

1 **The Atlantic Forest of South America: spatiotemporal dynamics of remaining**  
2 **vegetation and implications for conservation**

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21 Ecologia Espacial e Conservação, Rio Claro, SP, Brazil.

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## Supplementary material

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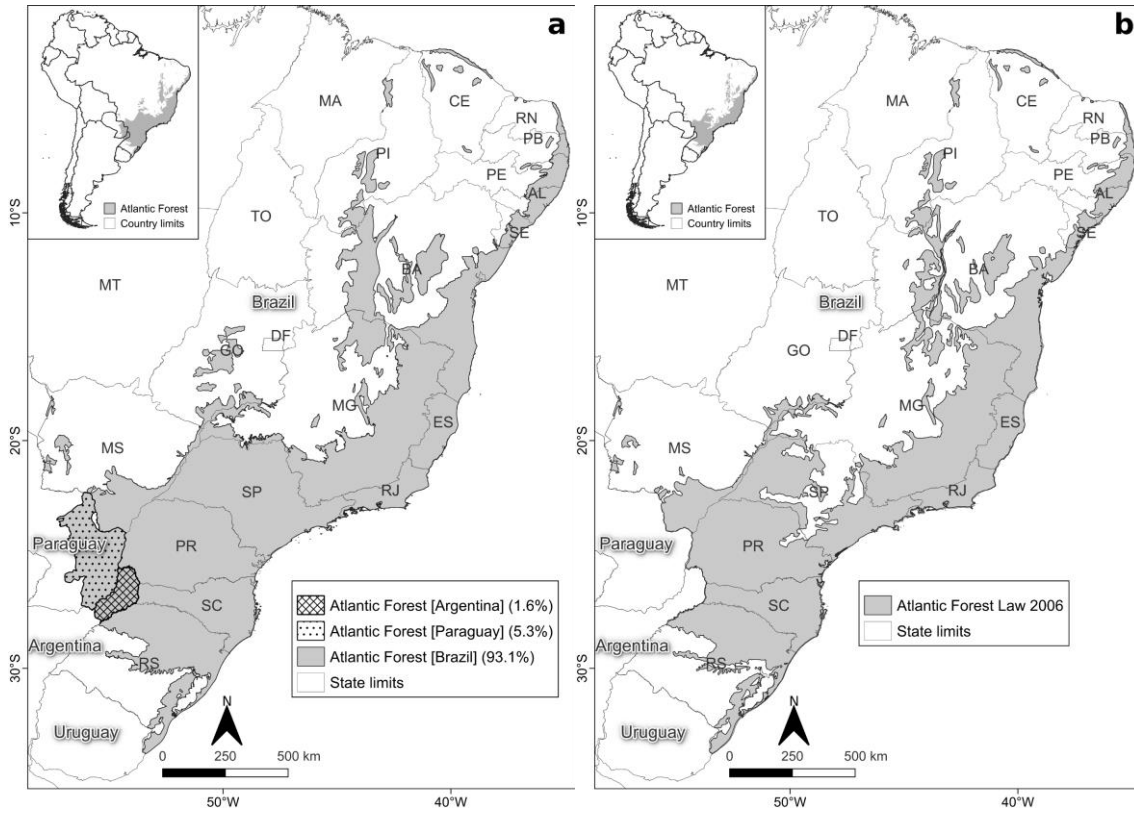
### Data

Roads and railways data were downloaded from official geospatial databases from three countries: Brazil (Instituto Brasileiro de Geografia e Estatística – IBGE; IBGE, 2021), Argentina (Instituto Geográfico Nacional – IGN; IGN, 2022), and Paraguay (Instituto Nacional de Estadística – INE; INE, 2022). The data comprised 14,072 km of railways and 124,187 km of roads, with a total of 138,259 km (Fig. S11). We did not find official railway data for Paraguay, so there may be an underestimation of this effect for this country. We couldn't differentiate the roads and railways by year, as it's almost impossible to find that information, so we used the same layer to trim all the fragments in all years. We assume that this may have overestimated the effect of roads in the past when some of these roads or railways did not exist or were not paved yet. For Brazil, we selected paved, operational, and constructed roads, and railways that were selected by relative surface position, and train section. The road and railways 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 resulted in more densified lines. This guaranteed that the roads and railways would take up space and trimmed the fragments. After rasterizing the lines, the raster covered 524,147 ha (0.32% from AF delimitation). Thus, we trimmed the fragments of vegetation from the rasterized data.

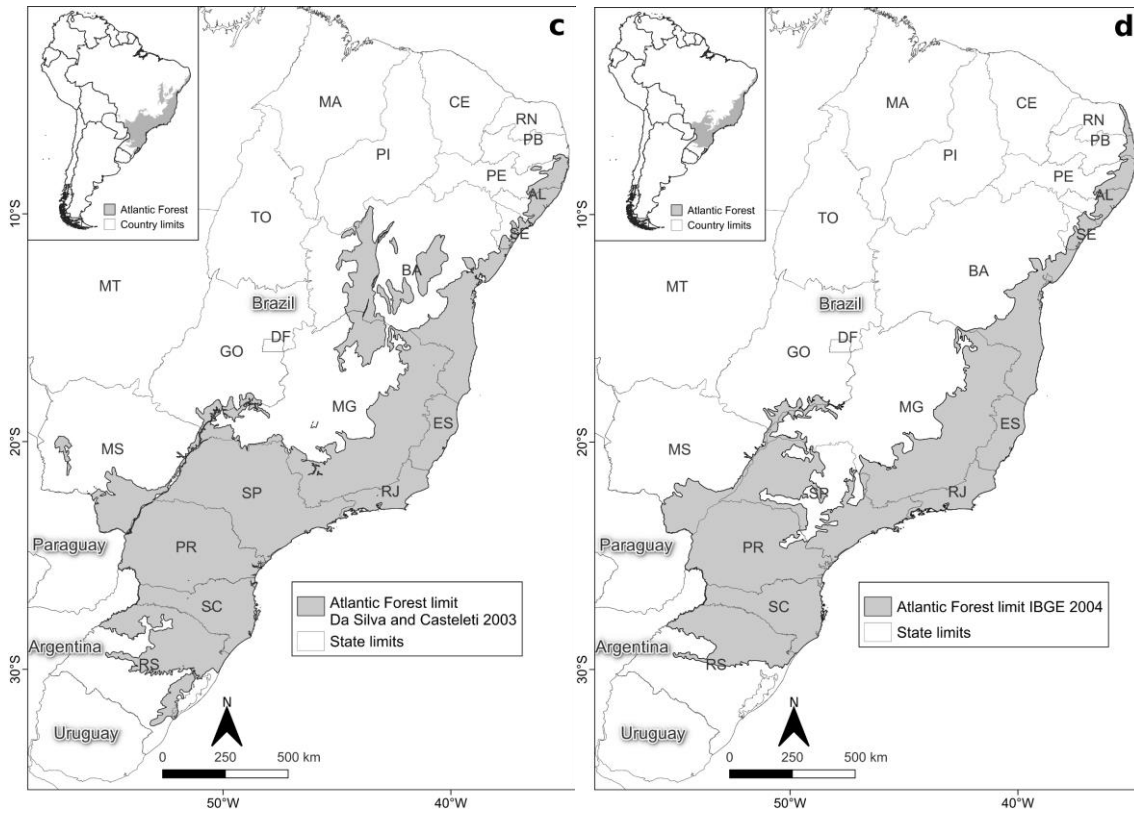
The Protected Areas (PA) were downloaded from Protected Planet (UNEP-WCMC and IUCN, 2022) for the IUCN categories of protected areas (“Ia”, “Ib”, “II”, “III”, and “IV”) following (Rezende et al., 2018), which comprises 986 reserves (4,620,245 ha; 2.84% from AF delimitation) (Fig. S12a). These IUCN categories encompass multiply protection categories for 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). The Indigenous Territories (IT) were downloaded for Brazil (Fundação Nacional dos Povos Indígenas; FUNAI, 2020) and Paraguay (Tierras Indígenas, 2022), which comprises 1023 territories (1,324,973 ha; 0.81% from AF delimitation) (Fig. S12b). We did not find official IT data for Argentina; therefore, we cannot analyze the contribution of IT to this country.

76 **Figures**

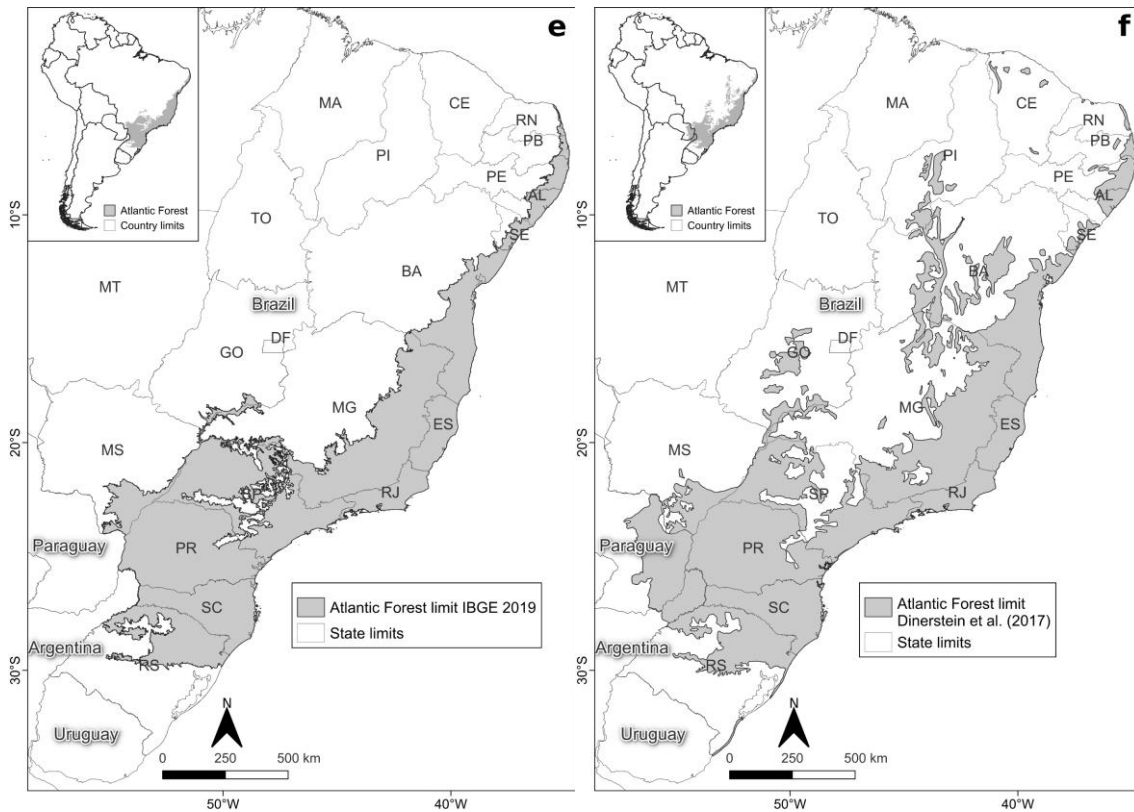
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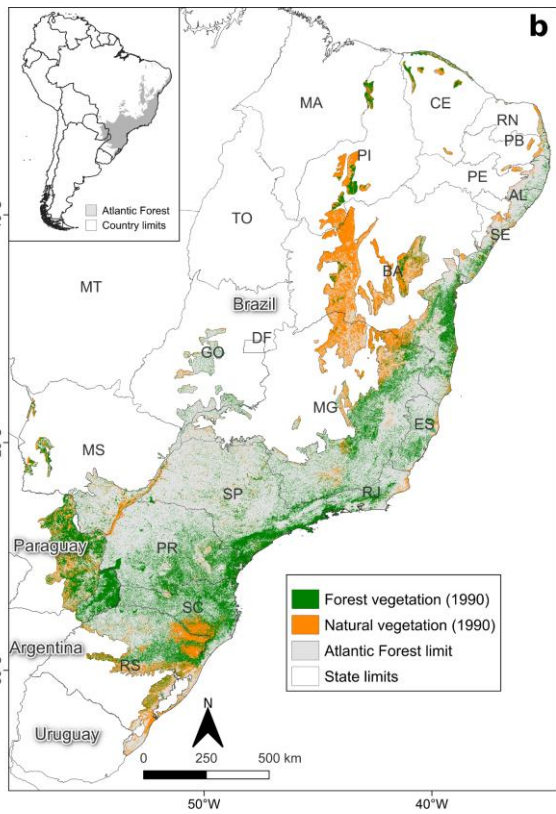
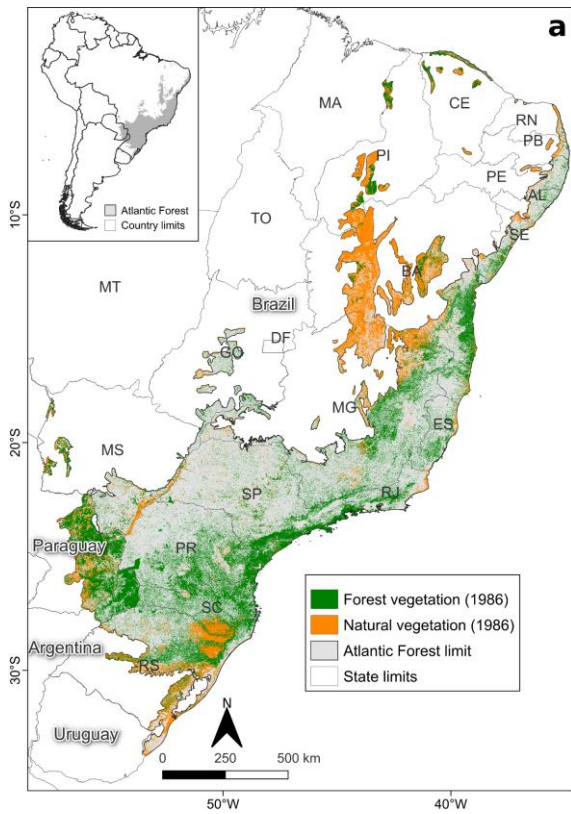


