ATLANTIC SPATIAL: a data set of landscape, topographic, hydrological, and anthropogenic metrics for the Atlantic Forest

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Open Research statement

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Introduction

In ecology, space matters. Space affects the main drivers of biodiversity since it regulates the underlying processes affecting the distribution and dynamics of species (Fletcher and Fortin 2018). These ecological processes, such as environmental filtering, biotic interactions, dispersal, and ecological drift, drive the response of organisms to environmental factors such as climate, topography, soil types, land use and land cover (LULC), and habitat connectivity and heterogeneity (Anderle et al. 2022, Messager et al. 2023). Thus, space is a fundamental component in the face of rapid effects of climate and LULC changes at local, regional, and global scales, as well as their widespread consequences for habitat loss and fragmentation (Jetz et al. 2007, He et al. 2019, Williams and Newbold 2020). Having available geospatial environmental data is essential to assess the effects of these changes on biodiversity at different spatial and temporal scales, extents, and grains (e.g., Lima-Ribeiro et al. 2015, Vega et al. 2017, Fick and Hijmans 2017, Souza et al. 2020, Karger et al. 2020, Poggio et al. 2021, Potapov et al. 2022b, 2022a, Hawker et al. 2022, Hansen et al. 2022, Tang and Werner 2023). Comprehensive spatial data sets are important to address conservation and restoration efforts to maintain biodiversity and their ecological processes (Dirzo et al. 2014, He et al. 2015, Young et al. 2016, Johnson et al. 2017). Ultimately, such data sets would help to unravel frequent 'spatial complications' [neglected contribution of space in explaining ecological processes] (Kareiva 1994) in ecology and other geospatial disciplines.

Habitat loss and fragmentation are currently the major threats to biodiversity and ecological processes worldwide (Fahrig 2003, Haddad et al. 2015, Chase et al. 2020). Landscape composition and configuration are essential factors determining biodiversity, population dynamics, species interactions, dispersal, and the functions that biota performs across the space (Fahrig 2003, Driscoll et al. 2013, Duflot et al. 2017). Besides, different landscape metrics can be used as proxies of landscape heterogeneity to predict biodiversity and ecosystem function (Tonetti et al. 2023). This is especially relevant in fragmented landscapes where natural vegetation fragments are surrounded by different anthropogenic land cover types (Fischer and Lindenmayer 2007, Turner and Gardner 2015). Landscape metrics can also be used to identify priority areas for conservation (Tambosi et al. 2014) and to predict species' potential distribution (Fletcher et al. 2016, Riva et al. 2024). Furthermore, these metrics must be computed considering different scales depending on the phenomenon of interest (Jackson and Fahrig 2015, Miguet et al. 2016), and the specific species' functional responses to landscape structure (Mimet et al. 2013, Riva and Nielsen 2020, Niebuhr et al. 2023).

The Atlantic Forest of South America (AF) is among the global biodiversity hotspots due to its high species richness and endemism associated with severe habitat loss (Myers et al. 2000, Sloan et al. 2014). The AF covers almost the entire coast of Brazil and reaches inland portions of the continent in parts of Paraguay and Argentina, and its vegetation covered over 1.6 million km^2 before the European colonization (Marques et al. 2021). Due to its wide longitudinal, latitudinal, and altitudinal range, the AF has high environmental heterogeneity with different vegetation types generated mainly by the rainfall distribution, from its coast as Mangrove and Sandy coastal plain vegetation (*restinga*), passing through humid forest (Dense Ombrophilous, Open Ombrophilous, Mixed Ombrophilous), and dry forest formations (Semideciduous and Deciduous Seasonal) (Joly et al. 2014). These geographical characteristics, combined with a large topographic variability and pre-historic process of formation, favored high species diversification rates and endemism (Carnaval et al. 2014, Peres et al. 2020).

The high diversification rate in AF is evidenced by its high biodiversity: it contains almost 18,000 species of plants (Flora e Funga do Brasil 2023); 2,645 species of Tetrapoda (Figueiredo et al. 2021); around 1,000 species of fish (Reis et al. 2016); 1400 species of social insects (Feitosa et al. 2021); more than 2,000 species of butterflies (Iserhard et al. 2017); more than 112,000 species of arachnids (Giupponi et al. 2017); and from 3 to 12 million species of unknown bacteria (Lambais et al. 2006). In addition to its high biodiversity, the AF directly provides ecosystem services for >150 million people, such as water provisioning and regulation, hydroelectric energy generation, food production, pollination, soil protection, climate regulation, carbon storage, air quality, and cultural services (Joly et al. 2014, Pires et al. 2021). A great part of the AF biodiversity is highly threatened, especially birds (Bonfim et al. 2021), small mammals (Palmeirim et al. 2019), medium and large mammals (Rios et al. 2021b), and amphibians (Almeida-Gomes and Rocha 2014). Furthermore, ecological processes are also affected by landscape modifications, such as interaction networks (Marjakangas et al. 2020, Monteiro et al. 2022), carbon storage (Bello et al. 2015, de Lima et al. 2020, Pyles et al. 2022), and pollination (Varassin et al. 2021). In addition, other threats to the AF landscapes include defaunation (Galetti et al. 2017, 2021), the introduction of non-native species (Vitule et al. 2021), and climate change (Scarano and Ceotto 2015, Vale et al. 2021).

The AF covers the three countries (Argentina, Brazil, and Paraguay) with the largest deforestation areas in the world between 1982 and 2016 (Song et al. 2018). Thus, landscape modifications within the AF have caused impacts reported by a series of studies that still show a warning scenario (de Lima et al. 2020, 2024, Carlucci et al. 2021, Vancine et al. 2024). Despite a recent temporal stability of around 28 Mha of forest, a considerable part of this forest is made up of the replacement of old native forests by young forests (Rosa et al. 2021). Furthermore, although recent estimates state that there are around about 23% of forest and 36% of natural vegetation, there is a high fragmentation scenario—97% of fragments are <50 ha, 60% of the forests are under edge effect (<90 m), and there is high isolation of vegetation fragments (mean of 250 to 830 m) (Vancine et al. 2024). Moreover, the high density of linear infrastructure (roads and railways) in AF affects the vegetation remnants—especially the large ones (>500,000 ha), proving to have a major negative impact on biodiversity (Cassimiro et al. 2023, Vancine et al. 2024).

The AF is one of the most intensely studied biomes in the world. A large initiative coordinated by Brazilian researchers – the ATLANTIC SERIES of data papers – has compiled hundreds of thousands of records of occurrence and abundance of animal and plant species in the AF (https://esajournals.onlinelibrary.wiley.com/doi/toc/10.1002/(ISSN)1939-9170.AtlanticPapers). Biodiversity data were collected for decades and have been recently synthesized for AF in numerous data papers from the collection ATLANTIC SERIES (Bello et al. 2017, Bovendorp et al. 2017, Figueiredo et al. 2017, Lima et al. 2017, Muylaert et al. 2017, Gonçalves et al. 2018a, 2018b, Hasui et al. 2018, Vancine et al. 2018, Santos et al. 2018, Souza et al. 2019, Culot et al. 2019, Ramos et al. 2019, Rodrigues et al. 2019, Silva et al. 2022, Boscolo et al. 2023, Franceschi et al. 2024).

These biodiversity data sets have provided an unprecedented opportunity for the assessment of how environmental conditions and species interactions can predict biodiversity patterns from species to assemblages (e.g., Bovendorp et al. 2019, Palmeirim et al. 2019, Rios et al. 2021b, 2021a, Bonfim et al. 2021). However, at least three elements might limit the comparison between these studies or the increased use of these data to answer new questions. First, such studies rely on a highly variable set of spatial background data, which often differ in scale and grain, as well as in the source and quality of these data. Second, computing and preparing spatial data for ecological studies and impact assessments frequently require time and intensive processing, and the resources for doing that are not always available. Third, even though other studies have compiled spatial datasets for the entire world (e.g., Branco et al. 2024), these are still making layers available at coarse scales (30 arc-min or ~1 km), which are generally insufficient to understand fine-scale processes and biodiversity responses to landscape change. Once this spatial data set becomes available, multiple studies would greatly benefit from having a standardized and ready-to-use set of variables representing spatial variation in the landscape and human pressures, as has been demonstrated in several studies (e.g., Bovendorp et al. 2019, Palmeirim et al. 2019, Marjakangas et al. 2020, Santos et al. 2020, Rios et al. 2021b, 2021a, Bonfim et al. 2021, Monteiro et al. 2022, Anunciação et al. 2023).

Thus, we describe and provide a set of spatial data sets for the AF that aim to tackle these questions and foster knowledge-building in ecology and conservation. First, this data set of spatial metrics can facilitate the performance of biodiversity studies in the AF, allowing for more standardization and direct comparison, as well as increase reproducibility, since several metrics were calculated from the same data set and from known sources. Second, having ready-to-use layers might facilitate analyses to explore data-relations or understand ecological questions with less resources. Third, the spatial data sets presented here are provided with a fine scale of 30 m, which brings high refinement to the spatial layers and the possibility of inferences at the scales where biodiversity data are collected. Thus, our aim was to facilitate the use of these spatial layers in a series of studies, within fields such as landscape ecology (Beca et al. 2017, Regolin et al. 2017, Marjakangas et al. 2020, Monteiro et al. 2022), species distribution modeling (SDMs) (Ferro e Silva et al. 2018, Bertassoni et al. 2019, Santos et al. 2020, 2022, Oshima et al. 2021, Tonetti et al. 2022, Riva et al. 2024), spatial prioritization (Tambosi et al. 2014, Rosa et al. 2021, Iezzi et al. 2022, Tonetti et al. 2024), and habitat restoration (Melo et al. 2013, Pinto et al. 2014, Zwiener et al. 2017, Lopes et al. 2022, Piffer et al. 2022, Schweizer et al. 2022, Zupo et al. 2022, Bicudo da Silva et al. 2023).

Here, we present the ATLANTIC SPATIAL data set, where we organize and synthesize spatial data on land cover and land use, landscape, topographic, hydrological, and anthropogenic metrics for the entire AF. Making these data available avoids complex and computationally demanding geoprocessing steps from having to be re-run and allows for different biodiversity studies to be more reproducible and potentially comparable, since they would use as source the same set of spatial data. We present raster maps at 30-m resolution, making it possible to easily integrate spatial and biodiversity data in ecological studies. We provide several metrics derived from spatial analyses using different moving window sizes, so that they can be used to evaluate scales of effect on multiple scale analyses (Jackson and Fahrig 2015, Niebuhr et al. 2023). We hope this information enables the integration of biodiversity and environmental data for the AF in ecological studies and expect it to be a common reference to be used as a basis for landscape planning, biodiversity conservation, and forest restoration programs. Although we recognize the temporal limitation of the data, which were compiled for the years 2020 to 2022, we used the most recent data available when performing the calculations. In addition, this data will be highly relevant, since as demonstrated by Vancine et al. (2024), the landscape structure of the Atlantic Forest has become relatively stable since 2005, with a small increase in forest vegetation (0.6% or ~1Mha). Thus, even future studies or those using data prior to this date will benefit from the extensive data processing we performed for this data set.

METADATA

Class I. Data set descriptors

A. Data set identity

Title: ATLANTIC SPATIAL: a data set of landscape, topographic, hydrological and anthropogenic metrics for the Atlantic Forest.

B. Data set identification code

ATLANTIC_SPATIAL.csv

C. Data set description

1. Originators

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2. Abstract

Space is one of the main drivers of biodiversity, once it regulates the underlying processes affecting the distribution and dynamics of species and communities. It is a fundamental factor in the face of the rapid climate and land use and land cover changes at local and global scales, which are linked to habitat loss and fragmentation and their impacts on various organisms. The Atlantic Forest of South America (AF) is among the global biodiversity hotspots because of its high species richness and endemism. Most of the threats to the AF biodiversity are due to the expansion of urbanization and industry, extensive agricultural and livestock production, and mining. Here, we make available integrated and fine-scale spatial information (resolution = 30 m) for the entire AF extent for the year 2020. The metrics consider different vegetation classes (forest and forest plus other natural vegetation), effects of linear structure (roads and railways), and multiple scales (radius buffer from 50 m to 2,500 m and up to 10 km for some metrics). The entire data set consists of over 500 rasters and the AF delimitation vector, available through the R package *atlanticr*, which we developed to facilitate the organization and acquisition of the data. The metrics consist of land cover (31 classes), distance to grouped land cover classes (forest vegetation, natural vegetation, pasture, temporary crop, perennial crop, forest plantation, urban areas, mining, and water), a set of landscape, topographic and hydrological metrics, and anthropogenic infrastructure. The landscape metrics include landscape morphology (classification as matrix, core, edge, corridor, stepping stone, branch, and perforation), fragment area and proportion, area and number of patches, edge and core areas and proportion,

structural and functional connectivity (for different organisms' gap-crossing capabilities), distance to fragment edges, fragment perimeter and perimeter-area ratio, and landscape diversity. Topographic metrics include elevation, slope, aspect, curvatures, and landform elements (peak, ridge, shoulder, spur, slope, hollow, footslope, valley, pit, and flat). Hydrological metrics comprise potential springs and their kernel density, and potential streams and their respective distances, and anthropogenic infrastructure maps contain roads, railways, protected areas, indigenous territories, and quilombola territories, and the respective distances to each of them. This data set will allow efficient integration of biodiversity and environmental data for the AF in future research, and we might be an important reference and data source for landscape planning, biodiversity conservation, and forest restoration programs.

D. Keywords

Biodiversity hotspot, covariates, habitat loss, habitat fragmentation, spatial ecology, rainforest, tropical ecology.

Class II. Research origin descriptors

A. Overall project description

1. Identity

A compilation of spatial covariates data of landscape, topographic, hydrological, and anthropogenic metrics for the entire AF at fine spatial resolution (30 m) for the year 2020.

2. Originators

The ATLANTIC SPATIAL project was coordinated by Maurício H. Vancine and Bernardo B. Niebuhr at the São Paulo State University (UNESP), and the data set was assembled with help from all the other authors. This is part of ATLANTIC SERIES, which is led by Mauro Galetti and Milton Cezar Ribeiro at the São Paulo State University (UNESP).

3. Period of study

Data were processed for the year 2020.

4. Objectives

The aim of this data paper was to provide a set of spatial covariates comprising landscape, topographic, hydrological, and anthropogenic metrics for the entire Atlantic Forest (AF) at fine spatial resolution (30 m) for the year 2020.

5. Abstract

Same as above.

6. Sources of funding

The compilation of this data set was supported by São Paulo Research Foundation (FAPESP) grants #2022/01899-6 (MVH), #2021/02132-8 (JEFO), #2020/11129-8 (EMZ), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) grants fellowships 88887.513979/2020-00 and 1588183 (MVH) and Conselho Nacional do Desenvolvimento Científico e Tecnológico (CNPq) grants #130909/2020-3 (EMZ). BBN is supported by the NINA basic funding (Research Council of Norway, Grant #160022/F40). RLM is supported by Bryce Carmine and Anne Carmine (née Percival), through the Massey University Foundation. CHG is a research fellow of the National Council for Scientific and Technological Development - CNPq (grant #311209/2021-1). MCR was supported by FAPESP (processes #2013/50421-2, #2020/01779-5, #2021/08322-3, #2021/08534-0, #2021/10195-0, #2021/10639-5, #2022/10760-1) and CNPq (processes #442147/2020-1, #440145/2022-8, #402765/2021-4, #313016/2021-6, #440145/2022-8) and São Paulo State University - UNESP for their financial support. This study was financed in part by CAPES Brazil – Finance Code 001. This study is also part of the Center for Research on Biodiversity Dynamics and Climate Change, which is financed by FAPESP.

