia*-specific question Gantzel focused on is more difficult to assess via remotely sensed data alone.

As far as can be told, Gantzel's methods have not been replicated or used on more recent satellite imagery, and although the classification of high-resolution remotely sensed images bears some promise for identifying individual *A. angustifolia* crowns (e.g. Disperati et al., 2009; Saad et al., 2021), this has not yet been used on a regional scale. Data from Brazil's National Forest Inventory (NFI) can provide alternative approaches for making comparisons against Gantzel's original

[1] The assessment also credits this figure to Enright & Hill's 1995 book 'Ecology of the Southern Conifers', but it very likely originated with the Gantzel study. The assessment cites the latter study as Gantzel (1982) in Revista Floresta 13: 38:40, but this includes only the abstract of the original study – Gantzel's unpublished 1979 master's dissertation, which is cited here.

estimates. With systematic and near-complete coverage of Paraná, Santa Catarina and Rio Grande do Sul, the NFI plots allow some evaluation of the status of surveyed Araucaria Forest stands. Methods and results on the presence/absence and basal area of *A. angustifolia* trees are presented in the main text, but the NFI data were also used to assess the proportion of the highlands' (potential) plot locations which had >50% Araucaria canopy cover.

The NFI's preliminary data on *A. angustifolia* were made available to download as part of the Brazilian Forestry Service's Dia da Árvore (Day of the Tree) celebration in 2020 (https://snif.florestal.gov.br/pt-br/component/content/article/17-ultimas-noticias/717-arvores-do-brasil, last accessed May 2022). General results from NFI surveys in Paraná, Santa Catarina and Rio Grande do Sul have previously been published (Serviço Florestal Brasileiro, 2018b, 2018a, 2018c). All Araucaria trees >10 cm diameter at breast height (dbh) in the NFI plots are listed, with additional information on, *inter alia*, their size (dbh, height), health, and phytosociological position. This analysis was restricted to plots on a regular 0.18° (ca. 20km) grid (see section 2.2 of the main text). To assess how many plot locations had >50% *A. angustifolia* canopy cover, the database was filtered to exclude trees outside the forest, and to retain only individuals in a dominant or emergent phytosocial position. These trees' dbh measurements (cm) were converted to basal area (m²):

$$BA = \pi(0.005 \times dbh)^2$$

The horizontal projection of crown area for phytosocially dominant *A. angustifolia* trees can be estimated ($R^2 = 0.7897$) from their basal area using the following equation (Costa et al., 2013):

$$CA = 505.6 \times BA + 5.0742$$

NFI plots are 4,000 m² (0.4 ha), so a plot's emergent and dominant Araucaria trees would need 2,000 m² of combined crown area to reach 50% coverage. Rearranging the above equation gives the following:

$$BA = \frac{2{,}000 - 5.0742}{505.6} = 3.946\ m^2$$

Across Paraná, Santa Catarina and Rio Grande do Sul, only four NFI plots exceeded this threshold for basal area and inferred canopy coverage – two (out of 422 NFI plot locations, -0.2 – 1.1%) in the Araucaria Forest region and two (of 51, -1.5 – 9.4%) in Campos/Araucaria Forest (fig. S3). Although there are moderate uncertainties and approximations around the conversion from dbh and basal area to crown area and canopy coverage, only order-of-magnitude-scale shifts would qualitatively change this finding, and these are highly unlikely. Araucaria trees can – and, historically, did – dominate Araucaria Forest canopies, but this result, like those in the main text, supports Gantzel's finding that natural forests with Araucaria-dominated canopies are now far rarer than they were before the onset of European colonisation and the 20th Century's intense and unsustainable spasm of logging and habitat conversion (de Carvalho, 2010; de Carvalho & Nodari, 2010; Gantzel, 1979).

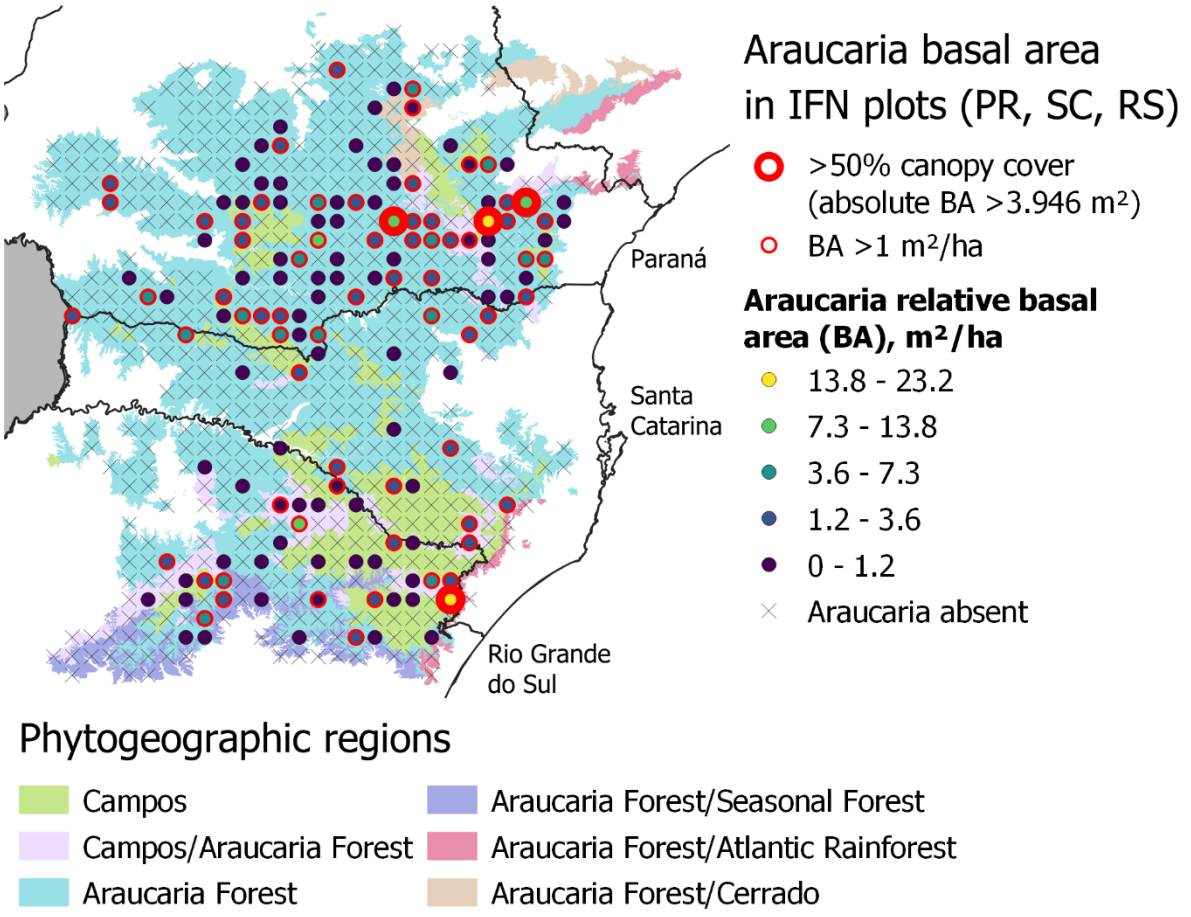

Figure S3: map showing Araucaria basal area in NFI plots in Paraná, Santa Catarina and Rio Grande do Sul, with plots exceeding the identified thresholds (relative BA >1 m²/ha or canopy coverage >50%) highlighted.

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