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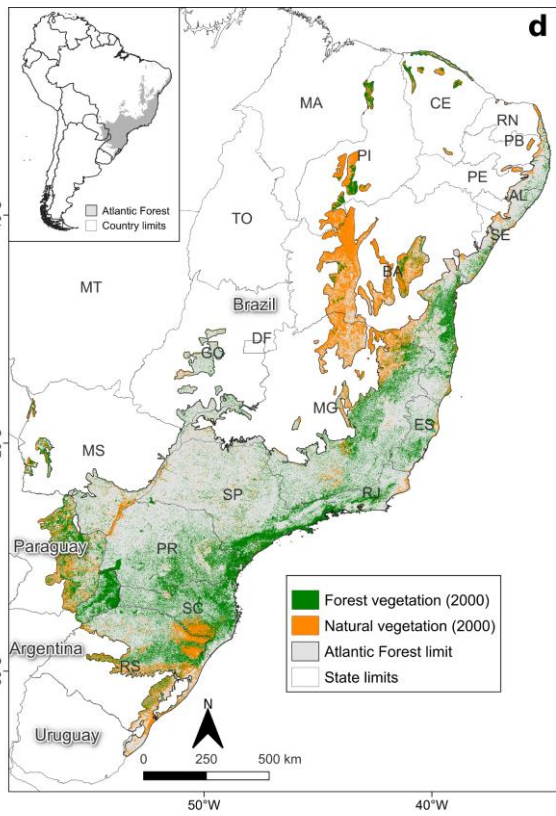
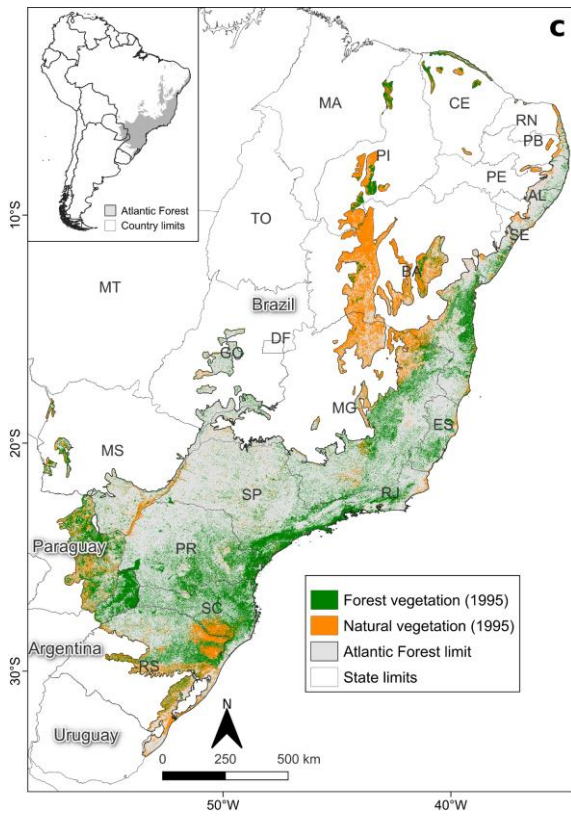
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82 **Figure S1.** Atlantic Forest delimitation, adapted from Muylaert et al. (2018) (a). Atlantic  
 83 Forest delimitations used to create the “integrative delimitation” incorporating different types  
 84 of ecosystems: (b) delimitation defined by Brazilian legislation (Federal Decree No. 750/93  
 85 and Atlantic Forest law No. 11 428, of December 22, 2006); (c) delimitation defined by Da  
 86 Silva and Casteleti (2003); (d) AF delimitation defined by IBGE (2004), (e) AF delimitation  
 87 defined by IBGE (2019) and; (f) AF delimitation defined by (Dinerstein et al., 2017) and used  
 88 in the Ecoregions 2017®.

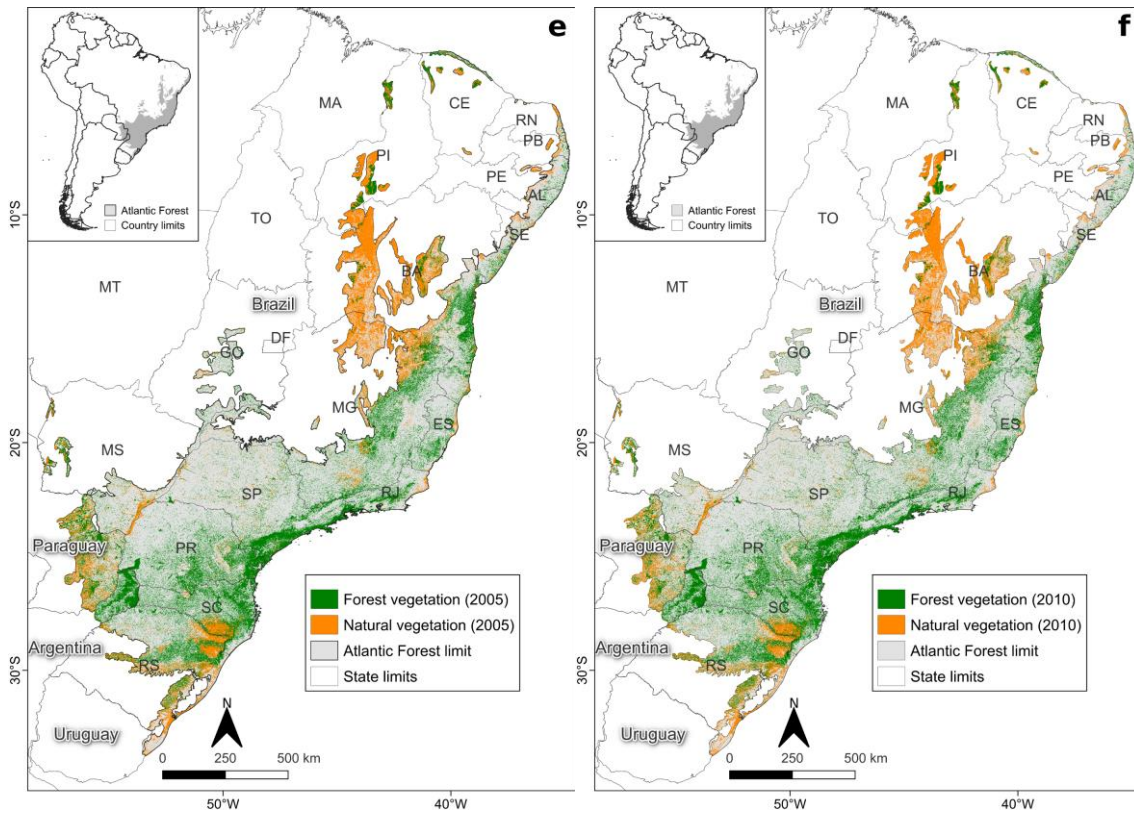
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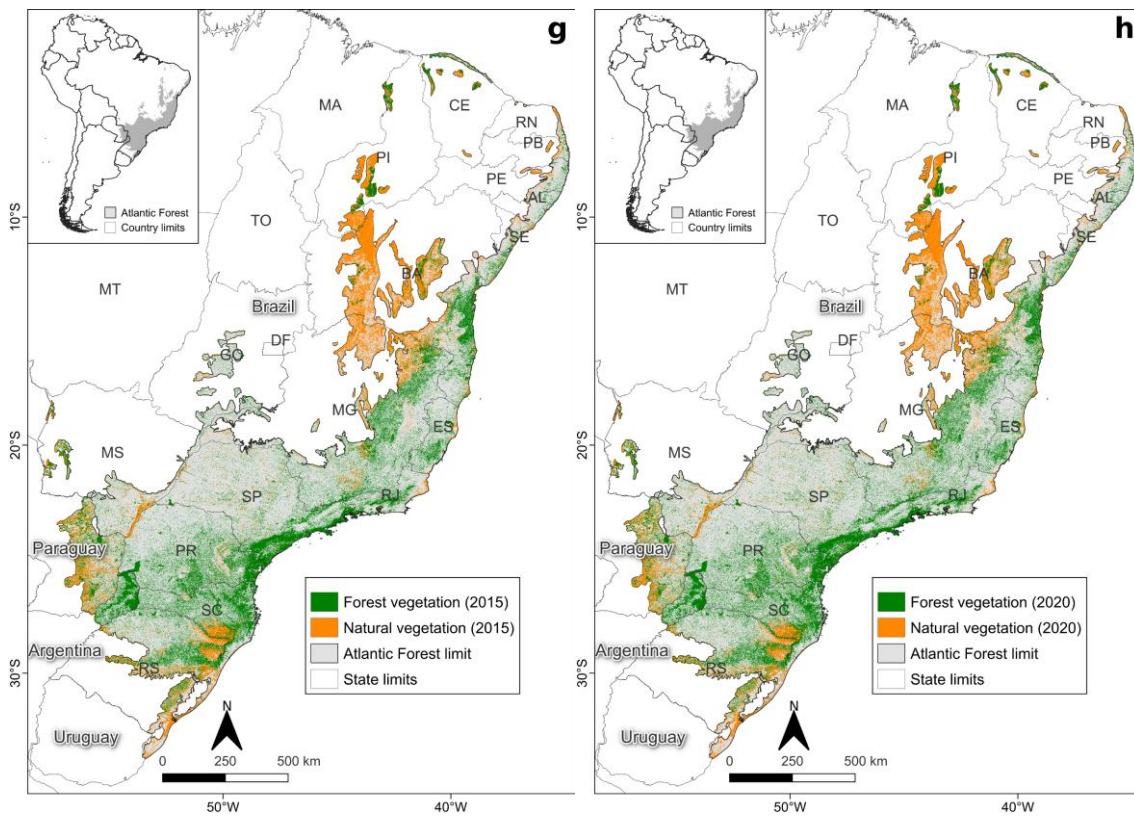
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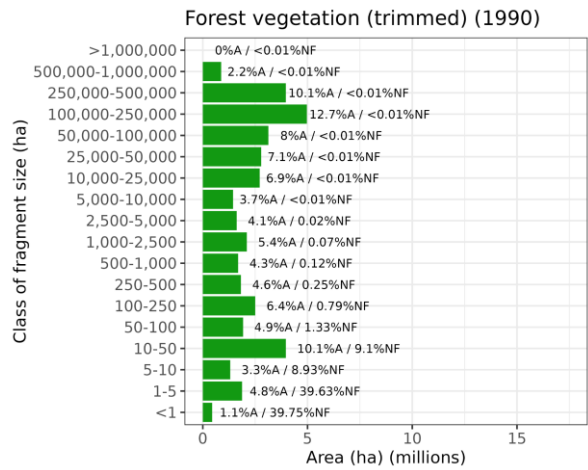
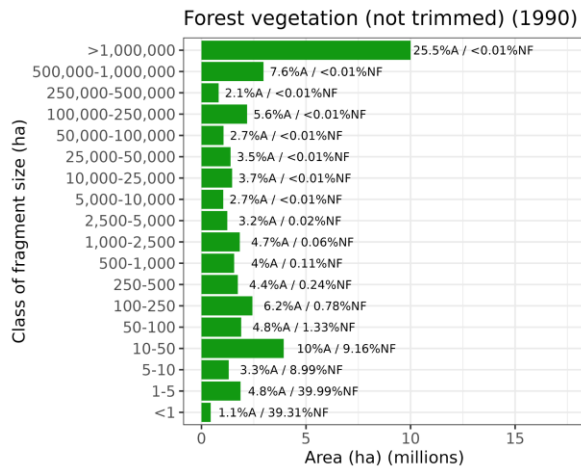


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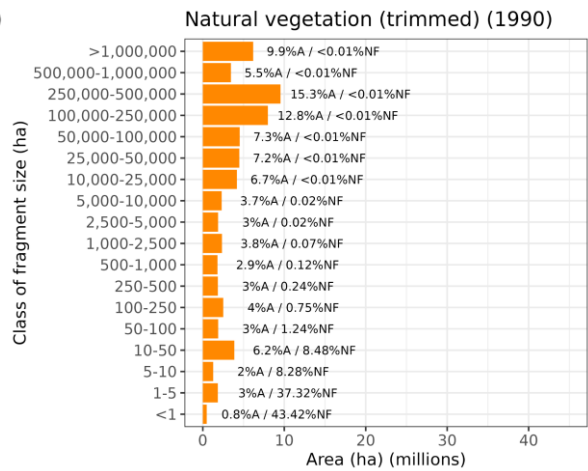
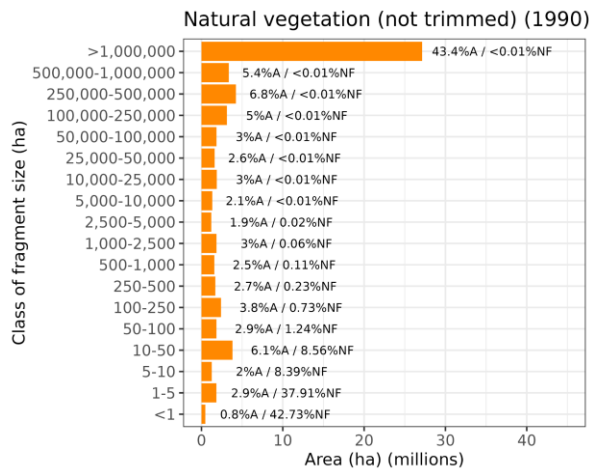
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**Figure S2.** FV and NV cover for the entire Atlantic Forest from 1986-2020 (a-h).