B. Specific subproject description

1. Site description

AF extends from 3ºS to 33ºS, and from 35ºW to 58ºW with ~163 Mha, covering coastal and inland portions of Brazil, Argentina, and Paraguay (Marques et al. 2021, Vancine et al. 2024) (Figure 1). Due to this large extension, the AF boundaries create important ecotones with other vegetation domains such as Cerrado, Caatinga, Chaco, and Pampa (Marques et al. 2021, Vancine et al. 2024). The vegetation from AF is a complex mosaic composed of five main vegetation types—Dense Ombrophilous, Open Ombrophilous, Mixed Ombrophilous, Semideciduous Seasonal, and Deciduous Seasonal (Joly et al. 2014). Additionally, the AF also includes mangroves and coastal scrub vegetation (Marques et al. 2021, Vancine et al. 2024). Furthermore, there are many associated ecosystems such as altitude grasslands (*campos rupestres* and *campos de altitude*), oceanic islands, beaches, rocky shores, dunes, marshes, inland swamps, and mountain forest (*brejos de altitude*) in the Northeast region (Scarano 2002). The main vectors of forest and natural vegetation change in the AF biodiversity include the expansion of urbanization and industry, extensive agricultural and livestock production, and mining (Silva et al. 2016, Lembi et al. 2020, Carlucci et al. 2021, Lira et al. 2021, Viveiros de Castro et al. 2021). The AF is inhabited by >150 million people, most in urban areas, but also by people in rural areas, including indigenous communities, quilombolas, traditional peoples and communities, and settlements from the Agrarian Reform and from rural social movements (Joly et al. 2014, Pires et al. 2021, Viveiros de Castro et al. 2021, Shennan-Farpón et al. 2022, Benzeev et al. 2023).

2. Experimental or sampling design

None.

3. Research methods

Atlantic Forest delimitation

We used the integrative AF delimitation adapted from Muylaert et al. (2018) and published in Vancine et al. (2024), a general delimitation encompassing the main proposed delimitations across several associated ecosystems (Muylaert et al. 2018, Cunha et al. 2019, Marques et al. 2021). We adapted this delimitation by merging the following original maps and the most recent ones: 1. AF delimitation defined by Brazilian legislation (Federal Decree No. 750/93 and Atlantic Forest Law No. 11,428/2006) named Atlantic Forest Law by IBGE (2018); 2. AF limit defined by Da Silva and Casteleti (2003); 3. AF delimitation defined by IBGE (2004); 4. AF's most recent delimitation defined by IBGE (2019) and; 5. AF delimitation defined by Dinerstein et al. (2017) and used in the Ecoregions 2017® (https://ecoregions.appspot.com).

Finally, we adjusted the resulting delimitation for the coastal areas using the Brazilian territorial delimitation from IBGE (https://www.ibge.gov.br) for 2021, to align the limit considering the most current delimitations of mangrove, dunes, and sandy coastal plain vegetation (*restinga*) (Scarano 2002). The final delimitation has an area total of 162,742,129 ha, that covers 3653 municipalities from 18 Brazilian states (151,470,253 ha, 93.07%), and parts of Argentina (2,668,855 ha, 1.64%) and Paraguay (8,603,022 ha, 5.29%) (Figure 1).

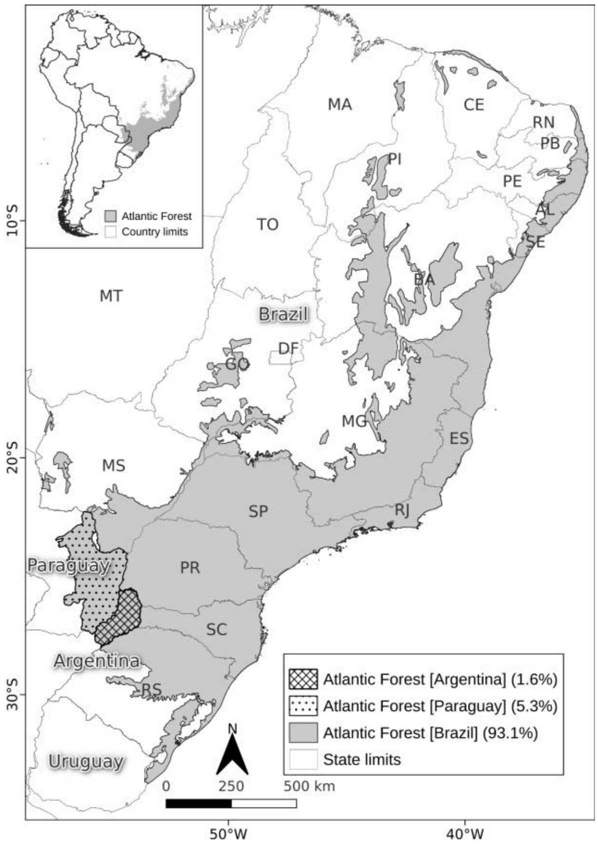


Figure 1. Integrative Atlantic Forest delimitation, adapted from Muylaert et al. (2018) and published in Vancine et al. (2024). Abbreviations are Brazilian states: MA = Maranhão, PI = Piauí, CE = Ceará, RN = Rio Grande do Norte, PB = Paraíba, PE = Pernambuco, AL = Alagoas, SE = Sergipe, BA = Bahia, MG = Minas Gerais, ES = Espírito Santo, RJ = Rio de Janeiro, SP = São Paulo, PR = Paraná, SC = Santa Catarina, RS = Rio Grande do Sul, MS = Mato Grosso do Sul, MT = Mato Grosso, Go = Goiás, DF = Distrito Federal, and TO = Tocantins.

Raster resolution and coordinate system

All geospatial data sets were rasterized with or adjusted to the resolution of 30 m (~1.8 billion cells with values). All rasters were reprojected to Albers Conical Equal Area Brazil (SIRGAS 2000) (https://brazil-data-cube.github.io/specifications/bdc-projection.html) and are therefore presented in meters.

Land use and land cover data

We compiled Land Use and Land Cover (LULC) maps from MapBiomas Brazil collection 7 (https://mapbiomas.org) (MapBiomas Project 2022, Souza et al. 2020), and MapBiomas Bosque Atlántico collection 2 (https://bosqueatlantico.mapbiomas.org) (MapBiomas Trinational Atlantic Forest Project, Souza et al. 2020). Considering these collections, these data sets reconstruct annual LULC information at the 30-m spatial resolution from 1985 to 2021, based on a pixel-based random forest classifier of Landsat satellite images processed through Google Earth Engine, and with posterior accuracy of 89.8% for the AF (MapBiomas Project 2022, Souza et al. 2020).

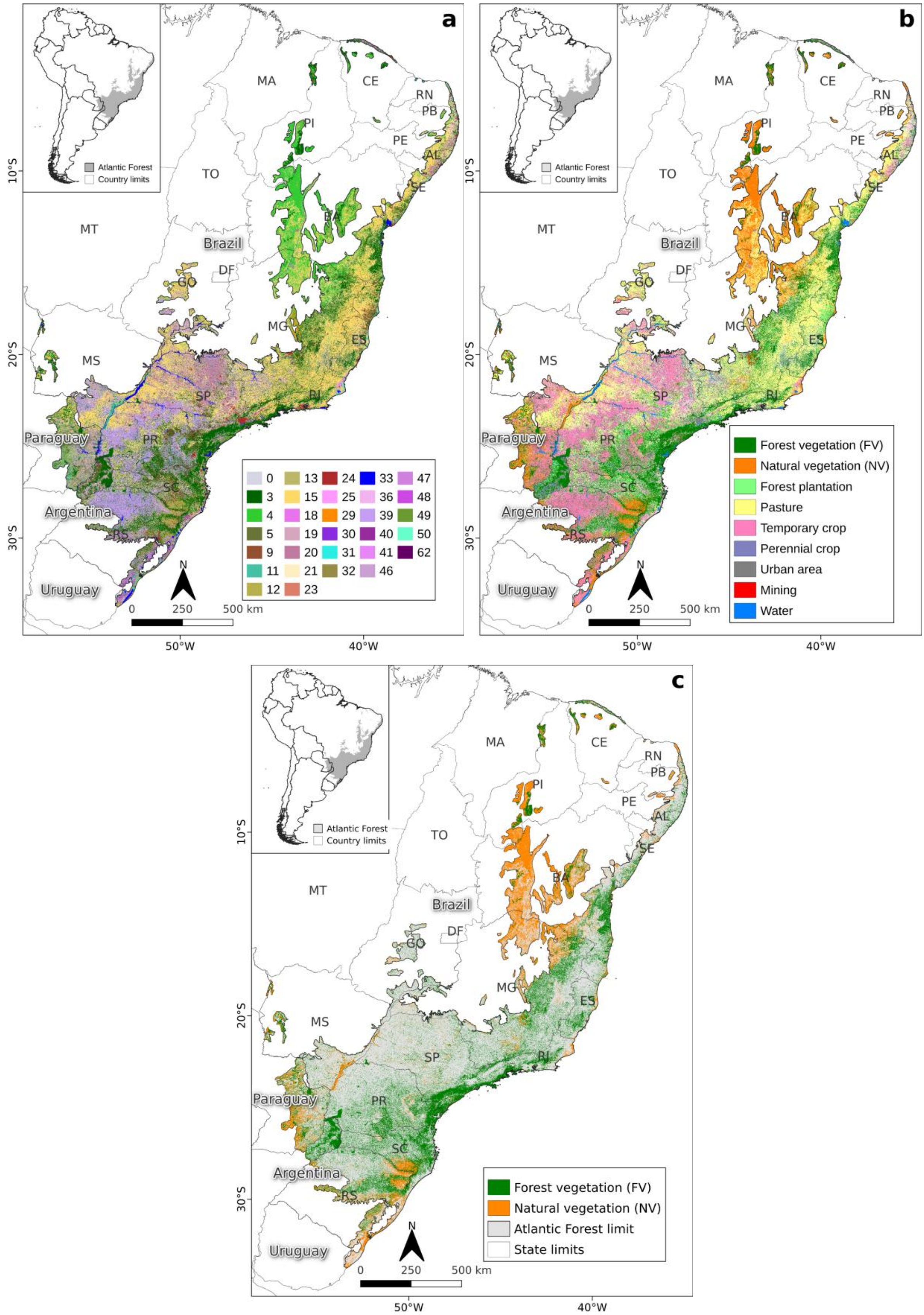


Figure 2. Data framework used to summarize land use land cover (LULC) classes into Atlantic Forest habitat types. (a) The LULC classes refer to MapBiomas in the AF (Brazil, Argentina, and Paraguay). (b) Grouped land cover classes. (c) Two vegetation classes were considered as habitat to calculate the landscape metrics. MapBiomas classes are presented in Table 1. Abbreviations correspond to Brazilian states presented in Figure 1.

We considered the LULC map for 2020 to provide the most recent data that included data validation for the previous year (2019) and subsequent year (2021), guaranteeing better accuracy for the LULC classes, when we performed the analysis (between 2022 and 2023). The LULC map from MapBiomas consists of a map with 31 classes (Table 1; Figure 2a). To calculate the distance from land cover class metrics, we grouped the classes into seven broad categories: pasture, temporary crop, perennial crop, forest plantation, urban areas, mining, and water (Table 1; Figure 2b). For the landscape metrics, we defined two vegetation classes for analysis: "Forest Vegetation" (FV), selecting the land cover classes of "Forest" and "Natural Vegetation" (NV), selecting the land cover classes of "Forest" and "Non-Forest Natural Formation" (Table 1; Figure 2c). The only exception for landscape metrics was heterogeneity, for which we used all original 31 classes from the MapBiomas LULC map in the calculation.

Table 1. Land use and land cover classes grouped as vegetation classes. The Atlantic Forest spatial maps were based on MapBiomas collection 7.

Land use and land cover class	MapBiomas class code	Grouped land cover classes	Vegetation class
Not specified	0	Not used	Not used
Forest formation	3	Forest vegetation	Forest vegetation (FV) and Natural vegetation (NV)
Savanna formation	4	Natural vegetation	Natural vegetation (NV)
Mangrove	5	Forest vegetation	Forest vegetation (FV) and Natural vegetation (NV)
Forest plantation	9	Forest plantation	Not used
Wetland	11	Natural vegetation	Natural vegetation (NV)
Grassland	12	Natural vegetation	Natural vegetation (NV)
Other non-forest formations	13	Natural vegetation	Natural vegetation (NV)

Pasture	15	Pasture	Not used
Temporary crop	19	Temporary crop	Not used
Sugar cane	20	Temporary crop	Not used
Mosaic of uses	21	Not used	Not used
Non vegetated area	22	Not used	Not used
Beach, dune and sand spot	23	Not used	Not used
Urban area	24	Urban area	Not used
Other non-vegetated areas	25	Not used	Not used
Rocky outcrop	29	Not used	Not used
Mining	30	Mining	Not used
Aquaculture	31	Not used	Not used
Salt flat	32	Natural vegetation	Natural vegetation (NV)
River, lake and ocean	33	Water	Not used
Perennial crop	36	Perennial crop	Not used
Soybean	39	Temporary crop	Not used
Rice	40	Temporary crop	Not used
Other temporary crops	41	Temporary crop	Not used
Coffee	46	Perennial crop	Not used
Citrus	47	Perennial crop	Not used
Other perennial crops	48	Perennial crop	Not used
Wooded sandbank vegetation	49	Forest vegetation	Forest vegetation (FV) and Natural vegetation (NV)

Herbaceous sandbank vegetation	50	Natural vegetation	Natural vegetation (NV)
Cotton	62	Temporary crop	Not used

We used linear infrastructure (roads and railways) to trim FV and NV areas overlapping with these structures. This way we avoided overestimating large fragments, since roads can decrease the connectivity of large patches (Martinez Pardo et al. 2023) for different taxa (Cassimiro et al. 2023). Road and railway data were downloaded from official geospatial databases for the three countries: Brazil (Instituto Brasileiro de Geografia e Estatística – IBGE; IBGE, 2021; https://www.ibge.gov.br), Argentina (Instituto Geográfico Nacional – IGN; IGN, 2022; https://www.ign.gob.ar) and Paraguay (Instituto Nacional de Estadística – INE; INE, 2022; https://www.ine.gov.py). The data summed 14,072 km of railways and 125,483 km of roads, totaling 139,554 km (Figure 3). We did not find official railway data for Paraguay, so this effect may be underestimated for this country. For Brazil, we selected paved, operational and constructed roads, and railways selected by their relative surface position and train section for 2021. For Argentina, we consider national and provincial paved roads for the year 2021. For Paraguay, we only considered the main roads (according to the Atlas nomenclature) for the year 2012, without making a distinction regarding the paving of roads, since this information was not available. The road and railway layers were rasterized using a parameter that creates densified lines, i.e., all cells touched by the line were included as data for rasterization, which implied in more densified lines. This guaranteed that the roads and railways would trim the fragments. After the lines were rasterized, the roads covered 528,983 ha (0.33% from the AF delimitation). We trimmed the fragments of vegetation using the rasterized data generated (Vancine et al. 2024).

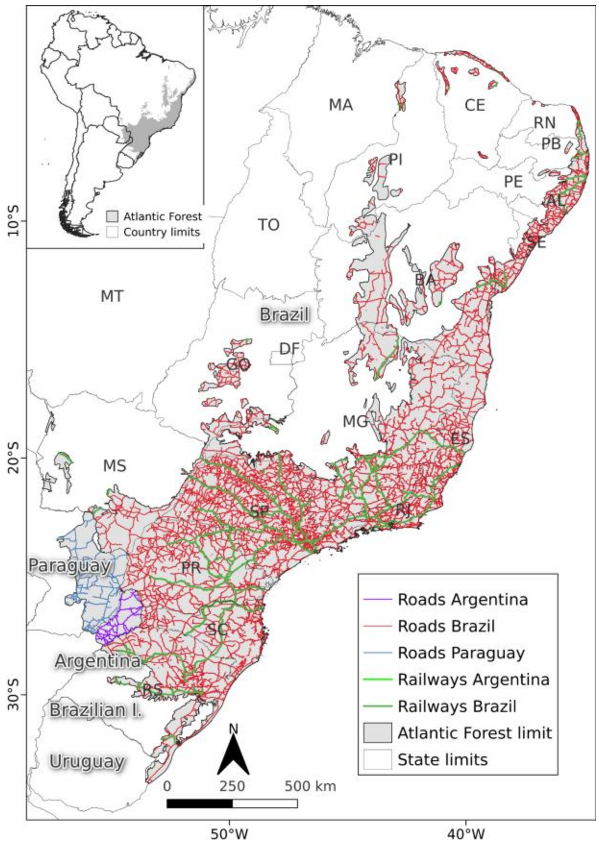


Figure 3. Linear infrastructure (roads and railways) network used to trim the forest vegetation (FV) and native vegetation (NV) fragments within the Atlantic Forest. Abbreviations correspond to Brazilian states presented in Figure 1.

Urban areas for Brazil were selected from MapBiomas. For Argentina, this data was downloaded from Instituto Geográfico Nacional (Instituto Geográfico Nacional – IGN, https://www.ign.gob.ar) and for Paraguay from Instituto Nacional de Estadística (Instituto Nacional de Estadística – INE, https://www.ine.gov.py) (Figure 4), and covered 2,401,850 ha (1.48% from the AF limit).

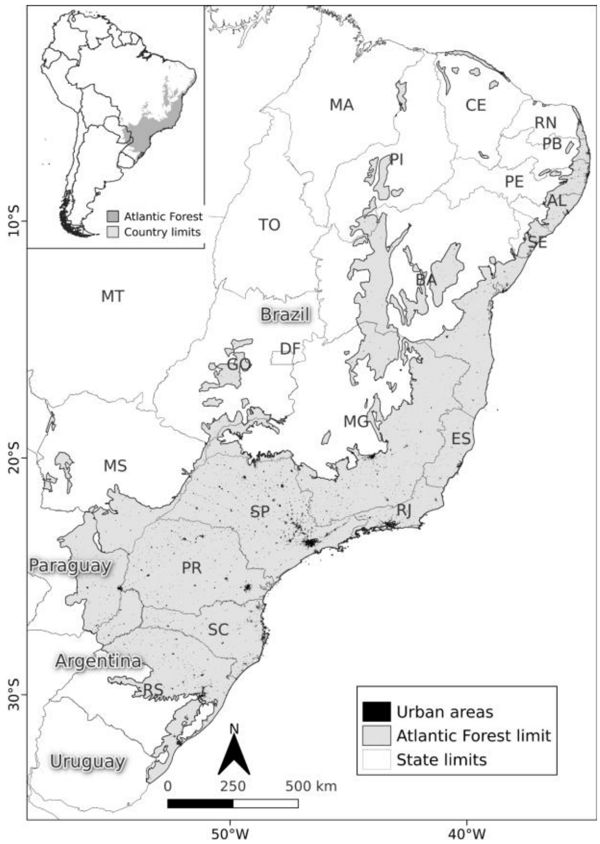


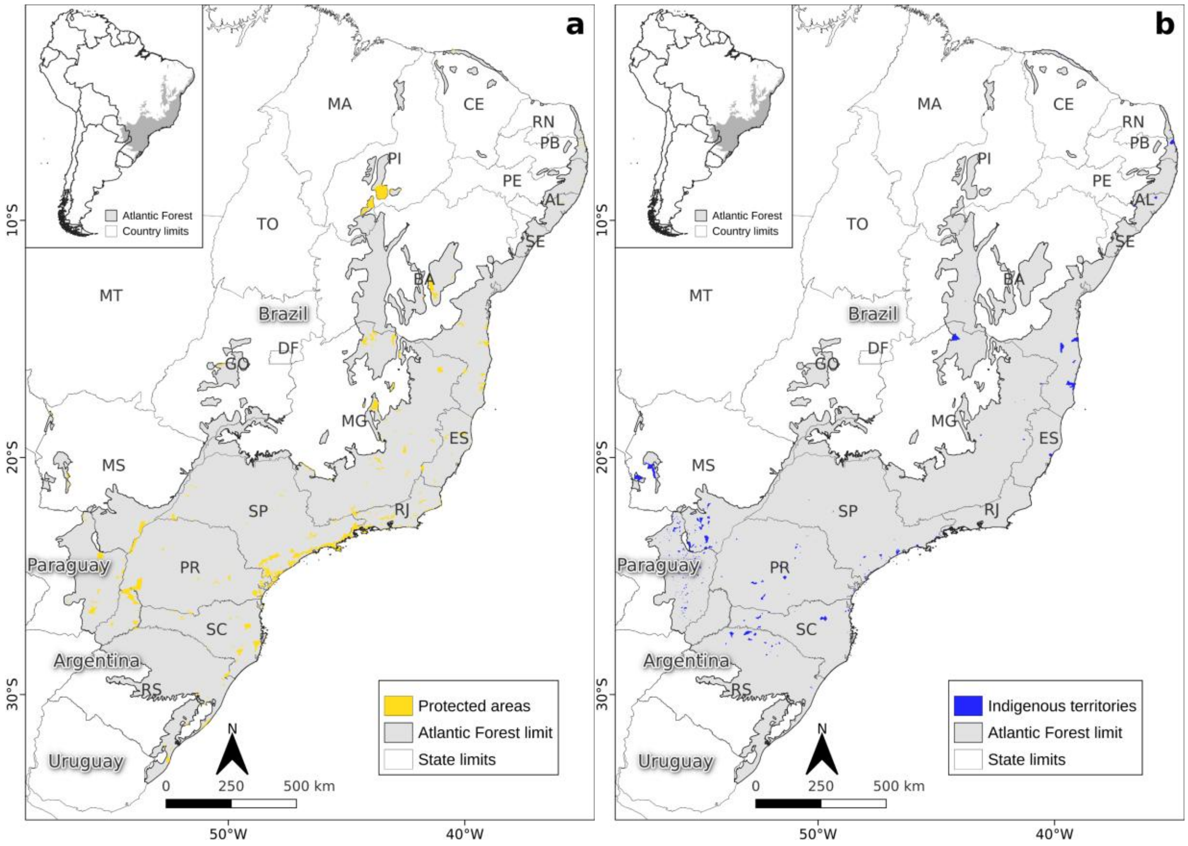
Figure 4. Urban areas within the Atlantic Forest. Abbreviations correspond to Brazilian states presented in Figure 1.

Protected areas, indigenous territories, and quilombola territories

The limits of the protected areas (PA) were downloaded from Protected Planet portal (UNEP-WCMC and IUCN, 2022, www.protectedplanet.net) for the IUCN categories of protected areas ("Ia", "Ib", "II", "III" and "IV"), which comprises 986 reserves (4,620,245 ha; 2.84% from AF limit) (Figure 5a). These IUCN categories encompass the following protection categories of Argentina (Municipal Nature Park, National Park, Nature Monument, Private Refuge, Private Wildlife Refuge, Provincial Park, Strict Nature Reserve, Wilderness Nature Reserve and Wildlife Reserve), Brazil (Area of Relevant Ecological Interest, Biological Reserve, Ecological Station, Natural Heritage Private Reserve, Natural Monument, Park, Ramsar Site, Wetland of International Importance, Wildlife Refuge), and Paraguay (National Park, Natural Private Reserve, Natural Reserve, Scientific Monument and Scientific Reserve).

Indigenous territories (IT) are lands traditionally occupied by indigenous communities and ethnic groups, defined as those inhabited by them on a permanent basis, those used for their productive activities, those essential to the preservation of the environmental resources necessary for their well-being and those necessary for their physical and cultural reproduction, being their uses, customs, and traditions (Benzeev et al. 2023). IT for Brazil were downloaded from Fundação Nacional dos Povos Indígenas (Fundação Nacional dos Povos Indígenas, 2020, https://www.gov.br/funai/pt-br) selecting only “Homologated”, and for Paraguay from Tierras Indígenas (Tierras Indígenas, 2022, https://www.tierrasindigenas.org), comprising in total 1023 territories (1,324,973 ha; 0.81% from AF limit) (Figure 5b).

Quilombola territories (QT) are delimited areas where quilombola communities live, which are ethnic groups predominantly made up of the rural or urban black population, who define themselves based on specific relationships with the land, kinship, territory, ancestry, traditions, and their own cultural practices (Cherol et al. 2021). QT were included only for Brazil, and their limits were downloaded from Instituto Nacional de Colonização e Reforma Agrária (INCRA) (https://certificacao.incra.gov.br/csv_shp/export_shp.py), which comprise 157 territories (486,533 ha; 0.30% from AF limit) (Figure 5c).



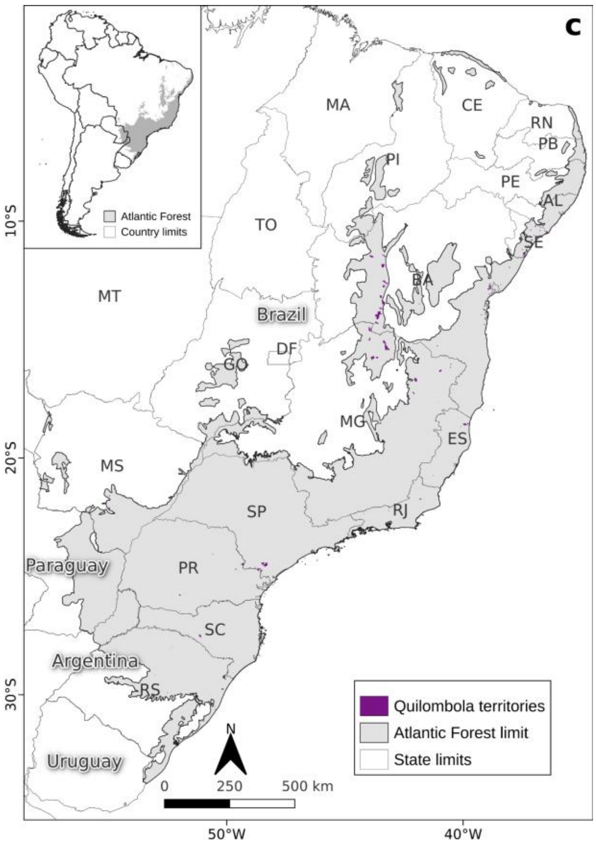


Figure 5. Protected areas (PA) (a), indigenous territories (IT) (b), and quilombola territories (QT) within the Atlantic Forest. Abbreviations correspond to Brazilian states presented in Figure 1.

Topography data

Topographic metrics were calculated from FABDEM v1.2 (forest and buildings removed Copernicus DEM), an elevation raster map that used machine learning to remove buildings and tree height biases from the Copernicus GLO 30 Digital Elevation Model (DEM) (Hawker et al. 2022) (Figure 6).

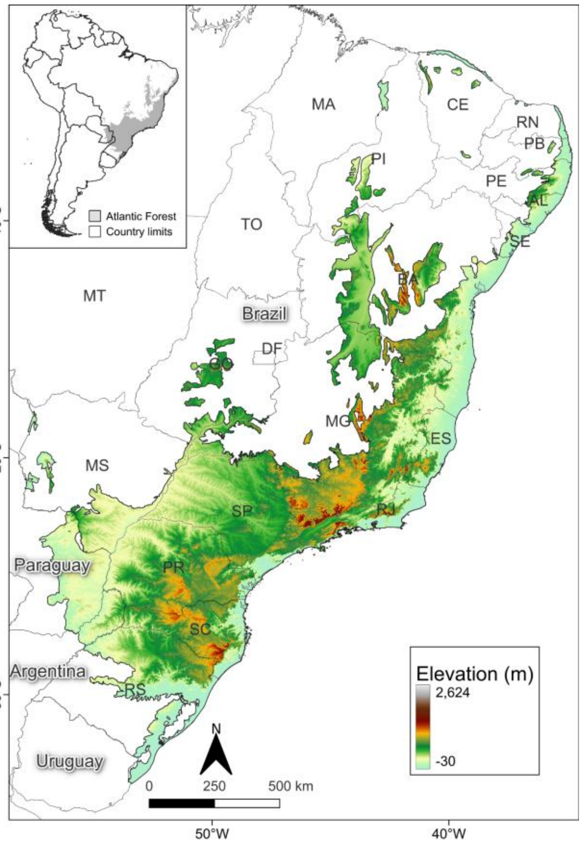


Figure 6. Elevation (meters above sea level) from FABDEM v1.2 across the Atlantic Forest. Abbreviations correspond to Brazilian states presented in Figure 1.

Data set source description

Table 2 summarizes all the sources and descriptions of spatial information used to integrate spatial variables presented in the ATLANTIC SPATIAL data set.

Table 2. Source and description of spatial information.

Type of information	Institution	Description
Land Use and Land Cover (LULC)	MapBiomas	Annual LULC information at the 30-m spatial resolution from 1985 to 2021, based on pixel-based random forest classifier of Landsat satellite images using Google Earth Engine. Only the data set for 2020 was used in the ATLANTIC SPATIAL data set. Source: Souza et al. (2020) Site: https://mapbiomas.org

Roads and railways	Instituto Brasileiro de Geografia e Estatística (IBGE) Instituto Geográfico Nacional (IGN) Instituto Nacional de Estadística (INE)	Continuous Cartographic Base of Brazil, 1:250,000, for the year 2023. Catalog of Geographical Objects of the Organism and forms part of the Institutional Geospatial Database, for the year 2020. Digital Cartography 2012, Directorate General of Statistics, Surveys, and Censuses and is merely referential, for the year 2021. Sources: Instituto Brasileiro de Geografia e Estatística (IBGE); Instituto Geográfico Nacional (IGN); and Instituto Nacional de Estadística (INE) Sites: https://www.ibge.gov.br; https://www.ign.gob.ar; and https://www.ine.gov.py
Urban areas	MapBiomas Instituto Geográfico Nacional (IGN) Instituto Nacional de Estadística (INE)	Annual LULC information at the 30-m spatial resolution from 1985 to 2021, based on pixel-based random forest classifier of Landsat satellite images using Google Earth Engine. Only the data set for 2020 was used in the ATLANTIC SPATIAL data set. Catalog of Geographical Objects of the Organism and forms part of the Institutional Geospatial Database, for the year 2021. Digital Cartography 2012, Directorate General of Statistics, Surveys, and Censuses and is merely referential, for the year 2012 Sources: Souza et al. (2020),

		Instituto Geográfico Nacional (IGN) and Instituto Nacional de Estadística (INE) Sites: https://mapbiomas.org, https://www.ign.gob.ar and https://www.ine.gov.py
Protected areas	Protected Planet	Up-to-date and complete source of data on protected areas and other effective area-based conservation measures, updated monthly with submissions from governments, non-governmental organizations, landowners, and communities, for the year 2022. Source: Protected Planet Site: www.protectedplanet.net
Indigenous territories	Fundação Nacional dos Povos Indígenas (FUNAI) Tierras Indígenas	Official indigenist body of the Brazilian State, which promotes studies of identification, delimitation, demarcation, land regularization, and registration of lands occupied by indigenous peoples, in addition to monitoring and inspecting indigenous lands, for the year 2022. Interactive online platform that provides accurate maps and critical information on the lands and territories of indigenous peoples and communities in Paraguay, for the year 2022. Sources: FUNAI and Tierras Indígenas Sites: https://www.gov.br/funai/pt-br and https://www.tierrasindigenas.org
Quilombola territories	Instituto Nacional de Colonização e Reforma Agrária (INCRA)	Brazilian federal agency responsible for implementing agrarian reform, managing public lands, and promoting the settlement

		and regularization of land ownership in rural areas, for the year 2020. Source: INCRA Site: https://certificacao.incra.gov.br/csv_shp/export_shp.py
Topography	Forest and Buildings Removed Copernicus DEM (FABDEM) v1.2	Elevation raster map that used machine learning to remove building and tree height biases from the Copernicus GLO 30 Digital Elevation Model (DEM), for the year 2022. Source: Hawker et al. (2022) Site: https://www.fathom.global/product/fabdem

Landscape metrics

We calculated 39 landscape metrics of nine types (Table 3) based on the habitat map (binary habitat/non-habitat map, Figure 2c) of FV and NV, and the multi-class map (31 classes, Figure 2a). The values of the landscape metrics were spatialized to the cells. The metrics derived from FV and NV were based on data trimmed by linear structure (roads and railways) (Vancine et al. 2024). Here, to exemplify the method used for calculating landscape metrics, we display two toy landscapes (Fletcher and Fortin 2018): a binary raster (Figure 7A) and a multi-class raster (Figure 7B). The toy landscapes have an arbitrary resolution of 100 meters, chosen to make it easier to understand the area metrics, as each pixel has 10,000 m^2 or 1 hectare, and the distance between pixels is 100 m.

Toy landscapes (Figure 7): two raster layers (16×16 cells with a spatial resolution of 100 m). Cells of the toy landscape (binary) were filled with 0 and 1 values, where 0 represents not-habitat and 1 represents habitat (Toy landscape A). For the toy landscape (multi-class), cells were filled with values from 0 to 5, where each value represents a different LULC class (Toy landscape B).