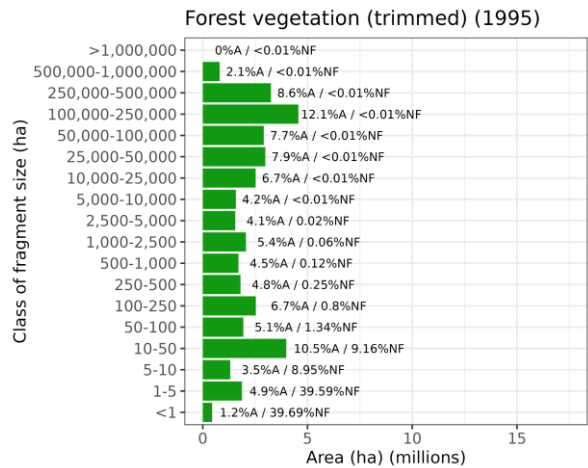
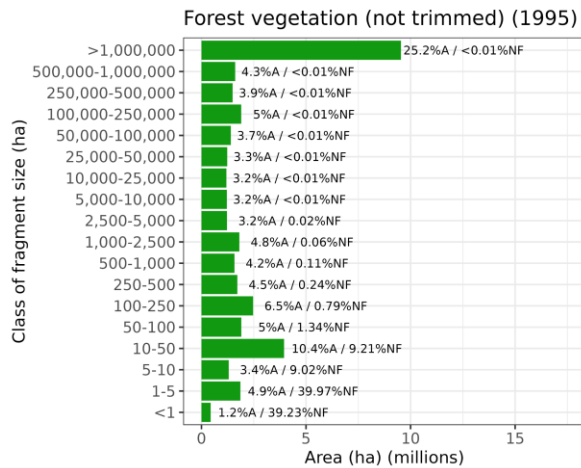
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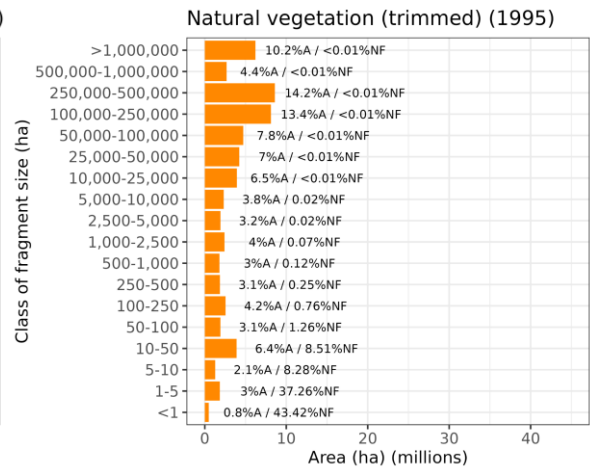
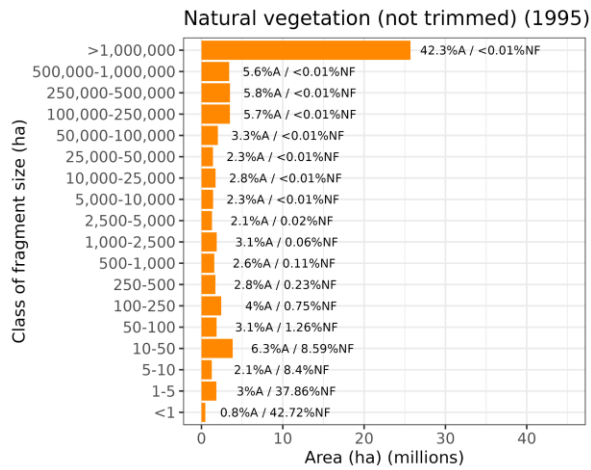
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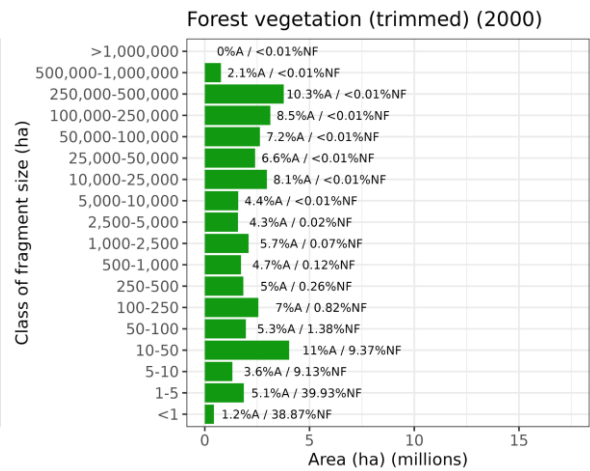
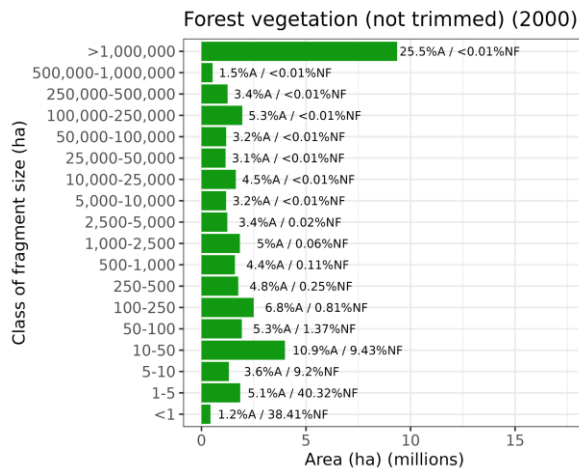
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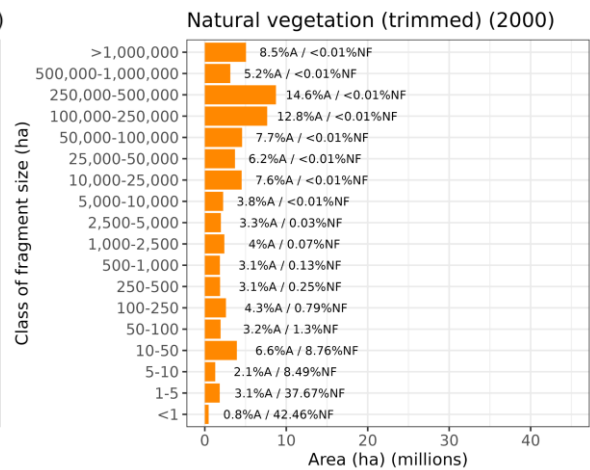
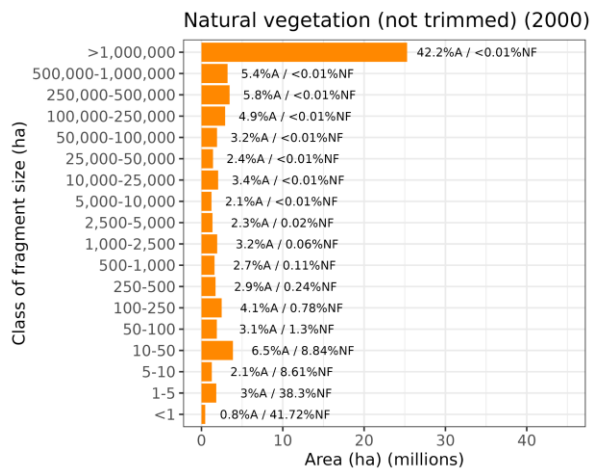
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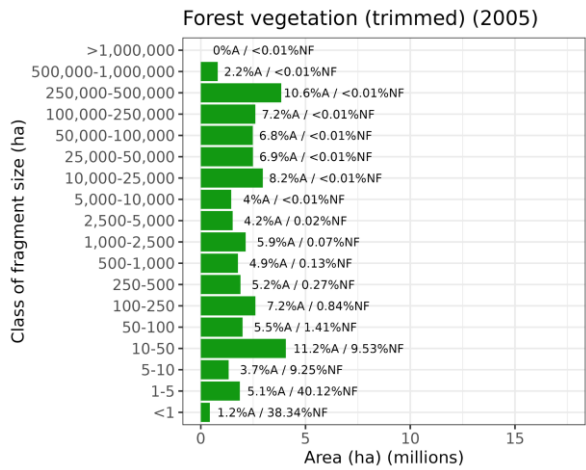
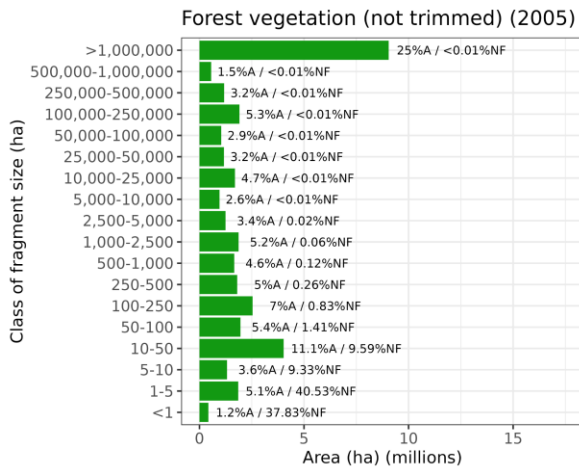


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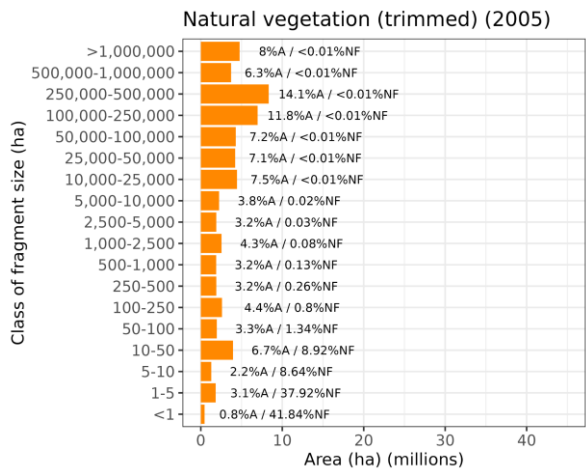
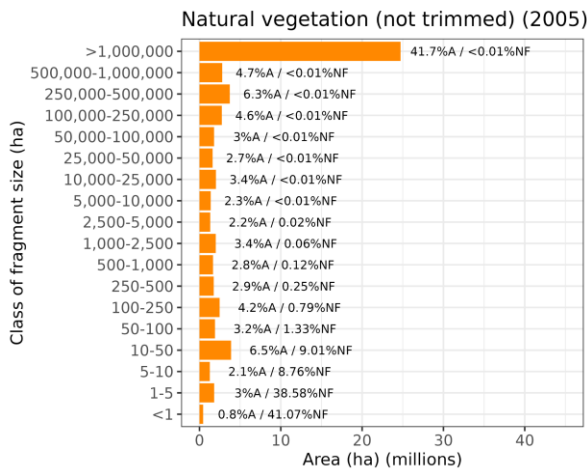


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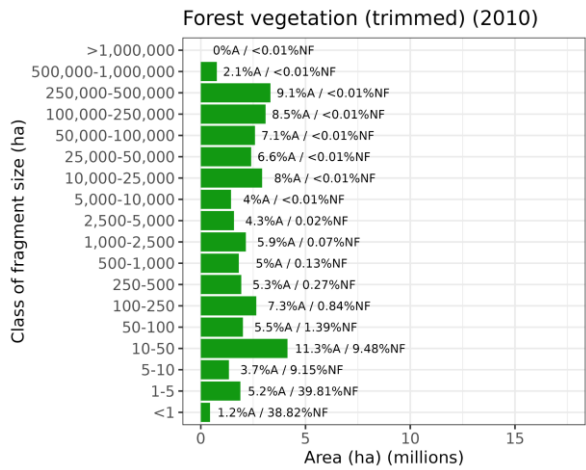
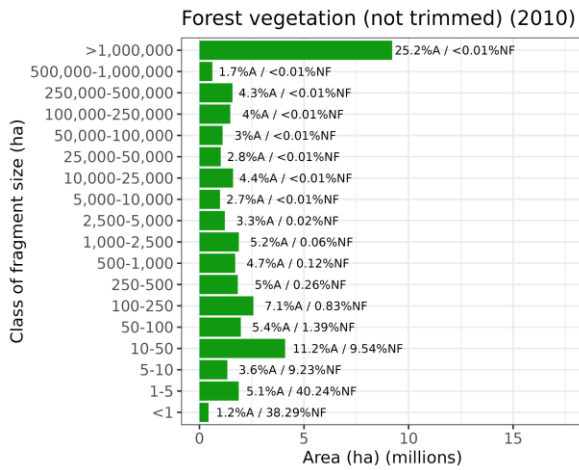




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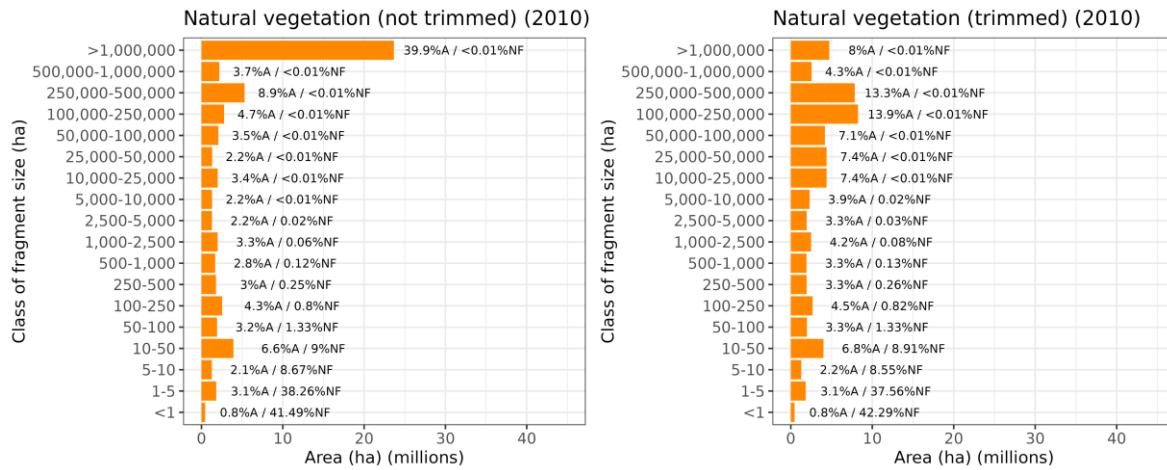


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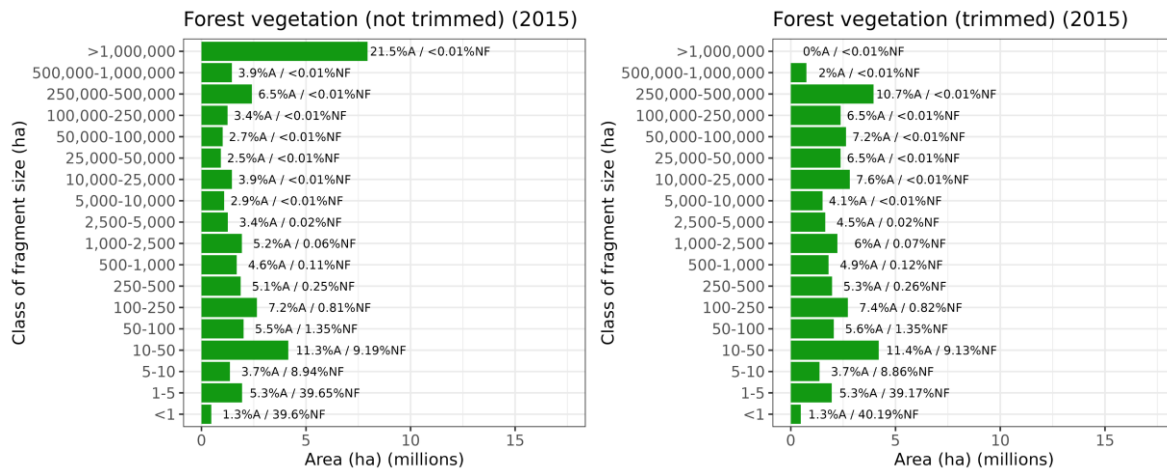


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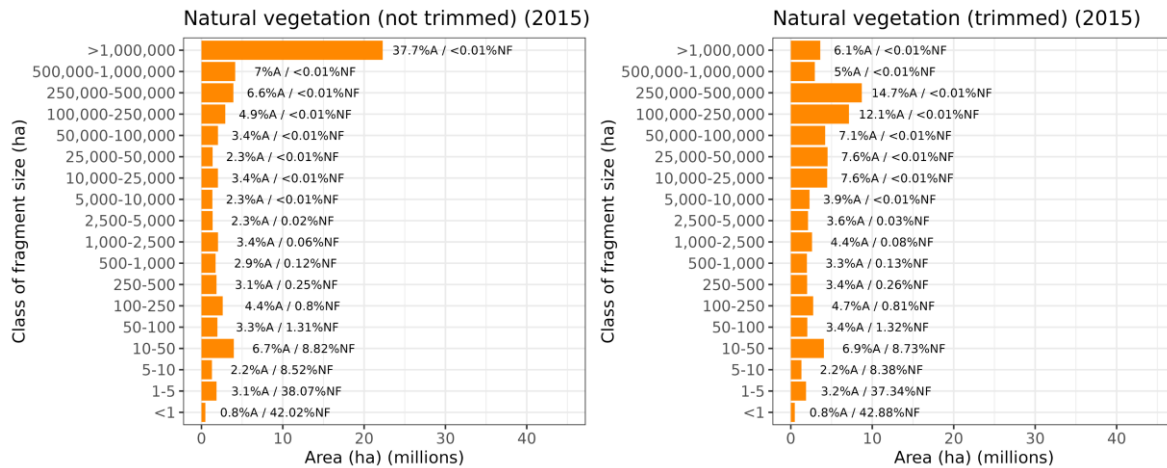
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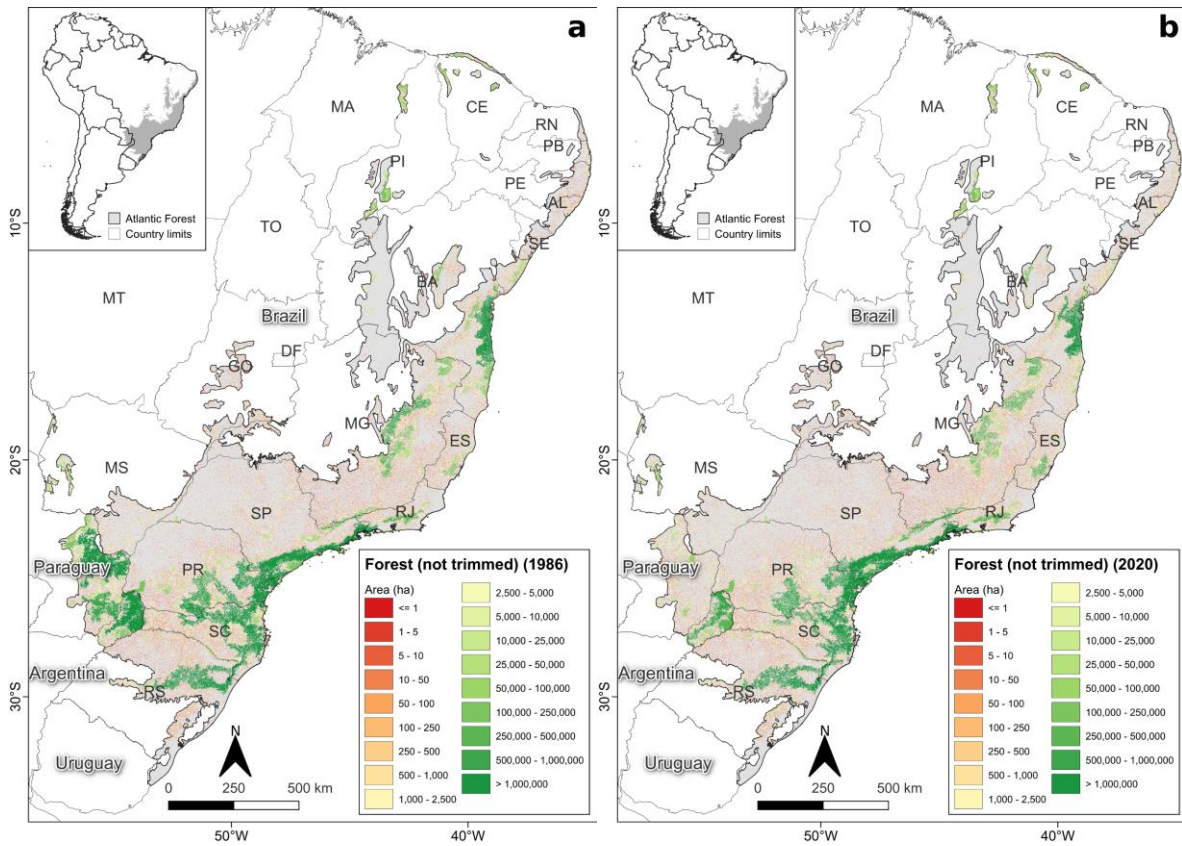


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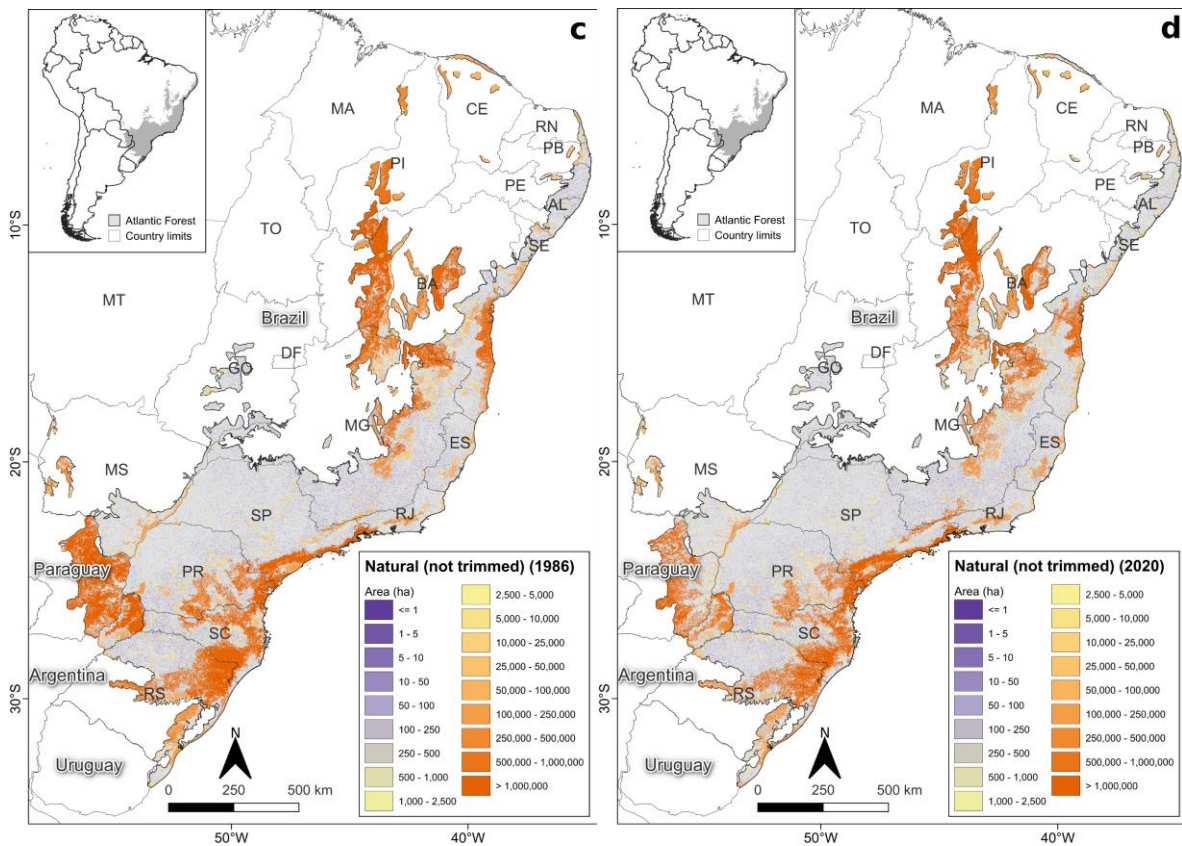


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**Figure S3.** Size distribution of forest vegetation and natural vegetation fragments in the Atlantic Forest (1990-2015), without and with road and railways effect. %A: percentage of total area; %NP: percentage of number of fragments.



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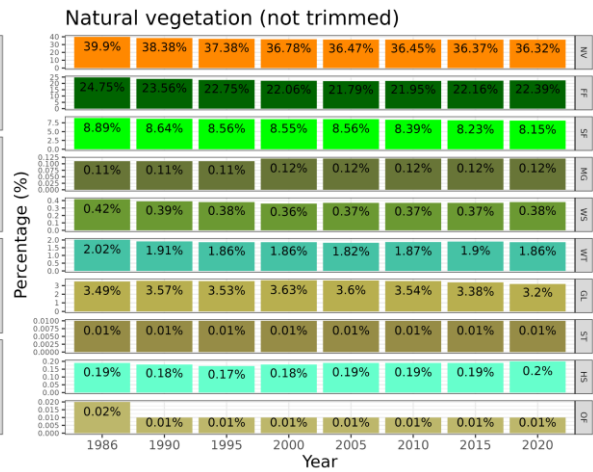
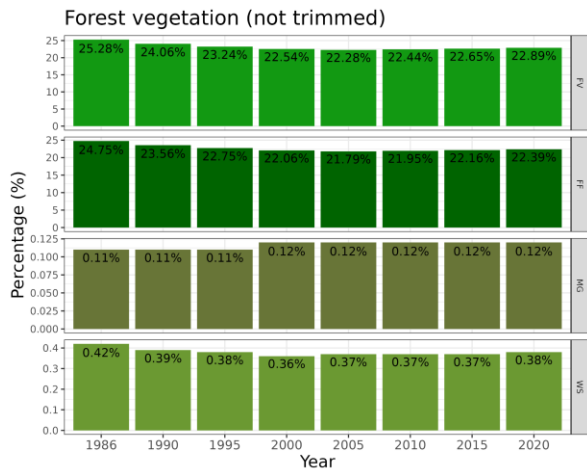
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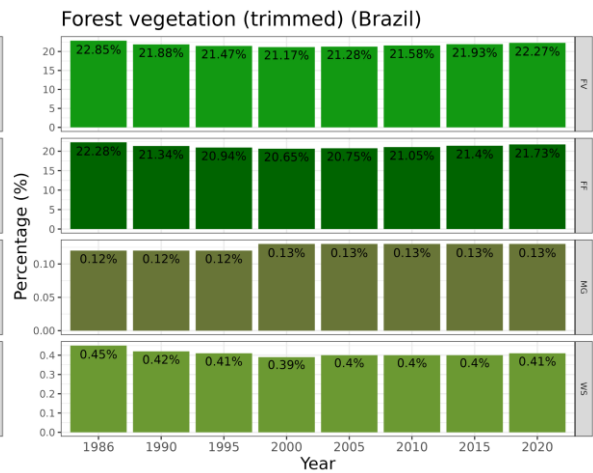
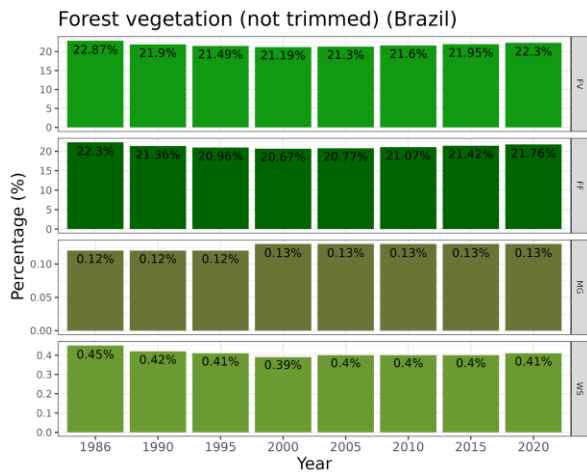
**Figure S4.** Fragment area for forest vegetation in 1986 (a) and 2020 (b), and for natural vegetation in 1986 (c) and 2020 (d), not trimmed for the entire AF.