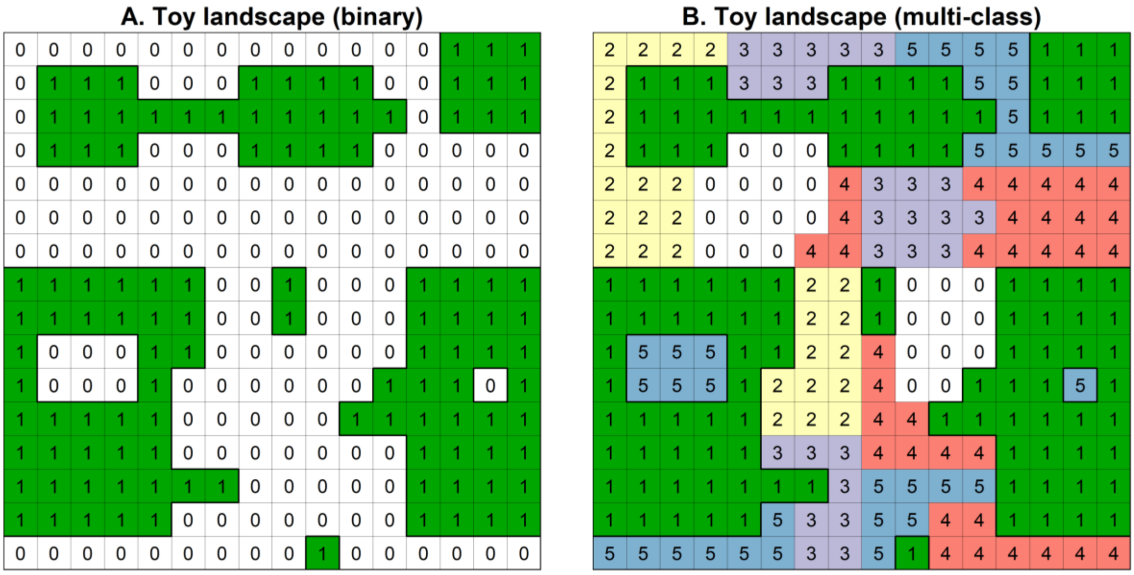


Figure 7. Toy landscapes. A) A binary toy landscape (on the left) that has 0 and 1 values (non-habitat/habitat); B) A multi-class toy landscape (on the right) that has values from 0 to 5 (land cover classes). Each cell has 100 m of resolution.

Table 3. Landscape metrics used and their description. Edge depth is the minimum distance at which cells are classified as edges, those that are further away are classified as cores. Gap-crossing considers the ability of an organism to cross non-habitat gaps, characterizing the distance to functional connectivity. Scale is the radius of the buffer to which the moving window is rotated to impute the effect of different scales on landscape metrics.

Metric	Metric type	Short description	Values	Edge depth (in meters)	Gap-crossing (in meters)	Scale (buffer radius in meters)	Reference
1. Fragment ID	Fragment	Fragment identification (cells clumped in its vicinity, considering the 8 neighboring cells)	Units	None	None	None	McGarigal et al. (2023)
2. Fragment area	Fragment	Fragment area (sum of the area of all cells belonging to each fragment ID)	Hectares	None	None	None	McGarigal et al. (2023)
3. Percentage of fragments	Fragment	Percentage of fragments in the vicinity (average neighborhood values for different buffer sizes)	0 to 100%	None	None	50, 100, 150, 200, 250, 500, 750, 1000, 1500, 2000, 2500, 5000, 7500, 10000	McGarigal et al. (2023)

Metric	Metric type	Short description	Values	Edge depth (in meters)	Gap-crossing (in meters)	Scale (buffer radius in meters)	Reference
4. Patch ID	Patch	Patch identification (cells clumped in its vicinity, considering the 8 neighboring cells), discarding branches and corridors	Units	30	None	None	McGarigal et al. (2023)
5. Patch area	Patch	Patch area (sum of the area of all cells belonging to each patch ID), discarding branches and corridors	Hectares	30	None	None	McGarigal et al. (2023)
6. Patch area original	Patch	Patch area assigned to the original fragment. Here each cell of a fragment will be assigned the value of the sum of the areas of all patches contained in the	Hectares	30	None	None	McGarigal et al. (2023)

Metric	Metric type	Short description	Values	Edge depth (in meters)	Gap-crossing (in meters)	Scale (buffer radius in meters)	Reference
		fragment					
7. Number of patches	Patch	Number of patches (number of patch IDs within a fragment) assigned to the original fragment. Here each cell of a fragment will be assigned the value number of patches contained in the fragment	Units	30	None	None	McGarigal et al. (2023)
8. Morphology	Morphology	Identifies landscape morphologies: matrix (0), core (1), edge (2), corridor (3), stepping stone (4), branch (5) and perforation (6)	0 to 6	30	None	None	Soille and Vogt (2009)
9. Matrix	Morphology	Identify matrix	0 and 1	30	None	None	Soille and Vogt

Metric	Metric type	Short description	Values	Edge depth (in meters)	Gap-crossing (in meters)	Scale (buffer radius in meters)	Reference
		(non-habitat cells = 1)					(2009)
10. Core	Morphology	Identify fragment cores (core cells = 1)	0 and 1	30	None	None	Soille and Vogt (2009)
11. Edge	Morphology	Identify fragment edges (external edge cells = 1)	0 and 1	30	None	None	Soille and Vogt (2009)
12. Corridor	Morphology	Identify corridors (linear elements that connect core cells = 1)	0 and 1	30	None	None	Soille and Vogt (2009)
13. Branch	Morphology	Identify branches (linear elements that do not connect core cells = 1)	0 and 1	30	None	None	Soille and Vogt (2009)
14. Stepping stone	Morphology	Identify stepping stones (isolated small elements without core cells = 1)	0 and 1	30	None	None	Soille and Vogt (2009)

Metric	Metric type	Short description	Values	Edge depth (in meters)	Gap-crossing (in meters)	Scale (buffer radius in meters)	Reference
15. Perforation	Morphology	Identify perforations (edge that compose the internal edge of a fragment = 1)	0 and 1	30	None	None	Soille and Vogt (2009)
16. Core	Core and edge	Identify core cells (core = 1)	0 and 1	30, 60, 90, 120, 240	None	None	McGarigal et al. (2023)
17. Core ID	Core and edge	Core identification (core cells clumped in its vicinity, considering the 8 neighboring cells)	Units	30, 60, 90, 120, 240	None	None	McGarigal et al. (2023)
18. Core area	Core and edge	Core area (sum of the area of all core cells belonging to that core ID)	Hectares	30, 60, 90, 120, 240	None	None	McGarigal et al. (2023)
19. Core area original	Core and edge	Core area assigned to the original fragment. Here each cell of a	Hectares	30, 60, 90, 120, 240	None	None	McGarigal et al. (2023)

Metric	Metric type	Short description	Values	Edge depth (in meters)	Gap-crossing (in meters)	Scale (buffer radius in meters)	Reference
		fragment will be assigned the value total area of all cores contained in the fragment					
20. Number of cores	Core and edge	Number of cores within a fragment. Here each cell of a fragment will be assigned the value number of cores contained in the fragment	Units	30, 60, 90, 120, 240	None	None	McGarigal et al. (2023)
21. Edge	Core and edge	Identify edge cells (edge = 1). This includes both external and internal edges (perforations)	0 and 1	30, 60, 90, 120, 240	None	None	McGarigal et al. (2023)
22. Edge ID	Core and edge	Edge identification (cells clumped in its vicinity, considering the	Units	30, 60, 90, 120, 240	None	None	McGarigal et al. (2023)

Metric	Metric type	Short description	Values	Edge depth (in meters)	Gap-crossing (in meters)	Scale (buffer radius in meters)	Reference
		8 neighboring cells)					
23. Edge area	Core and edge	Edge area (sum of the area of all edge cells belonging to that edge ID)	Hectares	30, 60, 90, 120, 240	None	None	McGarigal et al. (2023)
24. Edge area original	Core and edge	Edge area assigned to the original fragment. Here each cell of a fragment will be assigned the value total area edge in the fragment	Hectares	30, 60, 90, 120, 240	None	None	McGarigal et al. (2023)
25. Percentage of core	Core and edge	Percentage of core cells within the vicinity (average neighborhood values for different buffer sizes)	0 to 100%	30, 60, 90, 120, 240	None	50, 100, 150, 200, 250, 500, 750, 1000, 1500, 2000, 2500	McGarigal et al. (2023)
26. Percentage of edges	Core and edge	Percentage of edge cells in the	0 to 100%	30, 60, 90, 120, 240	None	50, 100, 150, 200, 250, 500,	McGarigal et al. (2023)

Metric	Metric type	Short description	Values	Edge depth (in meters)	Gap-crossing (in meters)	Scale (buffer radius in meters)	Reference
		vicinity (average neighborhood values for different buffer sizes)				750, 1000, 1500, 2000, 2500	
27. Perimeter	Perimeter	Perimeter (number of cells sides of a fragment facing the matrix, including any internal holes)	Meters	30	None	None	McGarigal et al. (2023)
28. Perimeter-area ratio	Perimeter	Perimeter-area ratio (ratio between fragment perimeter and fragment area)	0 to infinity	30	None	None	McGarigal et al. (2023)
29. Distance inside	Distance	Euclidean distance to the nearest fragment edge cell, inside the fragment	Meters	None	None	None	Ribeiro et al. (2009)
30. Distance outside	Distance	Euclidean distance to the nearest fragment	Meters	None	None	None	Ribeiro et al. (2009)

Metric	Metric type	Short description	Values	Edge depth (in meters)	Gap-crossing (in meters)	Scale (buffer radius in meters)	Reference
		edge cell, outside the fragment					
31. Distance	Distance	Euclidean distance to the nearest fragment edge cell, both inside (negative) and outside (positive) the fragment	Meters	None	None	None	Ribeiro et al. (2009)
32. Structural connectivity	Structural connectivity	Structural connectivity (represents the area of habitat structurally connected to a patch, taking into account corridors, branches, and possibly other patches, but disregarding the area of the own patch)	Hectares	30	None	None	Ribeiro et al. (2009)
33. Structurally	Structural	Structurally	Hectares	30	None	None	Ribeiro et al.

Metric	Metric type	Short description	Values	Edge depth (in meters)	Gap-crossing (in meters)	Scale (buffer radius in meters)	Reference
connected area	connectivity	connected area (calculated from the original fragment, where the structural connectivity of the patches was associated with the fragment)					(2009)
34. Functionally connected dilation	Functional connectivity	Functionally connected dilation (fragments dilate by half the value of the organism's gap-crossing capacity)	Hectares	None	60, 120, 180, 240, 300, 600	None	Ribeiro et al. (2009)
35. Functionally connected ID	Functional connectivity	Functionally connected identification (fragments that are at the shortest distance from the gap-crossing are grouped, receiving the	Hectares	None	60, 120, 180, 240, 300, 600	None	Ribeiro et al. (2009)

Metric	Metric type	Short description	Values	Edge depth (in meters)	Gap-crossing (in meters)	Scale (buffer radius in meters)	Reference
		same ID)					
36. Functionally connected area	Functional connectivity	Functionally connected area (area of these fragments with the same ID was summed)	Hectares	None	60, 120, 180, 240, 300, 600	None	Ribeiro et al. (2009)
37. Functional connectivity	Functional connectivity	Functional connectivity (difference between the functionally connected area and the fragment size)	Hectares	None	60, 120, 180, 240, 300, 600	None	Ribeiro et al. (2009)
38. Landscape Shannon diversity	Landscape diversity	Landscape Shannon diversity (consider the number of classes in each class cell within the window of analysis for the Shannon index)	0 to infinity	None	None	50, 100, 150, 200, 250, 500, 750, 1000, 1500, 2000	Rocchini et al. (2013)
39. Landscape Simpson	Landscape diversity	Landscape Simpson	0 to 1	None	None	50, 100, 150, 200, 250, 500,	Rocchini et al. (2013)

Metric	Metric type	Short description	Values	Edge depth (in meters)	Gap-crossing (in meters)	Scale (buffer radius in meters)	Reference
diversity		diversity (consider the number of classes in each class cell within the window of analysis for the Shannon index)				750, 1000, 1500, 2000	

Fragment area metrics (Figure 8): considering a binary habitat map, all cells of habitat were clumped with other cells of habitat in its vicinity (considering the 8 neighboring cells). Each clump of habitat was called a fragment and was given an ID (**Metric 1: Fragment ID**). For each fragment ID, its area (**Metric 2: Fragment area**) was calculated as the sum of the area of all cells belonging to that fragment ID. The unit used to calculate the area is hectares. Non-habitat cells are returned as NULL values.

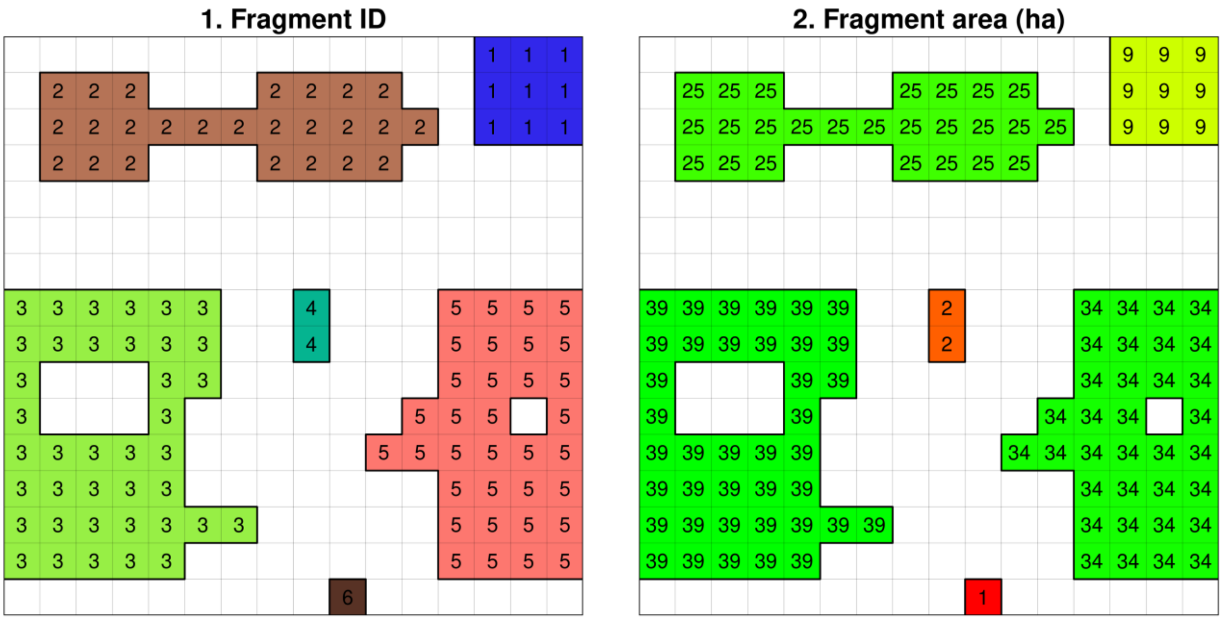


Figure 8. Fragment area metrics. Metric 1: Fragment ID is the fragment identification. Metric 2: Fragment area (ha) is the fragment area calculated in hectares. Each cell has 100 m of side length in the toy landscape.

Percentage of fragments metric (Figure 9): considering a binary habitat map, each cell of the map presented a value of the percentage of fragments within a circular window with a given size, centered in the focal cell (amount of habitat cells/total number of cells in the window). It varies between 0% and 100% (**Metric 3: Percentage of fragments**). Buffer radius represented half the size of a circular window, e.g., for a buffer size of 50 m, the window size was 100 m. Buffer radii used: 50 m, 100 m, 150 m, 200 m, 250 m, 500 m, 750 m, 1,000 m, 1,500 m, 2,000 m, 2,500 m, 5,000 m, 7,500 m, 10,000 m.