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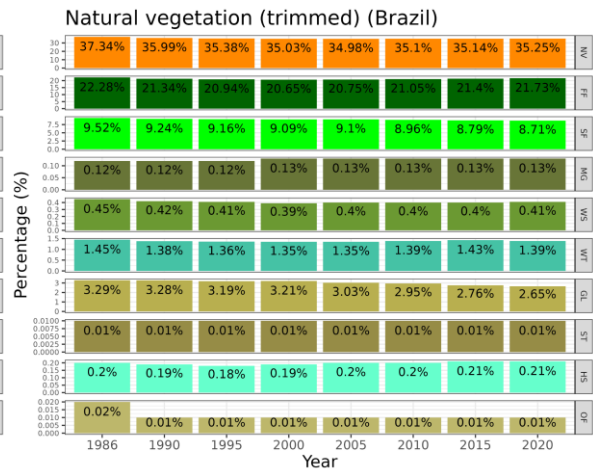
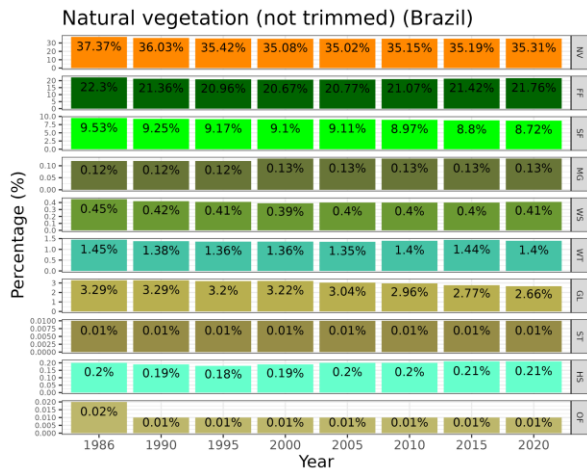
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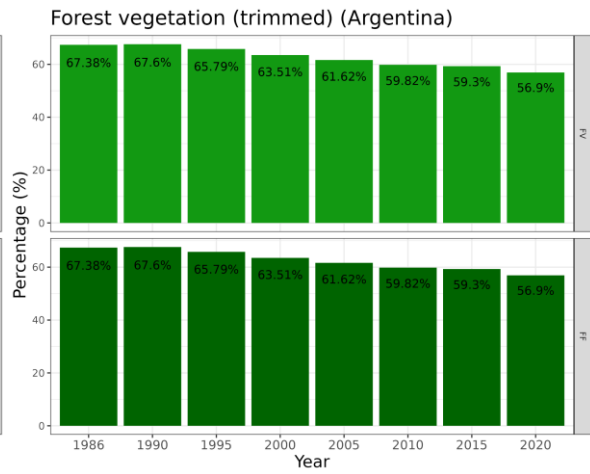
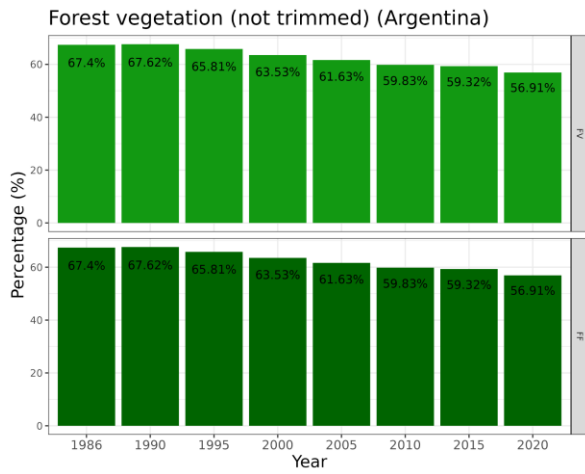
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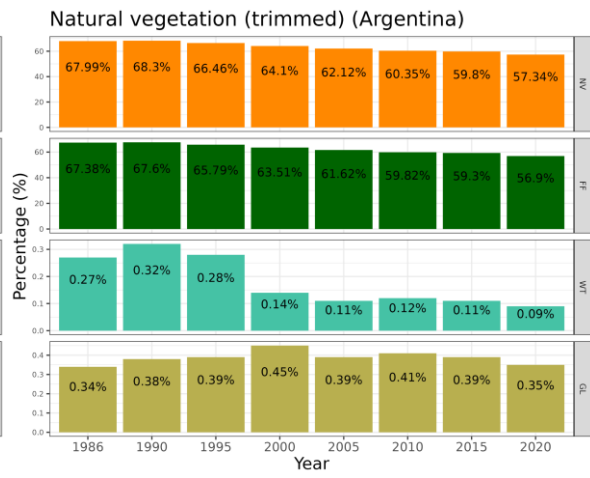
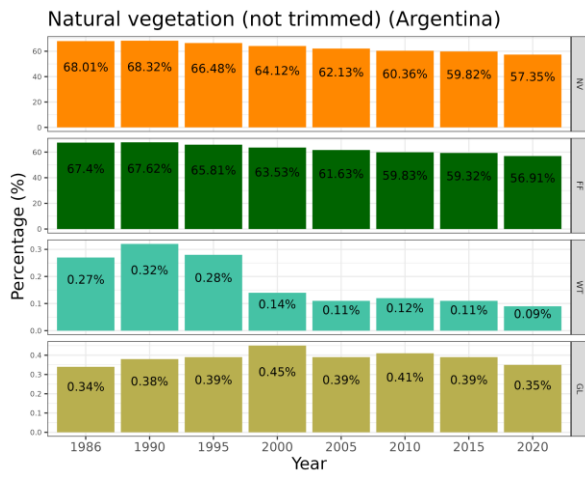
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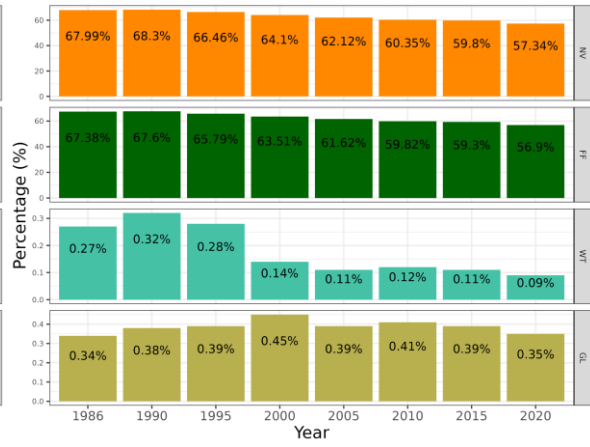
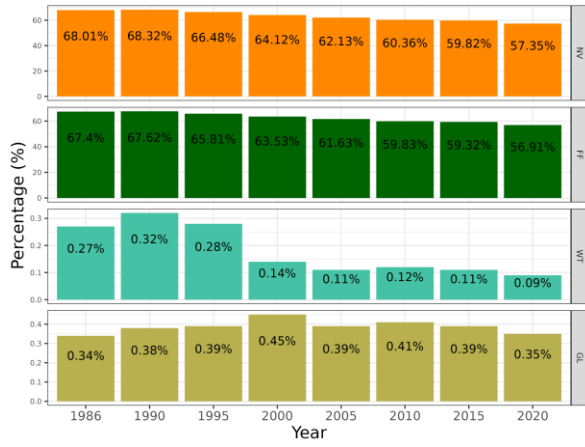
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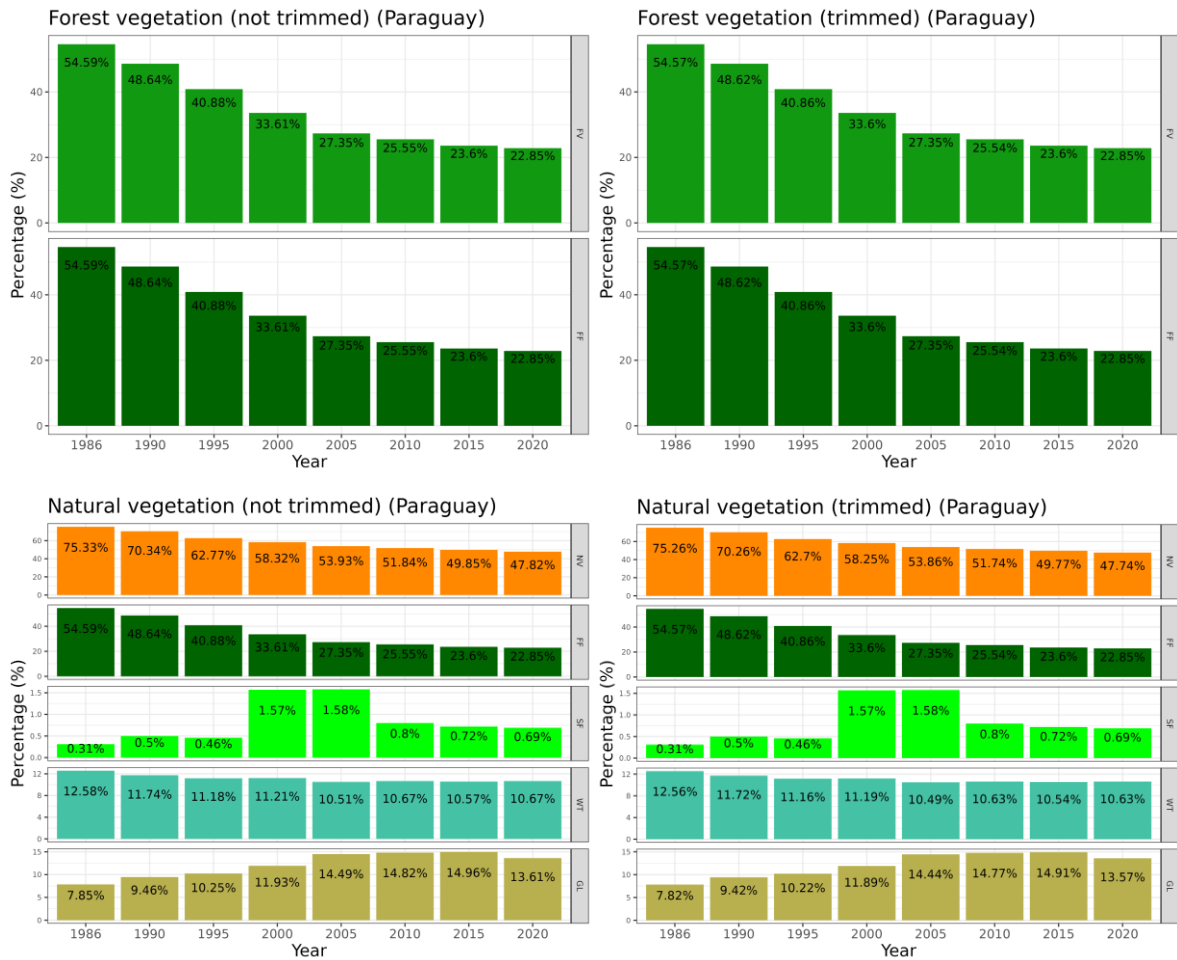