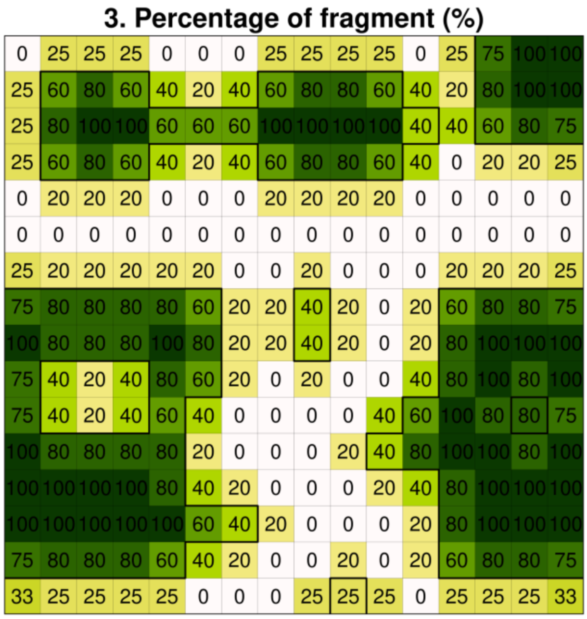


Figure 9. Percentage of fragments metric. Metric 3: percentage of fragments considering a buffer radius of 100 m (i.e., a circular window with a diameter of 200 m), illustrated in the toy landscape.

Patch area metrics (Figure 10): considering a binary habitat map, these metrics are equivalent to the fragment area metric, but discard habitat branches and corridors that are closer than a given edge depth from the edge between the fragment and the matrix. The result is a map of clusters (considering the 8 neighboring cells) of cells, which does not consider corridors or branches. Each habitat cluster was called a patch and given an ID (**Metric 4: Patch ID**). For each patch ID, its area (**Metric 5: Patch area**) was calculated as the sum of the area of all cells belonging to that patch ID. The patch area has also been attributed to the original fragment ID, which sums the area of all patches belonging to the same fragment (**Metric 6: Patch area original**). The amount of different patch IDs for a fragment is also calculated (**Metric 7: Number of patches**). Edge depths considered: 30 m. The unit used to calculate the area was hectares. Non-habitat cells were assigned with NULL values.

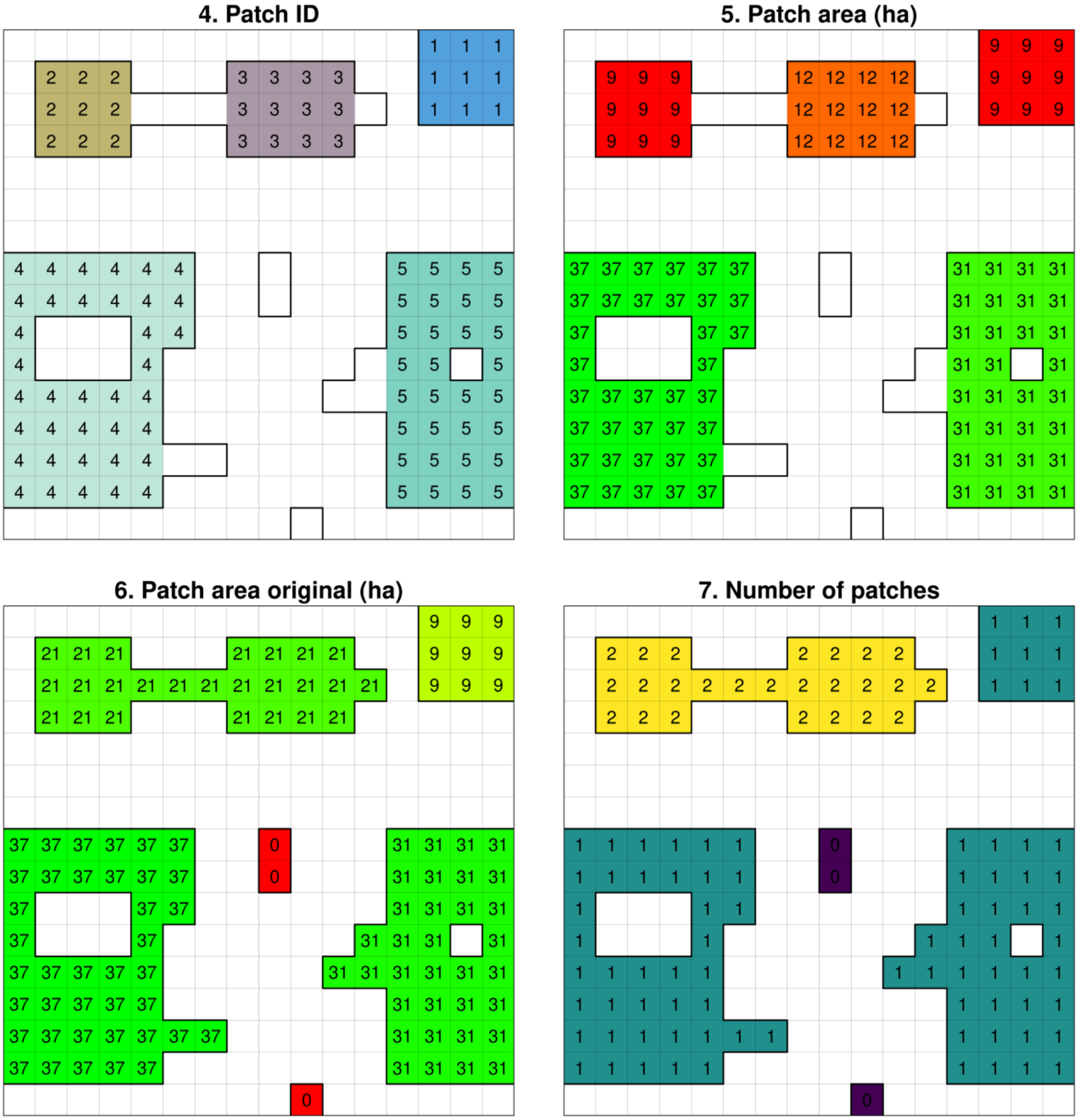
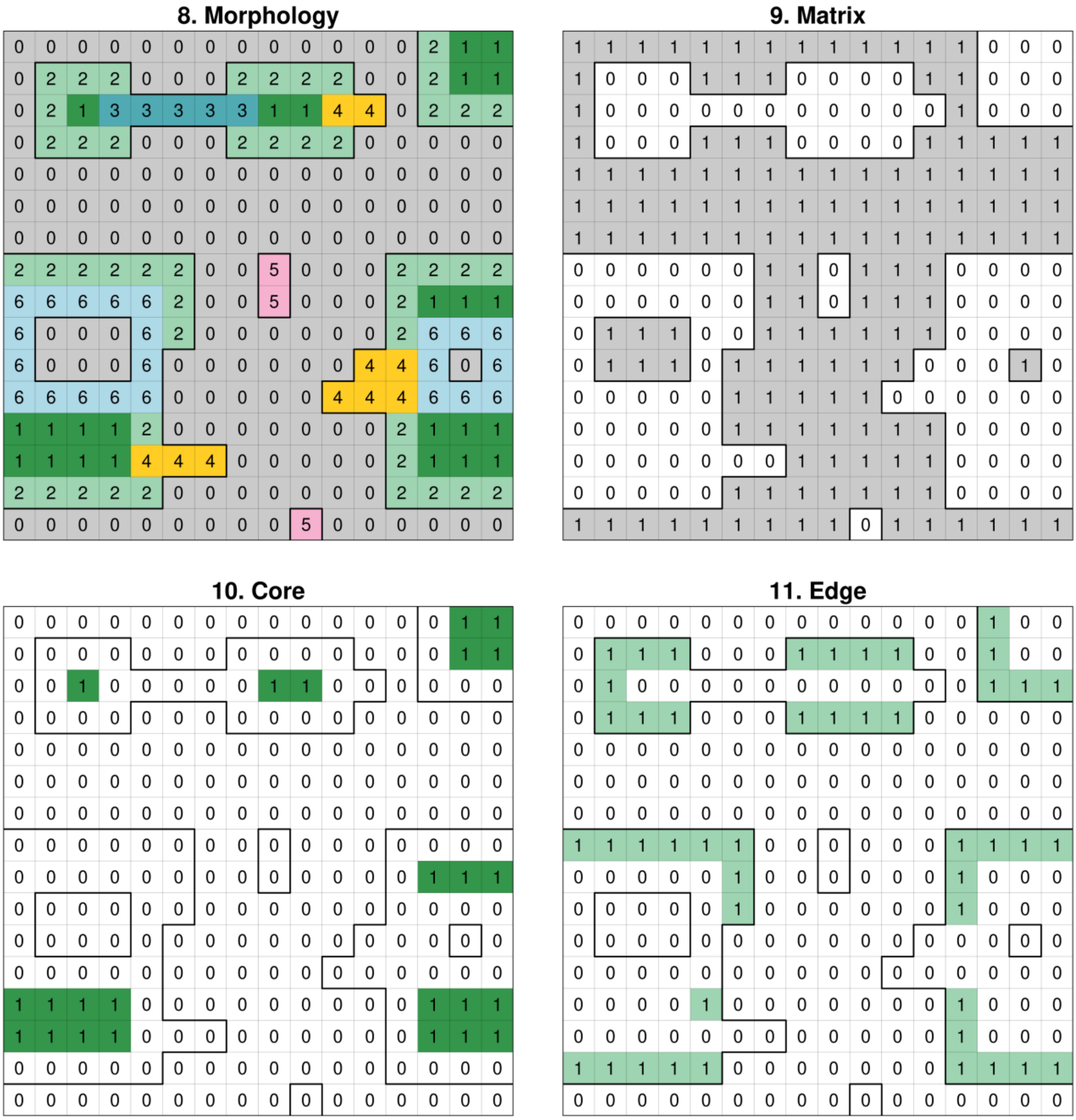


Figure 10. Patch area metrics. Metric 4: Patch ID is the patch identification. Metric 5: Patch area (ha) is the patch area in hectares. Metric 6: Patch area original (ha) is the patch area for the original fragment in hectares. Metric 7: Number of patches is the number of patches for the original fragment. The edge depth was set as 50 m in this example.

4. Morphological metrics (Figure 11): considering a binary habitat map, these metrics classify the landscape as a set of morphological/structural categories (**Metric 8: Morphology**), i.e., whether a cell is matrix, core, edge, corridor, branch, stepping stone or perforation. This classification is made by considering an edge depth to distinguish the edge and the core of a habitat fragment. Matrices are the non-habitat cells from the binary map (**Metric 9: Matrix**). Cores are habitat cells after removing the edge cells (**Metric 10: Core**). Edges are habitat cells that are closer to the edge than the chosen edge depth, but are not corridors, branches, stepping stones or perforations (**Metric 11: Edge**). Corridors are edge cells that connect two or more core cells (**Metric 12: Corridor**). Branches are edge cells that do not connect cores (**Metric 13: Branch**). Stepping stones are edge cells that do not have core cells inside them (**Metric 14: Stepping stone**). Perforations are edge cells that compose the internal edge of a fragment (**Metric 15: Perforation**). Edge depths considered: 30 m.



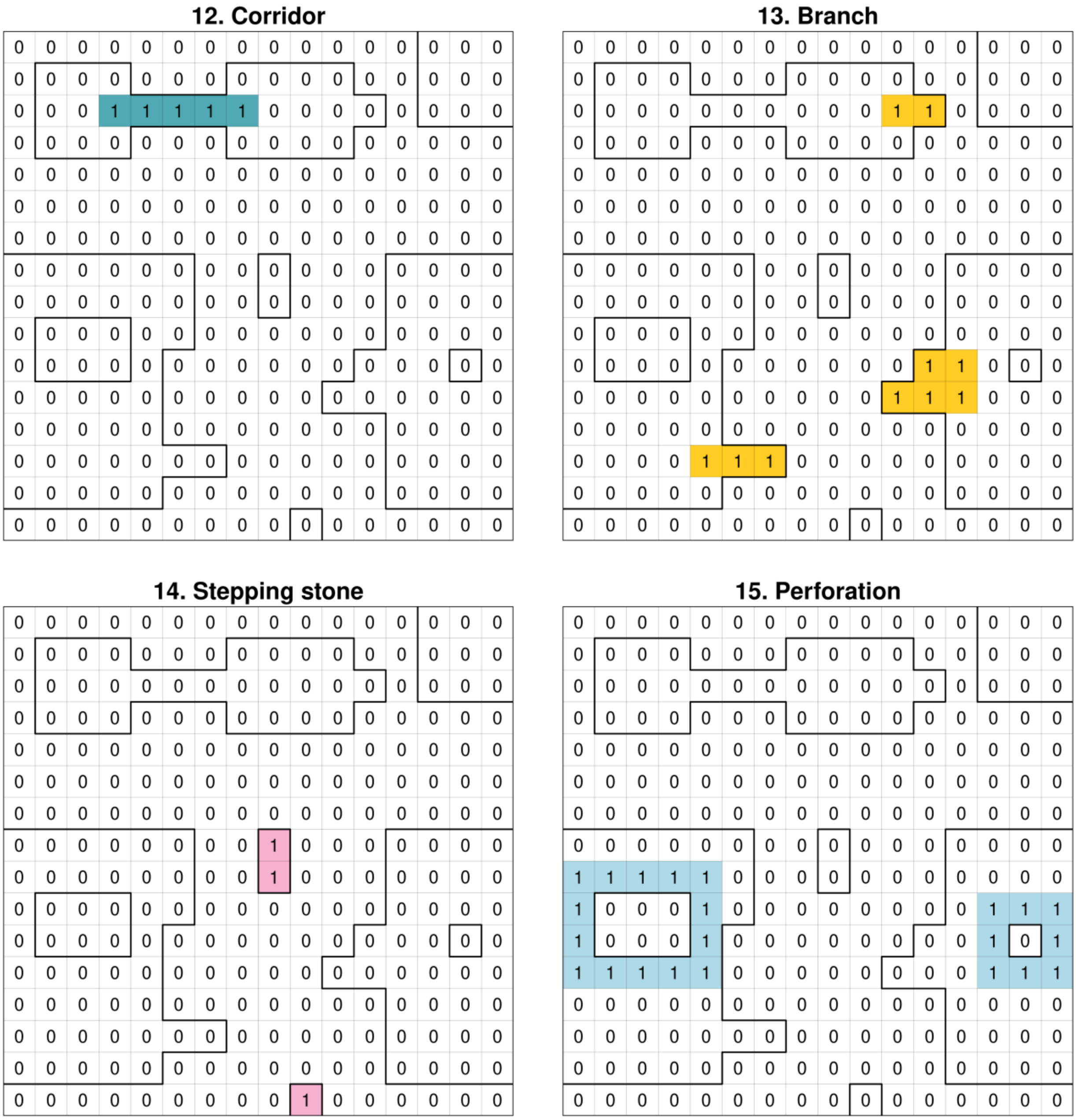
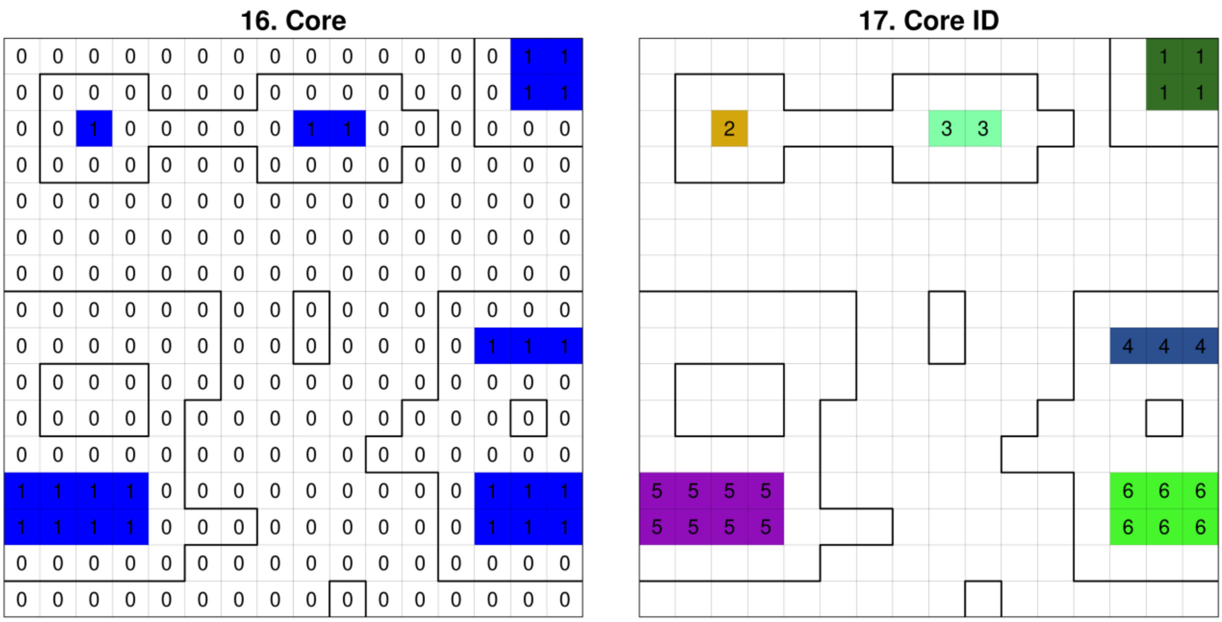
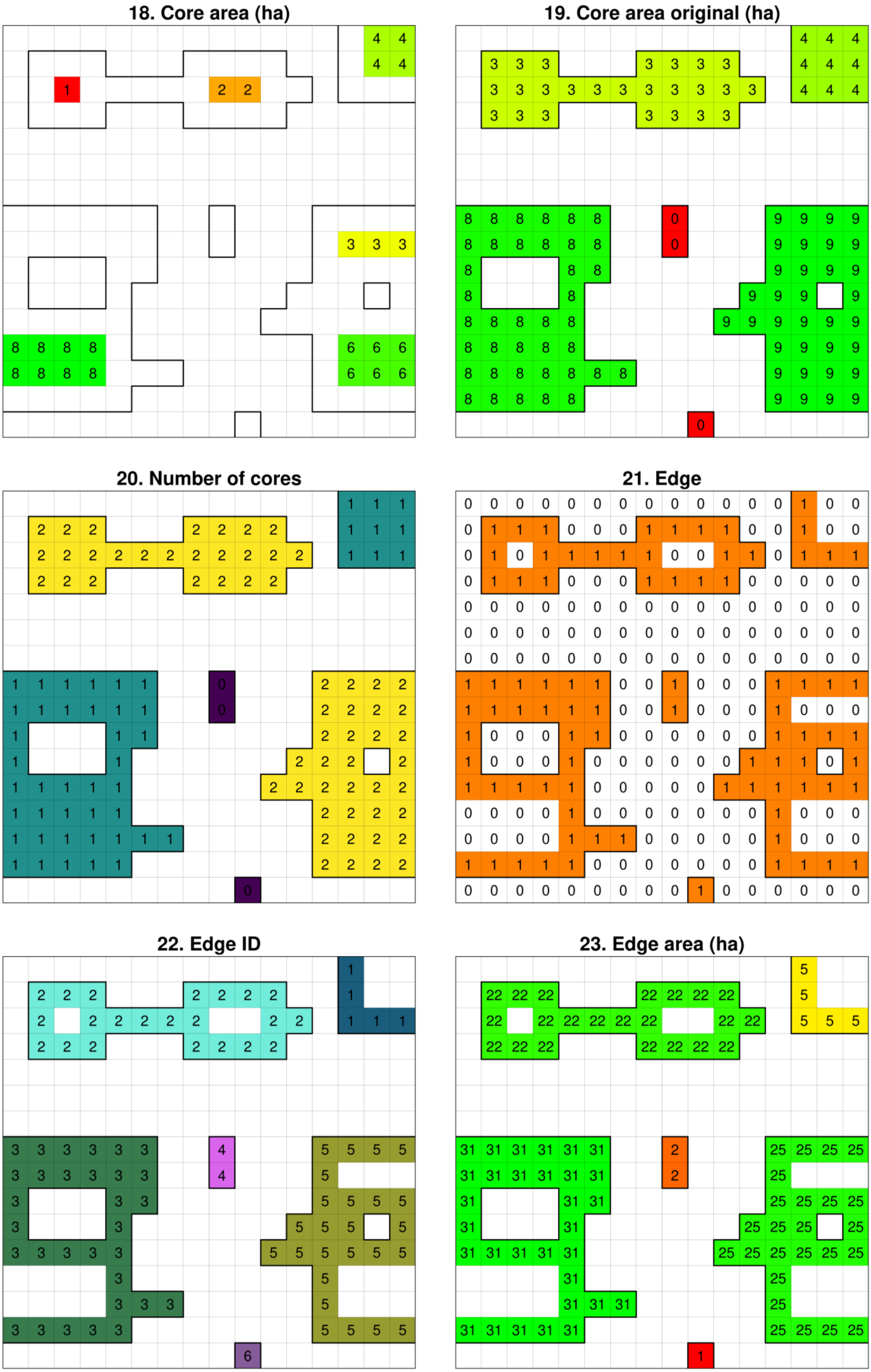