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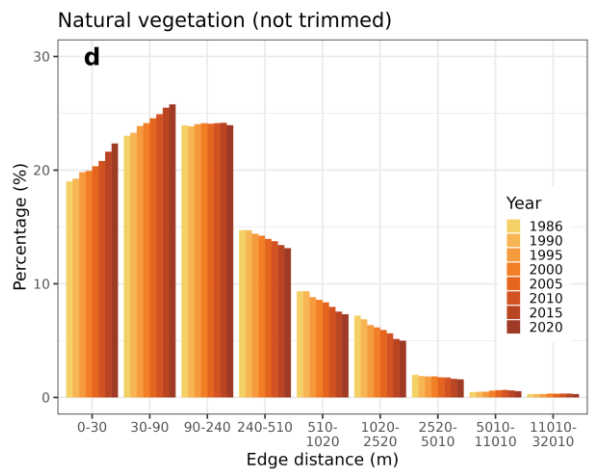
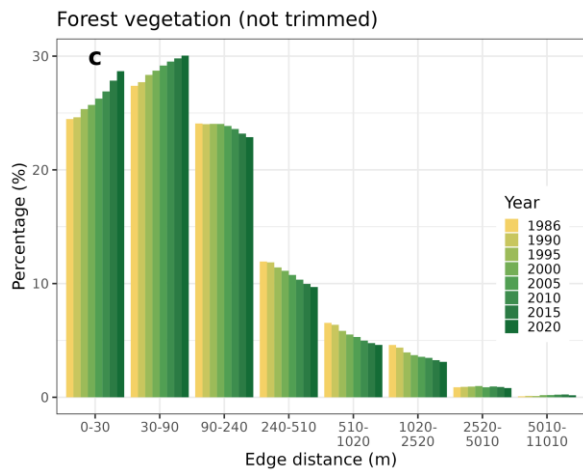
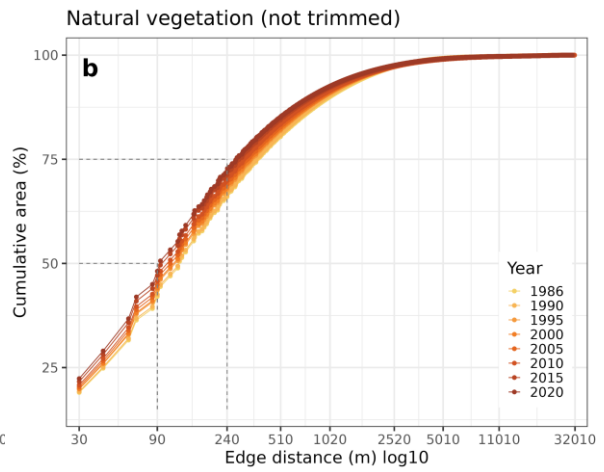
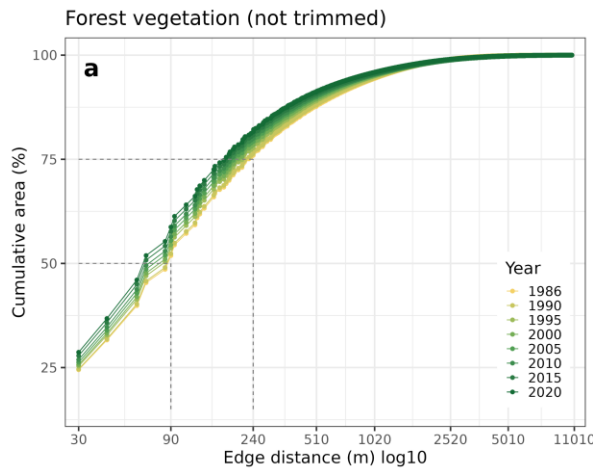
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124 **Figure S5.** FV and NV cover per year for the entire Atlantic Forest, Brazil, Argentina, and  
 125 Paraguay, trimmed and not trimmed. Abbreviations for FV cover are: FV = Forest vegetation,  
 126 FF = Forest formation, MG = Mangrove, WS = Wooded sandbank vegetation (*restinga*).  
 127 Abbreviations for NV cover are: NV = Natural vegetation, FF = Forest formation, SF =  
 128 Savanna formation, MG = Mangrove, WS = Wooded sandbank vegetation (*restinga*), WT =  
 129 Wetland, GL = Grassland, ST = Salt flat, HS = Herbaceous sandbank vegetation, OF =  
 130 Other non-forest formations. Class colors follow MapBiomass collection 7 and MapBiomass  
 131 Bosque Atlántico collection 2 legends.

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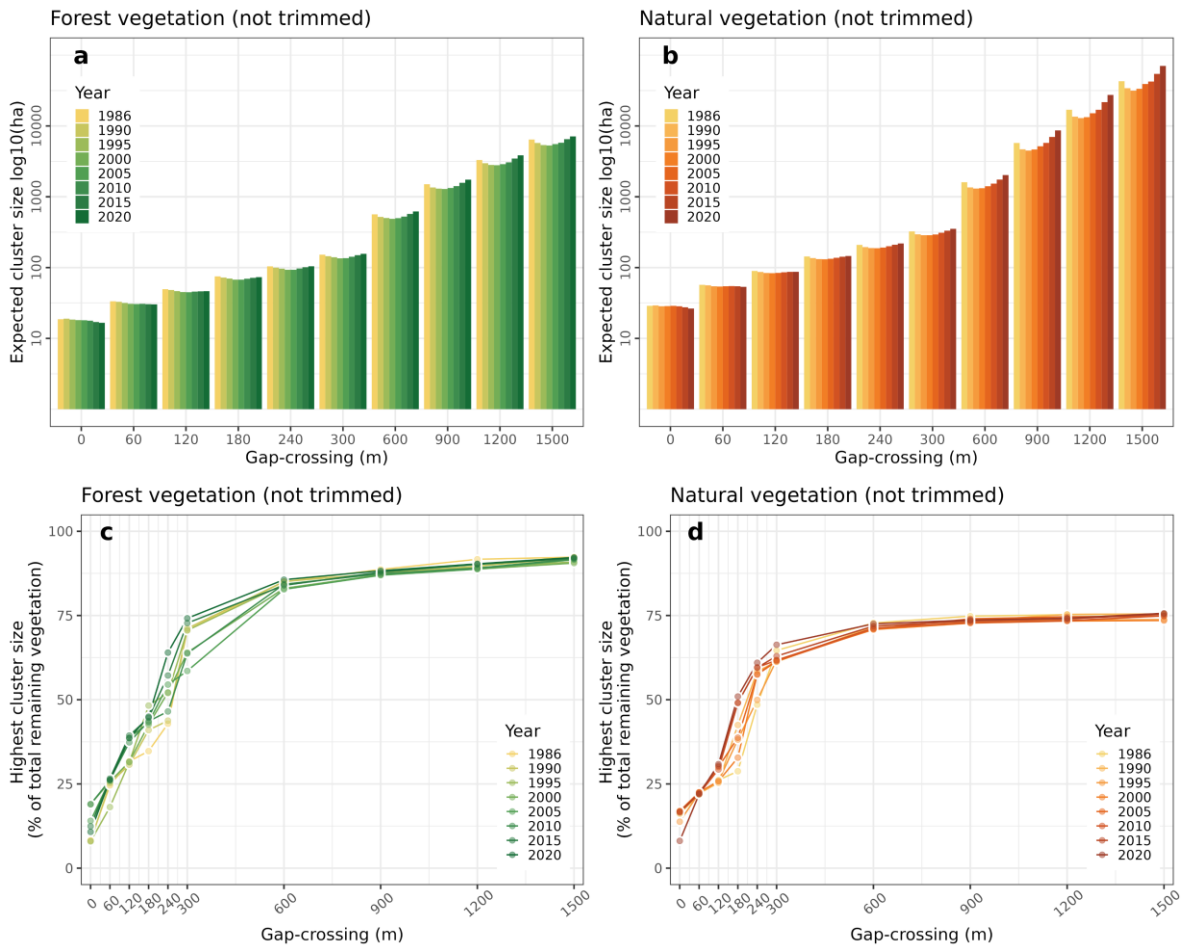
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**Figure S6.** Cumulative (a-b) and per class (c-d) area under edge effect at different edge depths for the FV and NV remaining in Atlantic Forest not trimmed.



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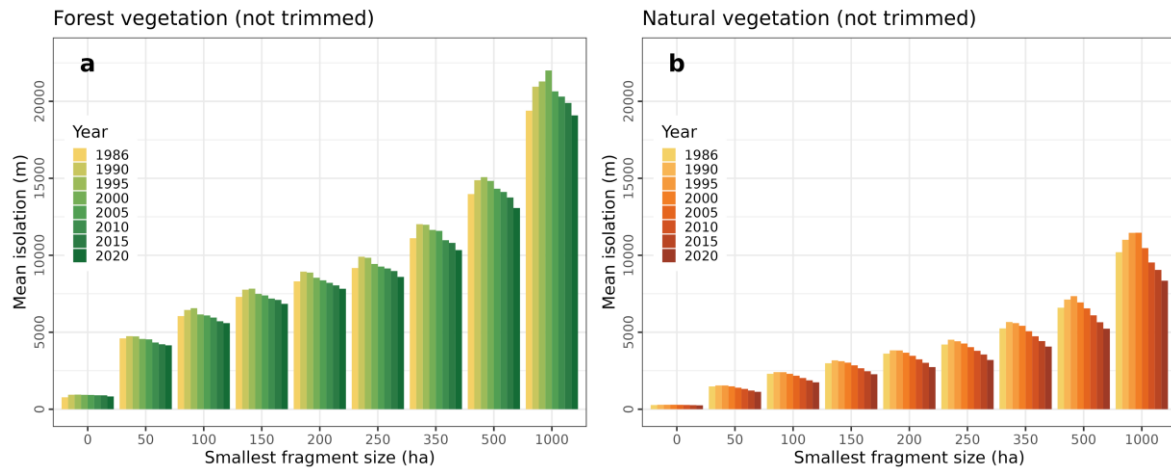
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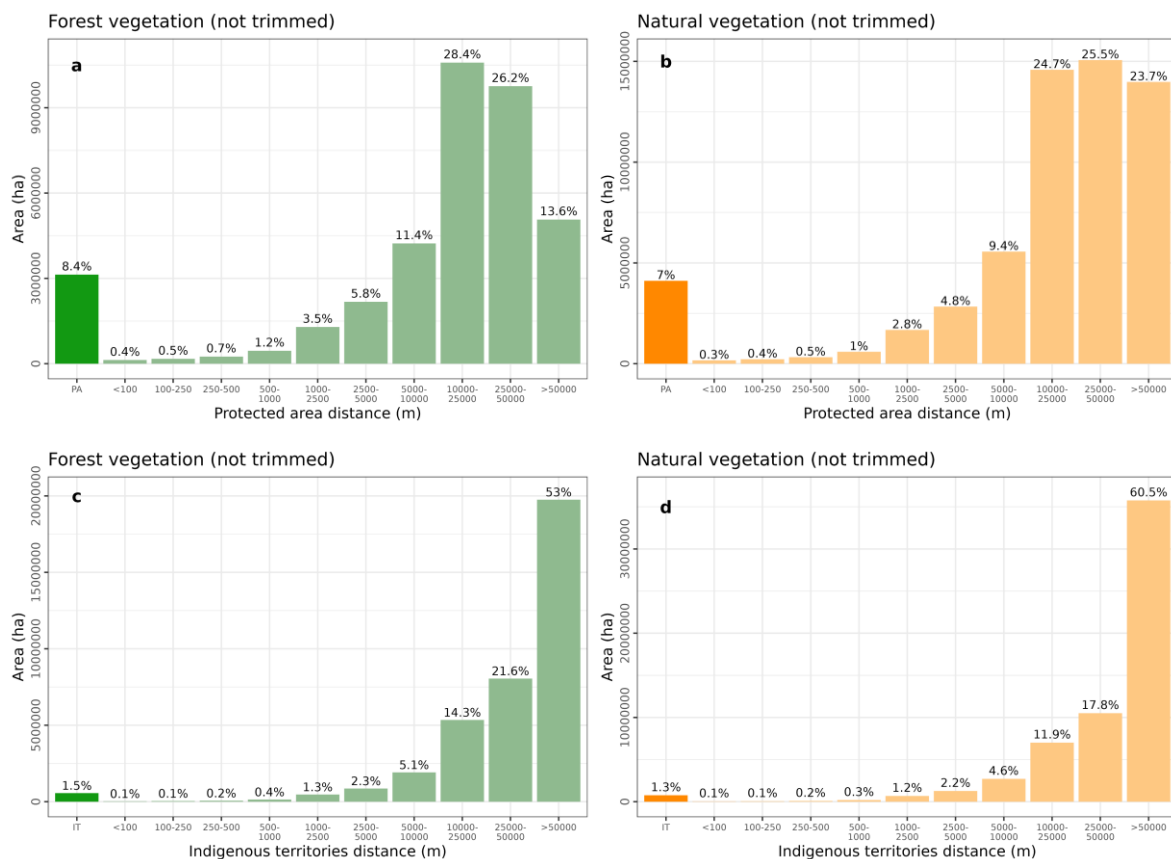
**Figure S7.** Expected cluster size (a-b) (average functional size; ha) of functionally connected fragments of FV and NV for different functional distances values (meters) for the Atlantic Forest. Highest functionally connected forest cluster (c-d) (% of total remaining of FV and NV) estimated across varying functional distances (m), for the Atlantic Forest not trimmed by roads and railways.





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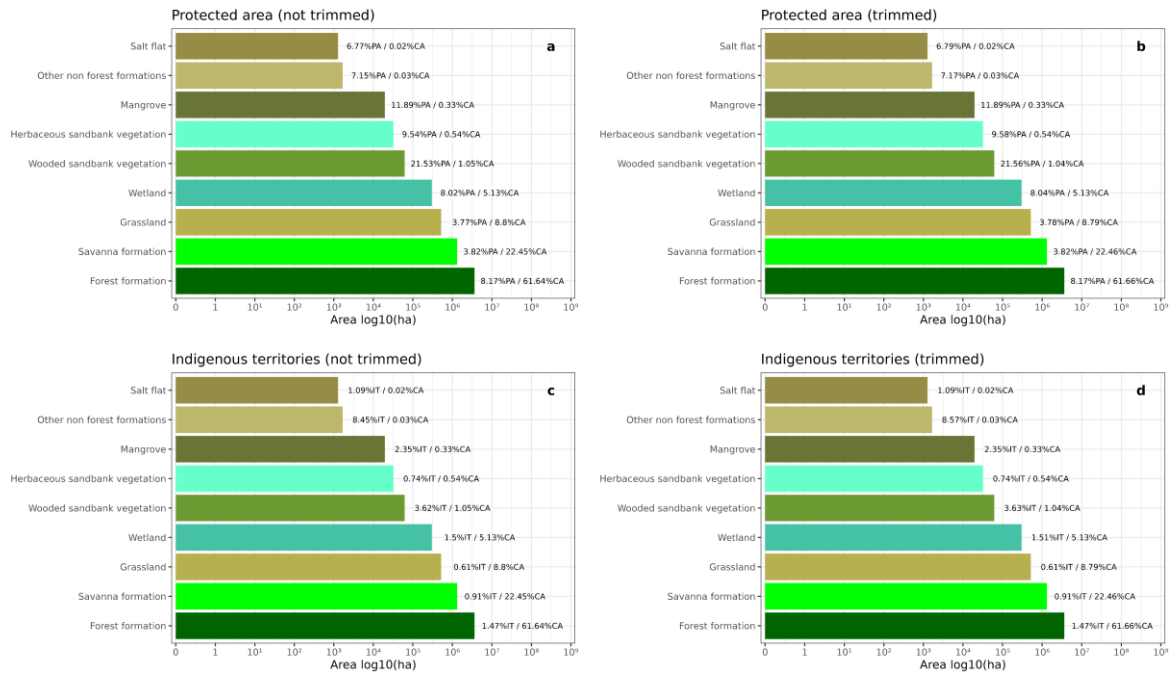
**Figure S8.** Influence of the smallest fragment size (ha) on the mean isolation (m) between fragments of FV and NV for the Atlantic Forest: mean isolation (a-b) not trimmed. Smallest fragments size: 0 ha (all fragments), 50 ha, 100 ha, 150 ha, 200 ha, 250 ha, 350 ha, 500 ha, and 1000 ha.