Figure 11. Morphological metrics. Metric 8: Landscape morphologies: matrix (0), core (1), edge (2), corridor (3), stepping stone (4), branch (5), and perforation (6). Metric 9: matrix = non-habitat cells. Metric 10: Core = habitat cells, removing the edge cells. Metric 11: Edge =habitat cells that are closer to the habitat edge than the chosen edge depth. Metric 12: Corridor = edge cells that connect two or more core cells. Metric 13: Branch = edge cells that do not connect cores. Metric 14: Stepping stone = edge cells that do not have core cells. Metric 15: Perforation = edge cells that compose the internal edge of a fragment. The edge depth used in this illustrative figure was 50 m.

Core and edge area metrics (Figure 12): considering a binary habitat map, these metrics classify cells in core or edge, considering a depth of edge. Cells that are closer (or at the same distance) from the edge than the edge depth are classified as edges, those that are further away inside the habitat patches are classified as core. We clumped the core and edge cells (considering the 8 neighboring cells; **Metric 16: Core** and **Metric 21: Edge**) and gave it an ID (**Metric 17: Core ID** and **Metric 22: Edge ID**). For each core and edge ID, its area was calculated as the sum of the area of all cells belonging to that core or edge ID (**Metric 18: Core area** and **Metric 23: Edge area**). We also calculated the area of a core or edge of the original fragment by summing the area of the core or edge cells belonging to a fragment (**Metric 19: Core area original** and **Metric 24: Edge area original**), and the number of cores (**Metric 20: Number of cores**), which was the number of different cores IDs for a fragment. Notice that Metric 21 (Edge) differs from the morphological classification of edges (Metric 11) because the latter subdivides edge cells into edges, corridors, branches, stepping stones, and perforations. Metric 21 includes all these in a single category. Edge depths considered: 30 m, 60 m, 120 m, 240 m. The unit used to calculate the area was hectares. Non-habitat cells were assigned with NULL values, except for core and edge binary maps.




18. Core area (ha)
19. Core area original (ha)
20. Number of cores
21. Edge
22. Edge ID
23. Edge area (ha)

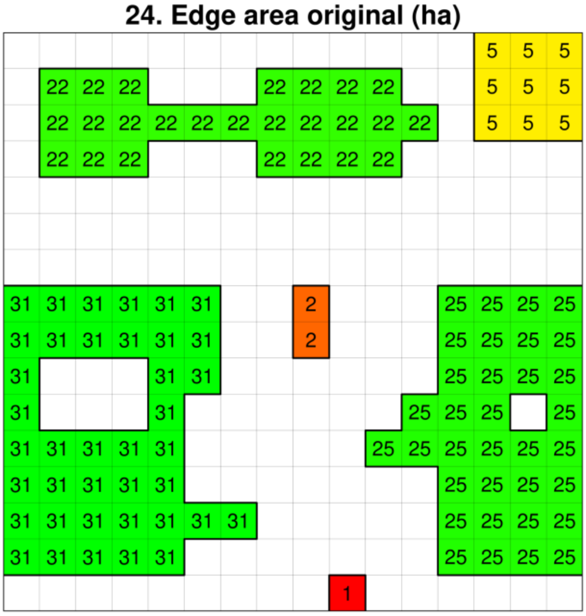


Figure 12. Edge and core area metrics. Metric 16: Core is the binary core and not-core. Metric 17: Core ID is the core identification. Metric 18: Core area (ha) is the core area in hectares. Metric 19: Core area original (ha) is the core area for the original fragment in hectares. Metric 20: Number of cores is the number of cores for the original fragment. Metric 21: Edge is the binary edge and not-edge classification. Metric 22: Edge ID is the edge identification. Metric 23: Edge area (ha) is the edge area in hectares. Metric 24: Edge area original (ha) is the edge area for the original fragment in hectares. Each cell of the toy landscape has 100 m of side length and the edge depth was chosen as 50 m in this illustrative example.

Percentage of core and edge metrics (Figure 13): considering a binary habitat map, each cell of the map presents a value of the proportion of core or edge area within a circle window with a given size, centered in the focal cell (amount of core or edge cells/total number of cells in the window). It varies between 0 and 100% (**Metric 25: Percentage of core** and **Metric 26: Percentage of edges**). Edge depths considered: 30 m, 60 m, 120 m, 240 m. Buffer radius represented half the size of a circular window, e.g., for a buffer size of 50 m, the window size was 100 m. Buffer radius used: 50 m, 100 m, 150 m, 200 m, 250 m, 500 m, 750 m, 1000 m, 1500 m, 2000 m, 2500 m.

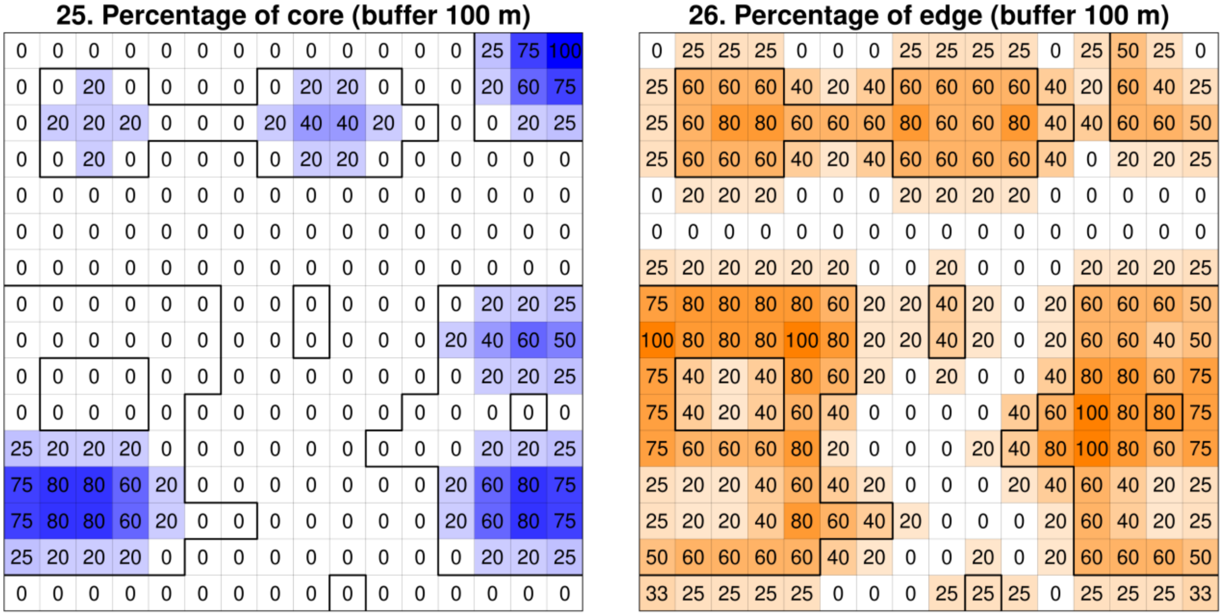


Figure 13. Percentage of core and edge metrics. Metric 25: Percentage of core and Metric 26: Percentage of edge for a circular window with 100 m size, as an example in the toy landscape.

Perimeter metrics (Figure 14): considering a binary habitat map, the perimeter is the length of the cells located on the sides of a fragment facing the matrix, including any internal holes, in meters (**Metric 27: Perimeter**). Perimeter-area ratio is the ratio between fragment perimeter and fragment area, without a measurement unit (**Metric 28: Perimeter-area ratio**). This is a simple measure of shape complexity, the higher its value, the greater the complexity of the fragment shape. A limitation in using this metric as a shape complexity index is that it varies with the area of the fragment. For example, holding shape constant, an increase in fragment area will cause a decrease in the perimeter-area ratio. Edge depths considered: 30 m. Non-habitat cells were assigned with NULL values.

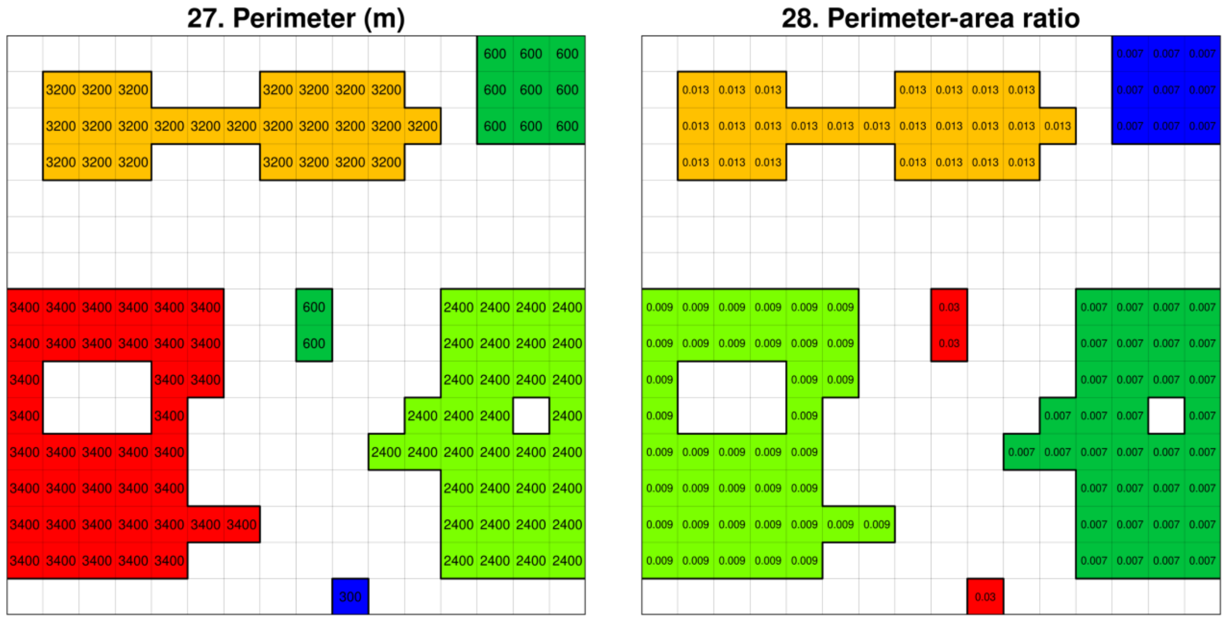


Figure 14. Perimeter metrics. Metric 27: Perimeter (m) is the number of pixel sides of a fragment facing the matrix. Metric 28: Perimeter-area ratio is a shape complexity metric.

Distance metrics (Figure 15): considering a binary habitat map, these metrics are based on maps of Euclidean distance inside and outside from fragment edges, in meters. Each cell outside the habitat (matrix, non-habitat) was given a positive value equal to the distance to the nearest habitat cell edge (**Metric 29: Distance outside**). Cells inside the habitat were given a negative value, corresponding to the distance to the nearest edge with matrix cells (**Metric 30: Distance inside**). Inside and outside distances were combined in a metric by summing outside and inside distance metrics, only for FV and NV (**Metric 31: Distance**).

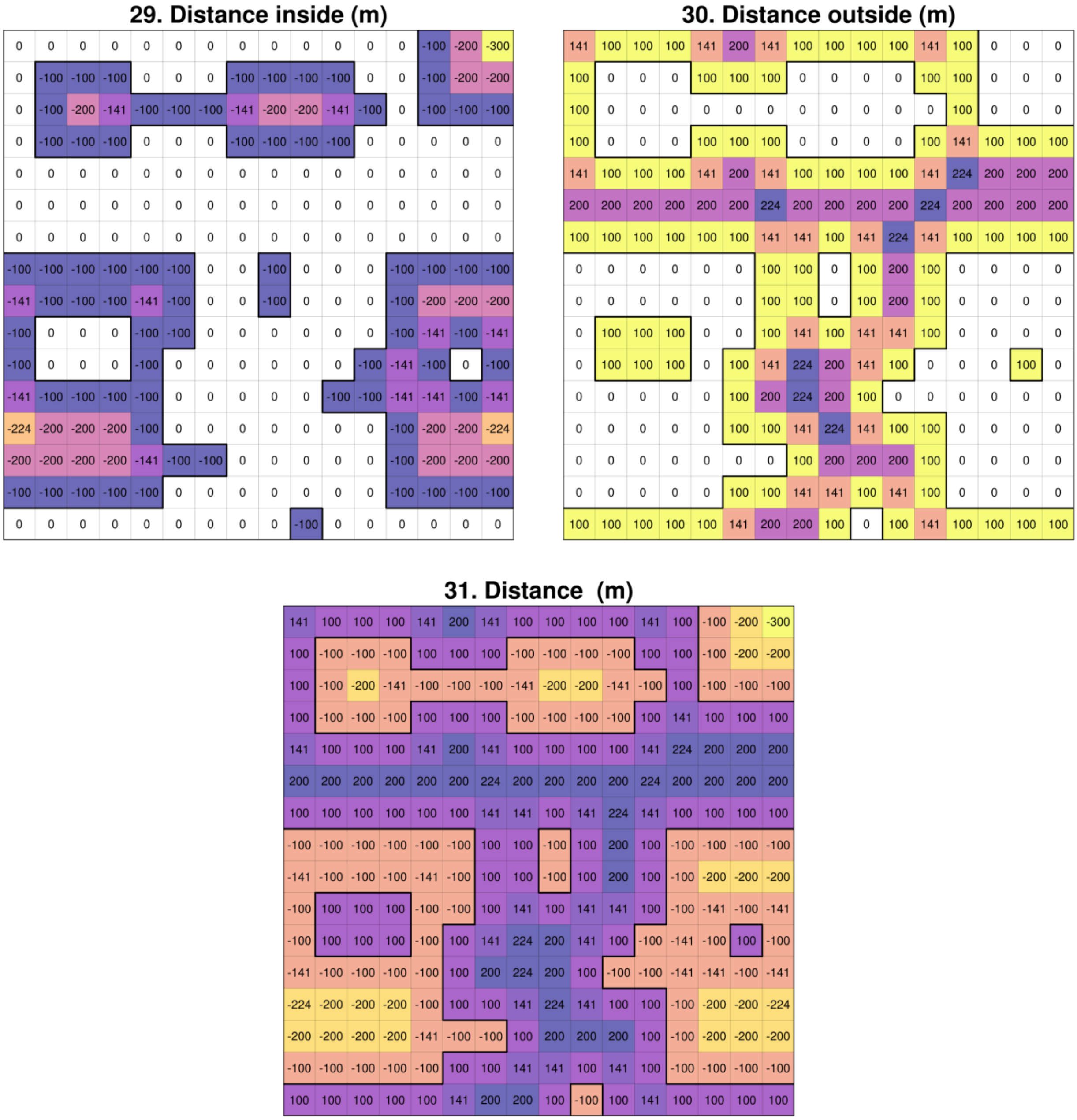


Figure 15. Distance metrics. Metric 29: Distance inside (m) is the distance inside from the habitat with negative values. Metric 30: Distance outside (m) is the outside distance from the habitat with positive values. Metric 31: Distance (m) is the distance to habitat (FV and NV only) resulting from summing Distance inside (m) and Distance outside (m).

Structural connectivity metrics (Figure 16): considering a binary habitat map, these metrics represent the area of habitat structurally connected to a patch, considering corridors, branches, and possibly other patches (if the corridor connects these patches). In practice, it is calculated as the difference between the fragment area and the patch area. When a patch has no corridors or branches, its structural connectivity equals zero (i.e., it is not structurally connected to any other habitat). Each patch cell is assigned a structural connectivity value (**Metric 32: Structural connectivity**). The structural connected area was calculated from the original fragment, where the structural connectivity of the patches was associated with the fragment (**Metric 33: Structural connected area**). The definition of structural connectivity depends on what is considered patch, corridor, and branch, so this metric depends on the edge depth value considered. For the AF the depth of the chosen edge was 30 m. The unit used to calculate the area was hectares. Non-habitat cells were assigned with NULL values.

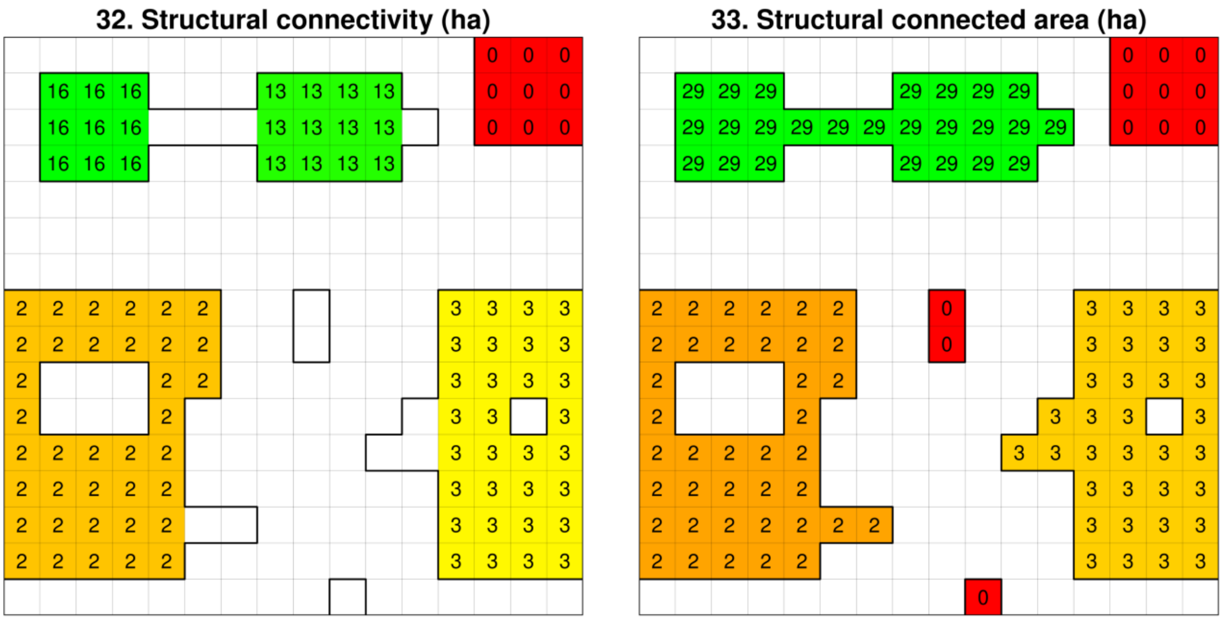


Figure 16. Structural connectivity metrics. Metric 32: Structural connectivity (ha) is the area of habitat structurally connected to a patch only for patches in hectares. Metric 33: Structural connected area (ha) is the area of structurally connected habitat to fragments in hectares.

Functional connectivity metrics (Figure 17): considering a binary habitat map, these metrics represent the habitat area functionally linked to a fragment, considering the ability of an organism to cross non-habitat gaps (gap-crossing value). First, the fragments were expanded/dilated by half the value of the organism's gap-crossing capacity (e.g., if an organism crosses 200 m, the fragments will be dilated by 100 m along their entire perimeter) (**Metric 34: Functionally connected dilation**). Then, the fragments that are at the shortest distance from the gap-crossing were grouped, receiving the same ID (**Metric 35: Functionally connected ID**). Then, the area of these fragments with the same ID was summed (**Metric 36: Functionally connected area**). Finally, to obtain the functional connectivity, the difference between the functionally connected area and the fragment area was calculated, representing how much habitat is accessible from a habitat fragment for an organism with a given gap-crossing ability, excluding the area of the very same fragment (**Metric 37: Functional connectivity**). Crossing capacities considered for the AF: 60 m, 120 m, 180 m, 240 m, 300 m, 600 m. The unit used to calculate the area was hectares. Non-habitat cells were assigned with NULL values.

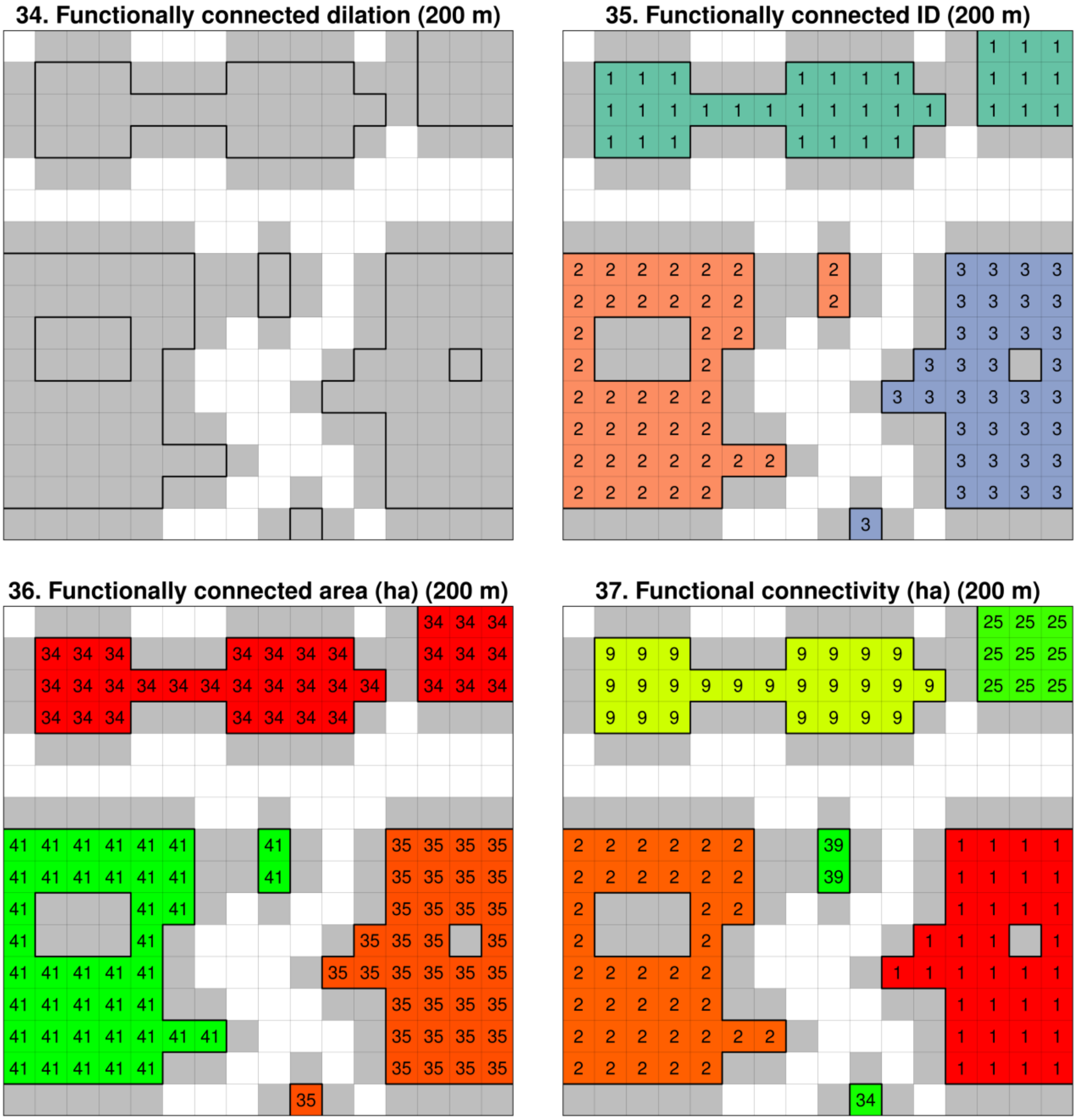


Figure 17. Functional connectivity metrics. Metric 34: Functionally connected dilation (200 m) is the dilation of fragments for gap-crossing of 100 m (gray pixels). Metric 35: Functionally connected ID (200 m) is the functionally connected area identification. Metric 36: Functionally connected area (ha) is the fragment area connected in hectares. Metric 37: Functional connectivity (ha) (200 m) is the functional connectivity in hectares.

Landscape diversity metrics (Figure 18): considering a multi-class map, each cell of the map presented a value of the diversity of LULC classes within a square window with a given size, centered in the focal cell. Diversity (Shannon and Simpson) indices consider the number of classes in each class cell within the window of analysis. Shannon's diversity values are positive and vary between 0 and infinity (**Metric 38: Landscape diversity (Shannon)**) and Simpson's diversity values vary between 0 and 1 (**Metric 39: Landscape diversity (Simpson)**). Buffer radius represented half the size of a square window, e.g., for a buffer size of 50 m, the window size was 100 m. Buffer radii used: 50 m, 100 m, 150 m, 200 m, 250 m, 500 m, 750 m, 1000 m, 1500 m and 2000 m. Due to computational limitations, we were unable to calculate landscape diversity metrics for the 2,500 m buffer radius.

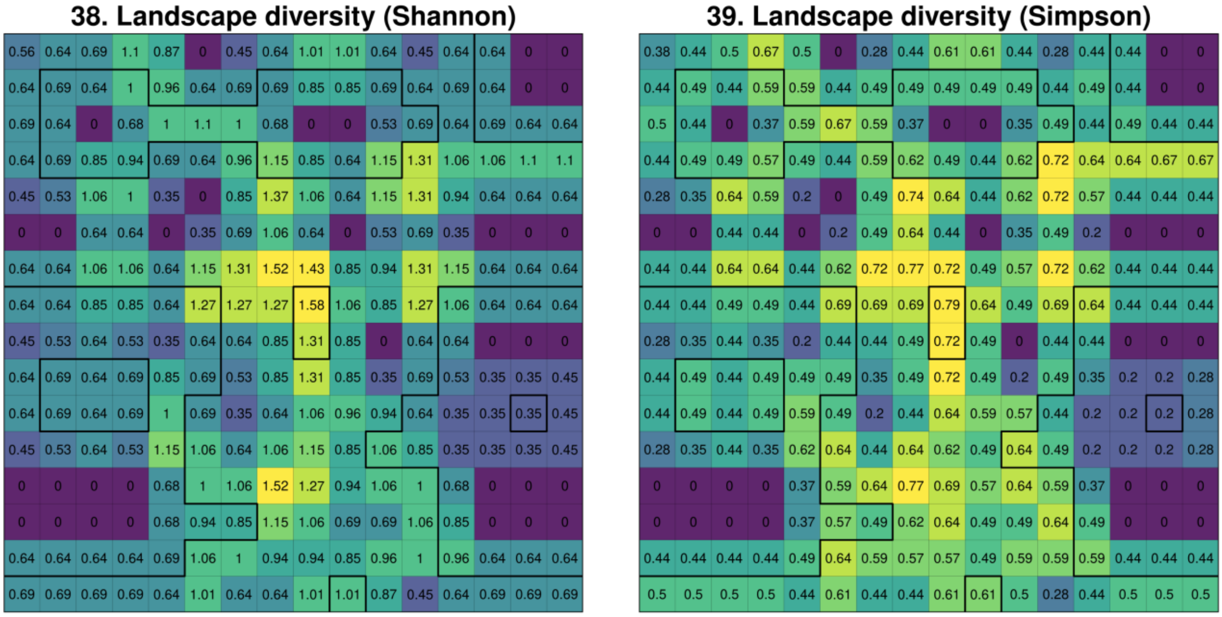


Figure 18. Landscape diversity metrics. Metric 38: Landscape diversity (Shannon) and Metric 39: Landscape diversity (Simpson) indices for a square window with 100 m size, in the illustrative example for the toy landscape.

Topographic metrics

We calculated six metrics of topography using a Digital Elevation Model (DEM) map from FABDEM v1.2 (Hawker et al. 2022) (Table 4). We used two GRASS GIS modules: *r.slope.aspect* and *r.geomorphon*.

Table 4. Topographic metrics description.