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**Figure S9.** Remaining vegetation within (area and percentage) and its distance by class (meters) from protected areas (PA; a – FV and b – NV) and indigenous lands (IT; c – FV and d – NV) to AF not trimmed.

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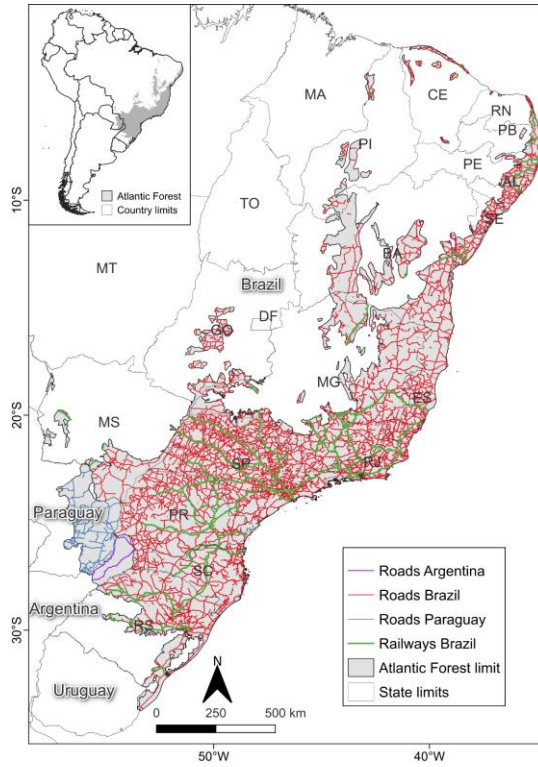
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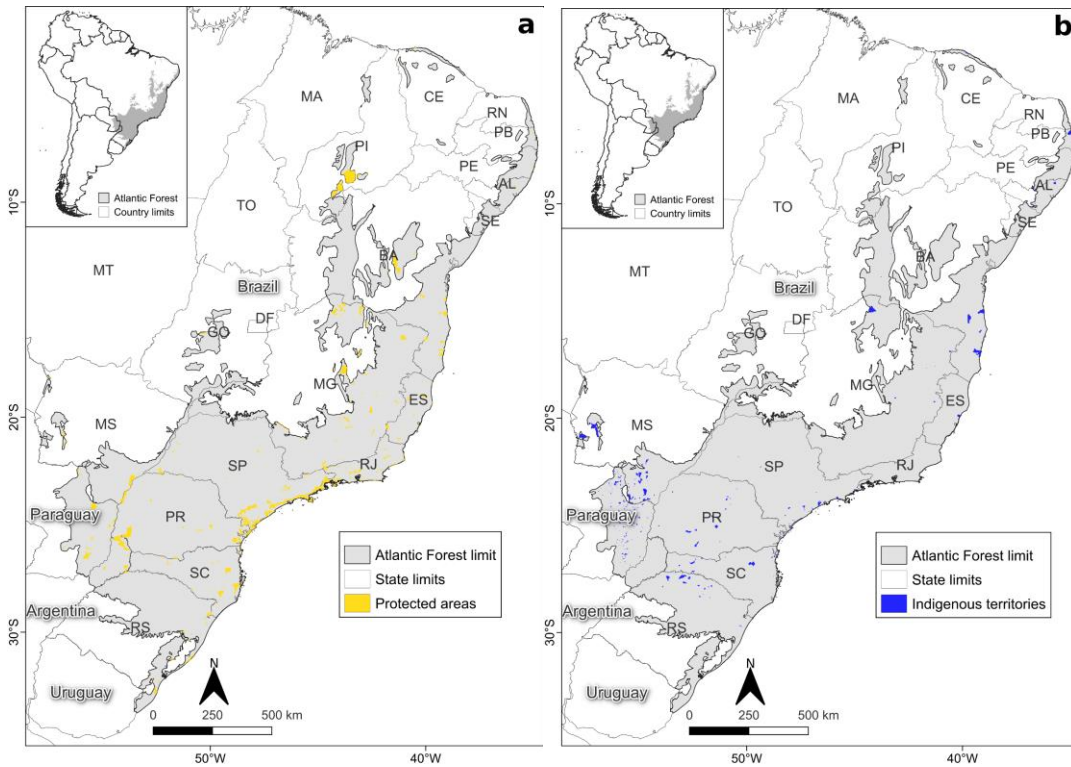
**Figure S10.** Remaining classes cover for FV and NV (area and percentage) within protected areas (PA) (a-b) and indigenous territories (TI) (c-d) for the Atlantic Forest not trimmed and trimmed. %PA: percentage of class area inside PA in relation to the total area of the class; %IT: percentage of class area inside IT in relation to the total area of the class; %CA: percentage of the class area in relation to the total area of vegetation for PA and IT.



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172 **Figure S11.** Roads and railways used to trim the FV and NV fragments.

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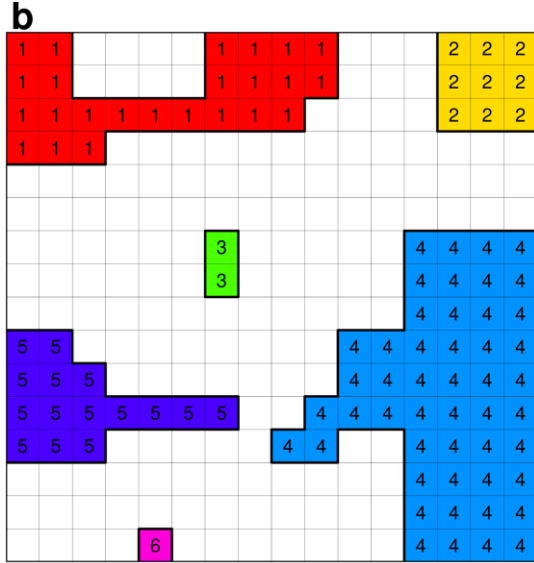
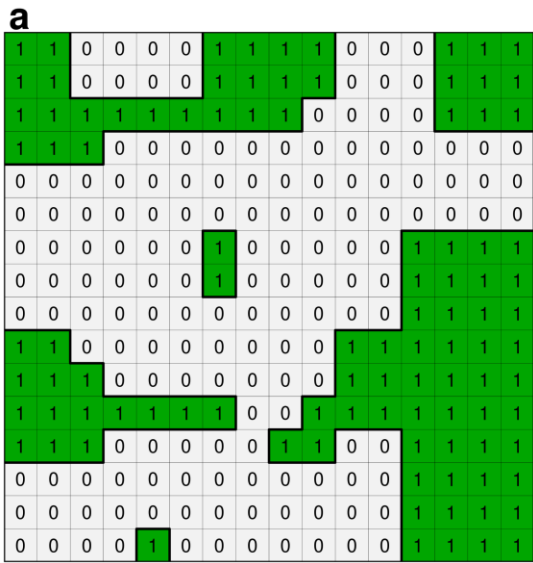


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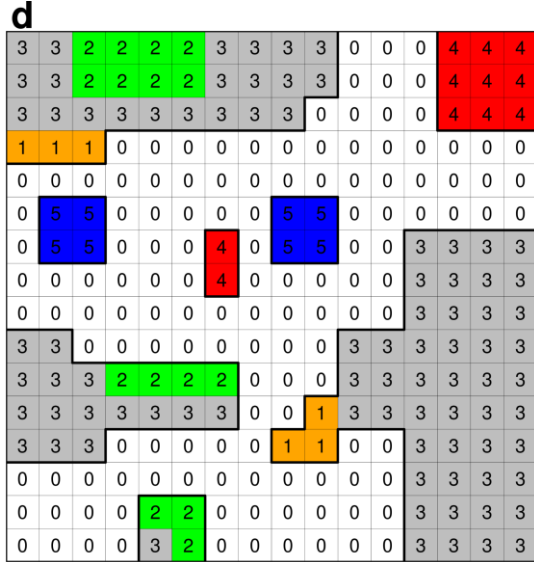
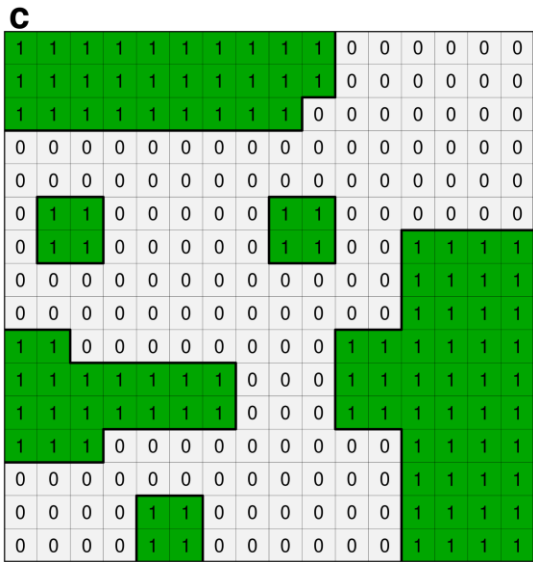
175 **Figure S12.** Protected areas (a) and indigenous territories (b) within the Atlantic Forests of  
 176 South America.

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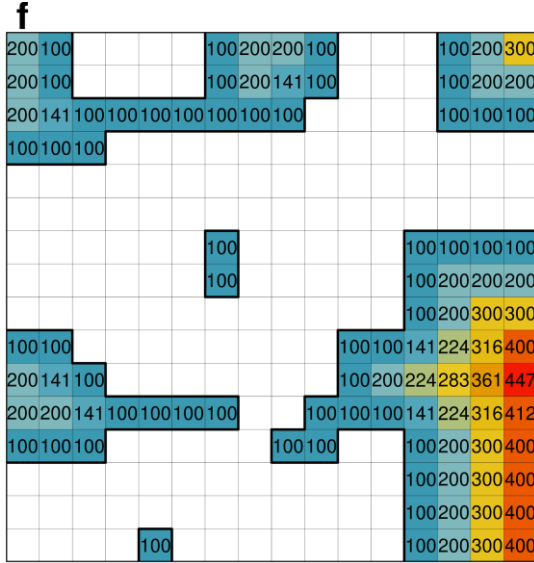
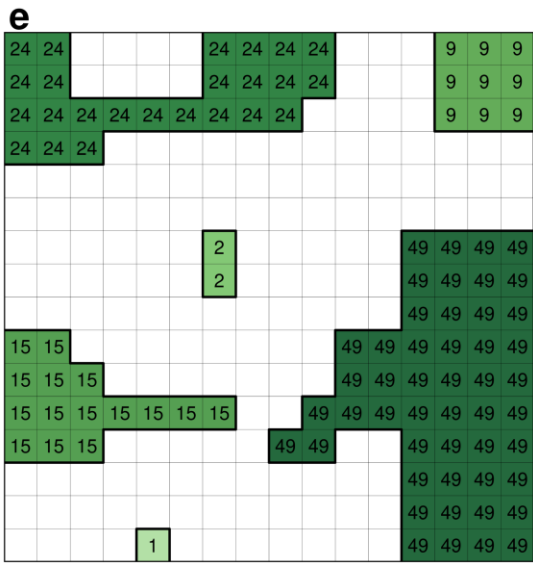
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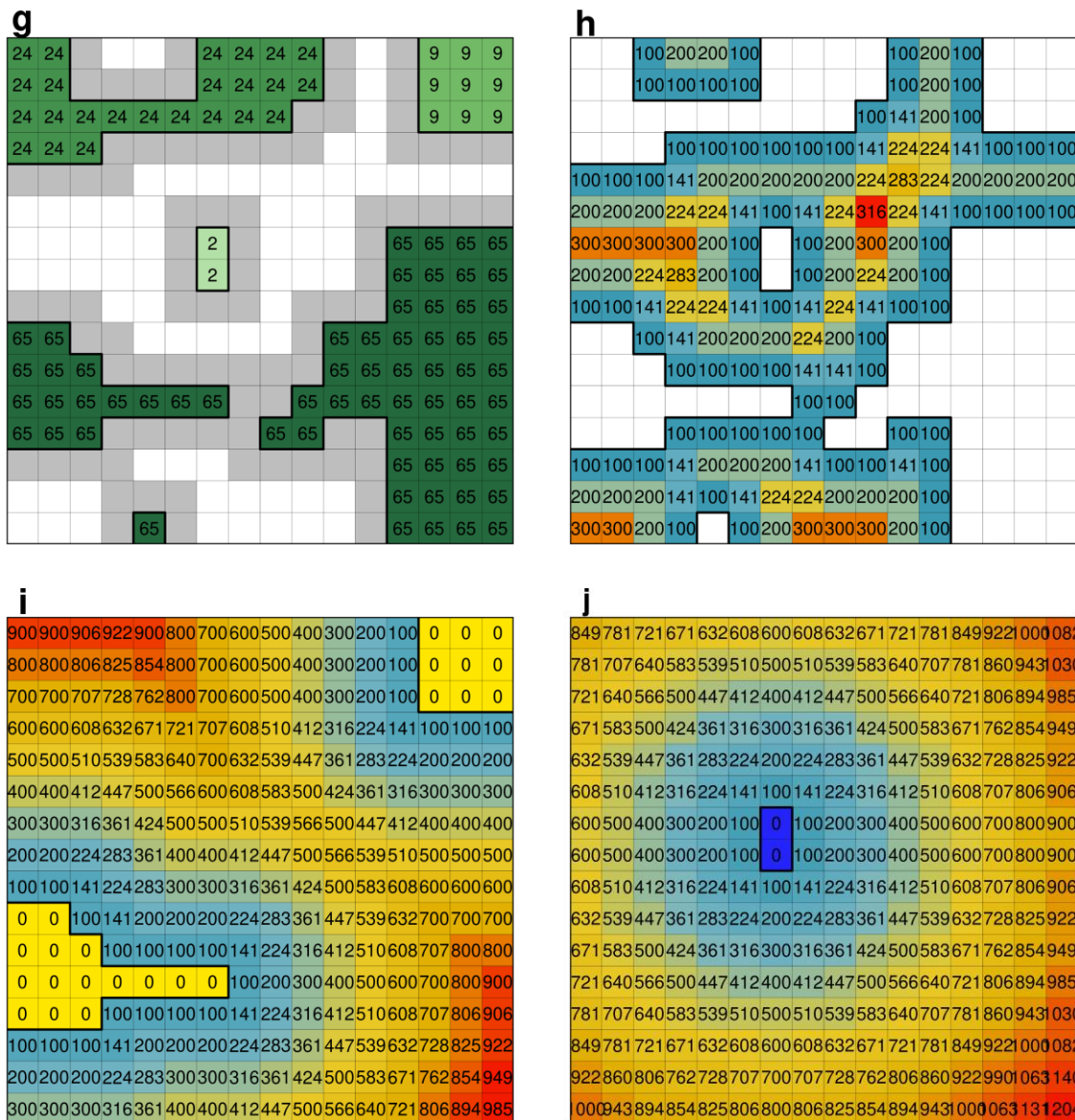
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**Figure S13.** Illustration exemplifying the landscape metrics used to analyze the landscape structure of the AF. Here, the rasters have 100 m of spatial resolution. (a) toy landscape containing binary forest and non-forest data, (b) number of fragments; (c) second toy landscape; (d) temporal fragment analysis—matrix (0), loss area (1), gain area (2), stable area (3), loss fragment (4), gain fragment (5); (e) fragment size; (f) edge area; (g) functional connectivity; (h) isolation; (i) distance from protected areas; and (j) distance from indigenous territories.