Metric	Short description	Values	Reference
1. Elevation	Digital representation of elevations (or height) in meters through the	Meters	Hawker et al. (2022)

	Digital Elevation Model (DEM).		
2. Slope	Inclination from the horizontal stated in degrees	Degrees (0º to 90º)	Hawker et al. (2022)
3. Aspect	Direction that slopes are facing counterclockwise from East in degrees: 90 degrees is North, 180 is West, 270 is South, 360 is East	Degrees (0º to 360º)	Hawker et al. (2022)
4. Profile curvature	Curvature in the direction of steepest slope in 1/meters. A curvature of 0.05 corresponds to a radius of curvature of 20 meters and positive and negative values represent convex and concave forms, respectively	Units	Hawker et al. (2022)
5. Tangential curvature	Curvature in the direction of the contour tangent in 1/meters. A curvature of 0.05 corresponds to a radius of curvature of 20 meters and positive and negative values represent convex and concave forms, respectively	Units	Hawker et al. (2022)
6. Geomorphon	Classification and mapping of landform elements from a DEM based on the principle of pattern recognition (geomorphon)	Classes: flat (1), peak (2), ridge (3), shoulder (4), spur (5), slope (6), hollow (7), footslope (8), valley (9), pit (10)	Jasiewicz and Stepinski (2013)

Hydrological metrics

We calculated four hydrological metrics using a Digital Elevation Model (DEM) map from FABDEM v1.2 (Hawker et al. 2022) (Table 5). Due to the large extension, we first calculated these metrics for hydrological smaller basins using the HydroBASINS level 5 (Lehner and Grill 2013); after that, we merged the results into single maps for the four metrics. We used two GRASS GIS modules to calculate the potential streams and springs: *r.watershed* and *r.stream.extract*, both with threshold = 100. With the potential streams and strings done, we deleted the lines and points, respectively, that overlap with masses of water from HydroLAKES (Messager et al. 2016) and official masses of water from three countries: Brazil (Instituto Brasileiro de Geografia e Estatística – IBGE; IBGE, 2021), Argentina (Instituto Geográfico Nacional – IGN; IGN, 2023) and Paraguay (Instituto Nacional de Estadística – INE; INE, 2023). Stream Euclidean distance was generated using *r.grow.distance* GRASS GIS module with metric = euclidean, and spring kernel density was generated using *v.kernel* module with radius varying (50 m, 100 m, 150 m, 200 m, 250 m, 500 m, 750 m, 1000 m, 1500 m, 2000 m, 2500 m) and kernel = gaussian.

Table 5. Hydrological metrics description.

Metric	Short description	Values	Scale (buffer radius in meters)	Reference
1. Stream	Potential streams generated from DEM	0 and 1	None	Holmgren (1994)
2. Stream distance	Euclidean distance from potential streams generated from DEM	Meters	None	Holmgren (1994)
3. Spring	Potential springs generated from DEM	0 and 1	None	Holmgren (1994)
4. Spring density	Density (kernel) of potential springs generated from DEM	Units	50, 100, 150, 200, 250, 500, 750, 1000, 1500, 2000, 2500	Okabe et al. (2009)

Anthropogenic metrics

We calculated 13 anthropogenic metrics (Table 6) represented by Euclidean distances outside (positive values) from roads, railways, protected areas, indigenous territories, quilombola territories, and the grouped classes categories: pasture, temporary crop, perennial crop, forest plantation, urban areas, mining, and water (Table 1; Figure 2b). These metrics can be used to represent the different forms of human activity and possibly their impact at the landscape scale. We used the *r.grow.distance* GRASS GIS module with metric = euclidean.

Table 6. Anthropogenic metrics description.

Metric	Short description	Values	Reference
1. Distance from roads	Euclidean distance from roads	Meters	Ribeiro et al. (2009)
2. Distance from railways	Euclidean distance from railways	Meters	Ribeiro et al. (2009)
3. Distance from roads and railways	Euclidean distance from roads and railways	Meters	Ribeiro et al. (2009)
4. Distance from protected areas	Euclidean distance from protected areas	Meters	Ribeiro et al. (2009)

5. Distance from indigenous territories	Euclidean distance from indigenous territories	Meters	Ribeiro et al. (2009)
6. Distance from quilombola territories	Euclidean distance from quilombola territories	Meters	Ribeiro et al. (2009)
7. Distance from the forest plantation	Euclidean distance from forest plantation	Meters	Ribeiro et al. (2009)
8. Distance from the pasture	Euclidean distance from pasture	Meters	Ribeiro et al. (2009)
9. Distance from the temporary crop	Euclidean distance from temporary crop	Meters	Ribeiro et al. (2009)
10. Distance from the perennial crop	Euclidean distance from perennial crop	Meters	Ribeiro et al. (2009)
11. Distance from the urban areas	Euclidean distance from urban areas	Meters	Ribeiro et al. (2009)
12. Distance from the mining	Euclidean distance from mining	Meters	Ribeiro et al. (2009)
13. Distance from the water	Euclidean distance from water (lakes and rivers)	Meters	Ribeiro et al. (2009)

Software

All the landscape, topographic, hydrological, and anthropogenic metrics were processed using GRASS GIS 8.3 (Neteler et al. 2012) and R language 4.3 (R Core Team, 2023) with the aid of the *rgrass* package (Bivand, 2023). All landscape metrics were calculated using custom functions based on *LSMetrics* and translated to R (https://github.com/LEEClab/LS_METRICS; Niebuhr et al. *in prep.*).

All codes used to calculate the metrics are available on GitHub (https://github.com/mauriciovancine/ATLANTIC-SPATIAL). These scripts represent the step-by-step process for calculating the metrics, allowing the process to be completely reproducible. For example, the script “01_01_download_limits.R” downloads the Atlantic Forest boundary, and “01_02_download_landscape.R” downloads the land use and land cover layers from MapBiomas using an integration with Google Earth Engine. Likewise, the other scripts download the other input sources of data, describe their process of import into GRASS GIS, and the computation of the different types of metrics presented in this data set. By making these scripts available, we believe that this approach to calculate these metrics can be replicated for other biomes or regions of the world, or for other timestamps using the available data for the AF. However, some steps were omitted or need to be performed in addition to the scripts for the full analysis to be performed.

4. Project personnel

None.

Class III. Data set status and accessibility

A. Status

1. Latest update

December 2024.

2. Latest archive date

December 2024.

3. Metadata status

Last updated in December 2024, version submitted.

4. Data verification

Last updated in December 2024, version submitted.

B. Accessibility

1. Storage location and medium

The ATLANTIC SPATIAL data set table (ATLANTIC_SPATIAL.csv) with all metric descriptions and links can be accessed as supporting information for this Data Paper publication in Ecology. Vector and rasters (spatial components) can be accessed in multiple Zenodo repositories (Table 7), organized by thematic groups of layers.

1) Table 7. **Zenodo repository, titles, links, and DOIs of ATLANTIC SPATIAL data set**. We have separated it into multiple Zenodo repositories due to file size and number limitations.

Variable ids	Zenodo repository title	Zenodo repository link	Zenodo DOI
000-004 041-064	ATLANTIC SPATIAL - Habitat	https://zenodo.org/records/14529439	https://doi.org/10.5281/zenodo.14529439
005-040; 375-388	ATLANTIC SPATIAL - Fragment	https://zenodo.org/records/14574196	https://doi.org/10.5281/zenodo.14574196

065-112	ATLANTIC SPATIAL - Core 30|60|90m Forest	https://zenodo.org/records/14529477	https://doi.org/10.5281/zenodo.14529477
113-144	ATLANTIC SPATIAL - Core 120|240m Forest	https://zenodo.org/records/14574249	https://doi.org/10.5281/zenodo.14574249
145-189	ATLANTIC SPATIAL - Edge 30|60|90m Forest	https://zenodo.org/records/14529566	https://doi.org/10.5281/zenodo.14529566
190-219	ATLANTIC SPATIAL - Edge 120|240m Forest	https://zenodo.org/records/14577603	https://doi.org/10.5281/zenodo.14577603
220-267	ATLANTIC SPATIAL - Core 30|60|90m Natural	https://zenodo.org/records/14577592	https://doi.org/10.5281/zenodo.14577592
268-299	ATLANTIC SPATIAL - Core 120|240m Natural	https://zenodo.org/records/14577598	https://doi.org/10.5281/zenodo.14577598
300-344	ATLANTIC SPATIAL - Edge 30|60|90m Natural	https://zenodo.org/records/14529647	https://doi.org/10.5281/zenodo.14529647
345-374	ATLANTIC SPATIAL - Edge 120|240m Natural	https://zenodo.org/records/14577617	https://doi.org/10.5281/zenodo.14577617
389-436	ATLANTIC SPATIAL - Connectivity	https://zenodo.org/records/14529380	https://doi.org/10.5281/zenodo.14529380
437-446	ATLANTIC SPATIAL - Diversity Shannon	https://zenodo.org/records/14529710	https://doi.org/10.5281/zenodo.14529710
447-456	ATLANTIC SPATIAL - Diversity Simpson	https://zenodo.org/records/14529750	https://doi.org/10.5281/zenodo.14529750
457-462	ATLANTIC SPATIAL - Topographic	https://zenodo.org/records/14529237	https://doi.org/10.5281/zenodo.14529237
463-476	ATLANTIC SPATIAL - Hydrological	https://zenodo.org/records/14500641	https://doi.org/10.5281/zenodo.14500641
477-502	ATLANTIC SPATIAL - Anthropogenic	https://zenodo.org/records/14529355	https://doi.org/10.5281/zenodo.14529355

Besides the direct download through the Zenodo repositories, we also created the R package *atlanticr* (https://mauriciovancine.github.io/atlanticr) (Vancine et al. in prep.; DOI: https://doi.org/10.5281/zenodo.14751252). This R package provides a table with all ATLANTIC SPATIAL metrics and their information "atlantic_spatial", beyond a function to download the vector and rasters, "atlantic_spatial_download()", from the corresponding Zenodo repositories. Each raster layer comprises two files: a GeoTiff (.tif) file and a TFW (.tfw) file. The GeoTiff files are the ones providing the geographic information for the variables and in most Geographical Information Systems they are enough for reading and using the data. The TFW layers (.tfw) are auxiliary files created due to the raster compression process, and that can be necessary for usage of the data in some Software.

Below we demonstrate a simple example to use the function *atlantic_spatial_download()* to download the raster with id = 1 (land use and land cover raster), whose details can be checked in the the *atlanticr::atlantic_spatial* table.

```
# install package
install.packages("remotes")
remotes::install_github("mauriciovancine/atlanticr")

# load package
library(atlanticr)

# list files
head(atlanticr::atlantic_spatial)

# file download
atlanticr::atlantic_spatial_download(id = 1, path = ".")
```

Furthermore, the *atlanticr* R package also facilitates access to other data papers from the ATLANTIC SERIES, providing an easy way to integrate biological and environmental data for the Atlantic Forest.

2. Contact persons

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3. Copyright restrictions

CC BY-NC 4.0: Creative Commons Attribution-Non-Commercial 4.0 International.

4. Proprietary restrictions

a. Release date

None.

b. Citation

Please, cite this data paper when the data are used in publications or teaching events.

c. Disclaimer(s)

None.

5. Costs

None.

Class IV. Data structural descriptors

The data set contains 1005 files and 267.3 GB. ATLANTIC_SPATIAL.csv contains a table describing the vector and raster files. The AF delimitation vector is available as Geopackage (.gpkg). The 502 rasters are available as GeoTiff (.tif) which contain the main data files and TFW files (.tfw) as an ancillary file. We created the rasters using DEFLATE compression from GDAL (https://gdal.org/en/stable/drivers/raster/gtiff.html), requiring the provision of an auxiliary TFW file (.tfw) for it to be opened in software such as ArcGIS® (https://www.arcgis.com/index.html).

A. Data set file

1. Identity: ATLANTIC_SPATIAL.csv

2. Size: 19 columns and 503 rows records, including header row, 290 KB.

3. Format and storage mode: comma-separated values (.csv).

4. Header information: See column descriptions in section B.

5. Alphanumeric attributes: Mixed.

6. Special characters/fields: None.

7. Authentication procedures: None.

B. Variable information

1) Table 8. **Information in the ATLANTIC SPATIAL data set**. Description of the fields related to the study site of the ATLANTIC_SPATIAL.csv.

Variable identify	Variable description	Levels	Example
id	Identification code for each metric	000-502	006
metric	Metric names	Detailed name of metric in text format	atlantic_spatial_forest_vegetation_fragment_area
metric_group	Description of metric groups	anthropogenic, hydrological, landscape,	landscape

		topographic	
metric_type	Detailed description of metric types	Detailed description of metric types in text format	fragment_area
metric_description	Detailed description of metrics	Detailed description of metrics in text format	forest vegetation fragment area
value	Metric values	Detailed metrics values in text and number formats	0.09 to infinity
value_description	Detailed description of metric values	Detailed description of metric values in text format	area
unit	Metric units	1/meters, angles in degrees, binary, categorical, discrete, hectares, meters, meters/hectares, proportion, unit, unitary	hectares
lulc_class	Land use and land cover classes	forest_plantation, forest_vegetation, mining, multiple, natural_vegetation, pasture, perennial_crop, temporary_crop, urban_areas, water	forest_vegetation
edge_depth_m	Edge depth for different metrics in meters. Edge depth is the minimum distance at which cells are classified as edges, those that are further away are classified as cores	30-240	NA
gap_crossing_m	Gap-crossing for different metrics in meters. Gap-crossing considers the ability of an organism to	60-600	NA

	cross non-habitat gaps, characterizing the distance to functional connectivity		
scale_buffer_radius_m	Scale for different metrics in meters. Scale is the radius of the buffer to which the moving window is rotated to impute the effect of different scales on landscape metrics	50-10,000	NA
resolution	Raster pixel width and height	30	30
file_name	Metric file names	Multiple metric name files	006_atlantic_spatial_forest_vegetation_fragment_area.tif
file_size	Metric file sizes	Multiple metric size files in GB	0.398
zenodo_repository	Zenodo repository name	Multiple repository names	ATLANTIC SPATIAL - Fragment
zenodo_link_main	Link to the main files on Zenodo	Multiple links	https://zenodo.org/records/14574196/files/006_atlantic_spatial_forest_vegetation_fragment_area.tif?download=1&preview=1
zenodo_link_auxiliary	Link to the auxiliary files on Zenodo	Multiple links	https://zenodo.org/records/14574196/files/006_atlantic_spatial_forest_vegetation_fragment_area.tfw?download=1&preview=1
zenodo_doi	Link to the DOI on Zenodo	Multiple links	https://doi.org/10.5281/zenodo.14574196

C. Data anomalies

If no information is available, this was indicated by “NA”.

Class V. Supplemental descriptors

A. Data acquisition

1. Data forms or acquisition methods

None.

2. Location of completed data forms

None.

3. Data entry verification procedures

None.

B. Quality assurance/quality control procedures

None.

C. Related materials

None.

D. Computer programs and data-processing algorithms

None.

E. Archiving

1. Archival procedures

2. Redundant archival sites

F. Publications and results

Vancine et al. (2024) used part of this data set to describe the spatiotemporal landscape structure of AF.

G. History of data set usage

1. Data request history

None.

2. Data set updates history

None.

3. Review history

None.

4. Question and comments from secondary users

None.

CRediT authorship contribution statement

MHV: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing— original draft, Writing—review and editing. **BBN**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing—original draft, Writing—review and editing. **RLM**: Conceptualization, Data curation, Investigation, Software, Writing—review and editing. **JEFO**: Conceptualization, Data curation, Writing—review and editing. **VT**: Data curation, Conceptualization, Writing—review and editing. **RB**: Data curation, Writing—review and editing. **RSCA**: Data curation, Writing—review and editing. **EMZ**: Data curation, Writing—review and editing. **VCS**: Data curation, Writing—review and editing. **JGRG**: Conceptualization, Data curation, Writing—review and editing. **JWR**: Conceptualization, Data curation, Investigation, Software, Writing—review and editing. **CDA**: Writing—review and editing. **CHG**: Data curation, Methodology, Software, Writing—review and editing. **MG**: Writing—review and editing. **MCR**: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Writing—original draft, Writing—review and editing.

Acknowledgments

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Literature Citations

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