197 **Tables**

198

199 **Table S1.** Atlantic Forest (AF) delimitations used to compose the AF “integrated delimitation”  
 200 adapted from Muylaert et al. (2018).

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Reference	Area (ha)	Percentage in relation to Muylaert et al. (2018)	Figure
Muylaert et al. (2018)	162,742,129	100.0%	Fig. S1a
Muylaert et al. (2018) – Brazil	151,470,253	93.1%	Fig. S1a
Muylaert et al. (2018) – Argentina	2,668,855	1.64%	Fig. S1a
Muylaert et al. (2018) – Paraguay	8,603,022	5.29%	Fig. S1a
Atlantic Forest Law (2006)	128,779,574	79.1%	Fig. S1b
Da Silva and Casteleti (2003)	136,422,859	83.8%	Fig. S1c
IBGE (2004)	111,751,193	68.7%	Fig. S1d
IBGE (2019)	110,656,961	68.0%	Fig. S1e
Dinerstein et al. (2017)	120,492,216	74.0%	Fig. S1f

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220 **Table S2.** Land use and land cover and MapBiomass class code used to compose the  
 221 “Forest Vegetation” (FV) and “Natural Vegetation” (NV).  
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Vegetation class	Land use and land cover class	Land use and land cover class abbreviation	MapBiomass class code
Forest Vegetation (FV)	Forest Formation	FF	3
	Mangrove	MG	5
	Wooded Sandbank Vegetation ( <i>restinga</i> )	WS	49
Natural Vegetation (NV)	Forest Formation	FF	3
	Savanna Formation	SF	4
	Mangrove	MG	5
	Wooded Sandbank Vegetation ( <i>restinga</i> )	WS	49
	Wetland	WT	11
	Grassland	GL	12
	Salt Flat	ST	32
	Herbaceous Sandbank Vegetation	HS	50
Other Non-forest Formations	OF	13	

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237 **Table S3.** Landscape and topographic metrics used to analyze the structure of the  
 238 landscapes of the AF.  
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Metric	Description	Class
Number of fragments and fragment size.	Number of fragments, fragment size and percentage of habitat cover for different size classes.	fragment size classes (ha): <1, 1–5, 5–10, 10–50, 50–100, 100–250, 250–500, 500–1000, 1000–2500, 2500–5000, 5000–10000, 10000–25000, 25000–50000, 50000–100000, 100000–250000, 250000–500000, 500000–1000000, and >1000000.
Temporal dynamics of the landscape: area and number of fragments.	Areas of increase, reduction, and stability of fragments that remained throughout time, and area and number of fragments that disappeared and appeared.	Values (Fig. S13): accounting area of loss (1), gain (2), and stable (3) of the stains that remained; number and area of fragments that disappeared (4) and appeared (5).
Edge area.	Percentage of habitat area submitted to edge effects for different edge widths.	Edge widths (m) (pixel size): <30, 30–90, 90–240, 240–510, 510–1020, 1020–2520, 2520–5010, 5010–11010, and 11010–32010.
Functional connectivity.	Area of functionally connected fragments, considering different distance rules for fragment linkage.	Gap-crossing (m) (pixel size): 0, 60, 120, 180, 240, 300, 600, 900, 1200, and 1500.
Mean isolation.	Mean isolation to the nearest habitat fragment. To analyze the effect of small fragments in estimating isolation, the smallest fragments were successively removed.	Size of the small fragments removed (ha): 0 (i.e., no fragments removed), <50, <100, <150, <200, <250, <350, <500, and <1000.
Distance from Protected Areas and Indigenous Territories.	Distance of any given habitat pixel to the nearest Protected Area and Indigenous Territories.	Distance classes (m): 0 (i.e., inside a Protected Area or Indigenous Territories), <100, 100–250, 250–500, 500–1000, 1000–2500, 2500–5000, 5000–10000, 10000–25000, 25000–50000, and >50000.

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**Table S4.** Remaining FV and NV for the entire Atlantic Forest between 1986 and 2020, trimmed and not trimmed. For each year and vegetation scenario, the following values are presented: total percentage, number of fragments, and descriptive statistics (average, standard deviation, median and maximum) in hectares.

Year	Scenario	Total percentage (%)	Number of fragments	Total area (ha)	Average area (ha)	Standard deviation area (ha)	Median area (ha)	Maximum area (ha)
1986	FV not trimmed	25.28	2,201,796	41,132,358	18.68	3,687	1.35	3,397,448
1986	FV trimmed	25.26	2,230,509	41,096,833	18.42	1,296	1.35	830,496
1986	NV not trimmed	39.9	2,251,224	64,909,217	28.83	9,245	1.17	10,490,715
1986	NV trimmed	39.86	2,301,140	64,832,991	28.17	2,956	1.17	2,711,898
1990	FV not trimmed	24.06	2,059,724	39,164,420	19.01	3,472	1.44	3,158,986
1990	FV trimmed	24.04	2,086,758	39,130,573	18.75	1,269	1.44	877,595
1990	NV not trimmed	38.38	2,136,171	62,471,881	29.24	9,277	1.26	10,532,927
1990	NV trimmed	38.34	2,185,346	62,397,614	28.55	2,953	1.26	2,677,168
1995	FV not trimmed	23.24	2,051,750	37,825,688	18.44	3,336	1.44	3,007,756
1995	FV trimmed	23.22	2,080,013	37,791,570	18.17	1,170	1.44	803,755
1995	NV not trimmed	37.38	2,137,418	60,831,540	28.46	7,985	1.26	8,386,742
1995	NV trimmed	37.34	2,188,098	60,757,173	27.77	2,893	1.26	2,714,043
2000	FV not trimmed	22.54	2,024,772	36,688,790	18.12	5,092	1.44	6,959,510
2000	FV trimmed	22.52	2,052,621	36,655,360	17.86	1,150	1.44	770,101
2000	NV not trimmed	36.78	2,091,472	59,861,952	28.62	8,774	1.35	10,157,618
2000	NV trimmed	36.74	2,143,016	59,786,308	27.9	2,810	1.35	2,662,722
2005	FV not trimmed	22.28	2,009,506	36,260,960	18.04	4,020	1.53	5,095,019
2005	FV trimmed	22.26	2,039,272	36,225,866	17.76	1,132	1.44	806,599
2005	NV not trimmed	36.47	2,060,924	59,344,869	28.8	8,663	1.35	10,017,365

2005	NV trimmed	36.42	2,114,253	59,266,718	28.03	2,764	1.35	2,603,116
2010	FV not trimmed	22.44	2,052,341	36,522,265	17.8	5,034	1.44	6,937,266
2010	FV trimmed	22.41	2,084,891	36,484,973	17.5	1,100	1.44	763,970
2010	NV not trimmed	36.45	2,085,299	59,314,001	28.44	8,356	1.35	9,792,496
2010	NV trimmed	36.39	2,142,699	59,232,818	27.64	2,700	1.35	2,625,471
2015	FV not trimmed	22.65	2,161,797	36,867,412	17.05	3,705	1.44	4,582,605
2015	FV trimmed	22.62	2,199,425	36,826,511	16.74	1,081	1.35	744,569
2015	NV not trimmed	36.37	2,151,325	59,180,724	27.51	8,195	1.35	9,895,304
2015	NV trimmed	36.3	2,215,181	59,096,027	26.68	2,574	1.26	2,532,163
2020	FV not trimmed	22.89	2,244,015	37,251,477	16.6	3,343	1.35	4,010,367
2020	FV trimmed	22.86	2,287,893	37,206,313	16.26	1,026	1.35	698,736
2020	NV not trimmed	36.32	2,241,089	59,110,442	26.38	6,103	1.26	4,779,875
2020	NV trimmed	36.27	2,310,919	59,022,773	25.54	2,406	1.26	2,120,105

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**Table S5.** Dynamics of the landscape for the entire Atlantic Forest, from 1986-2005 and from 2005-2020 for two scenarios: not trimmed and trimmed. Balance of total area represents the subtraction of area gained minus area lost. Balance of total area (%) is in terms of percentage in relation to the total AF area. Balance of number of fragments represents the subtraction of the number of fragments gained minus the number of fragments lost. Mean size of fragments gained (ha), and mean size of fragments lost (ha) represent the average size of fragments gained and lost. The table with all measures is presented in Table S3.

<b>Period</b>	<b>Scenario</b>	<b>Balance of total area (ha)</b>	<b>Balance of total area (%)</b>	<b>Balance of number of fragments</b>	<b>Mean size of fragments gained (ha)</b>	<b>Mean size of fragments lost (ha)</b>
1986-2005	FV not trimmed	-4,871,398	-2.99	-242,715	1.14	1.35
1986-2005	FV trimmed	-4,870,967	-2.99	-242,678	1.12	1.33
1986-2005	NV not trimmed	-5,564,348	-3.42	-227,621	1.11	1.21
1986-2005	NV trimmed	-5,566,273	-3.42	-226,734	1.08	1.20
2005-2020	FV not trimmed	990,517	0.61	373,616	1.08	0.97
2005-2020	FV trimmed	980,447	0.60	385,798	1.06	0.96
2005-2020	NV not trimmed	-234,427	-0.14	301,911	1.06	0.96
2005-2020	NV trimmed	-243,945	-0.15	314,062	1.03	0.94

**Table S6.** Remaining FV and NV for different AF delimitations for the year of 2020, trimmed and not trimmed by roads and railways. For each delimitation and vegetation scenario are presented: vegetation percentage, number of fragments, and total and average area in hectares. The AF delimitations can be seen in Fig. S1.

AF delimitation	Scenario	Vegetation percentage (%)	Number of fragments	Total area (ha)	Average area (ha)
Atlantic Forest Law (2006)	FV not trimmed	24.07	1,788,188	30,992,081	17.33
Atlantic Forest Law (2006)	FV trimmed	24.03	1,827,380	30,951,928	16.94
Atlantic Forest Law (2006)	NV not trimmed	35.98	1,835,652	46,333,549	25.24
Atlantic Forest Law (2006)	NV trimmed	35.93	1,892,400	46,264,936	24.45
Da Silva and Casteleti (2003)	FV not trimmed	23.18	1,902,365	31,622,147	16.62
Da Silva and Casteleti (2003)	FV trimmed	23.15	1,944,184	31,579,924	16.24
Da Silva and Casteleti (2003)	NV not trimmed	34.36	1,933,978	46,875,495	24.24
Da Silva and Casteleti (2003)	NV trimmed	34.31	1,993,589	46,806,306	23.48
IBGE (2004)	FV not trimmed	26.06	1,641,173	29,122,577	17.74
IBGE (2004)	FV trimmed	26.02	1,679,756	29,083,232	17.31
IBGE (2004)	NV not trimmed	31.84	1,671,550	35,586,103	21.29
IBGE (2004)	NV trimmed	31.79	1,722,521	35,529,739	20.63
IBGE (2019)	FV not trimmed	26.5	1,649,485	29,326,354	17.78
IBGE (2019)	FV trimmed	26.47	1,688,418	29,286,695	17.35
IBGE (2019)	NV not trimmed	31.5	1,662,346	34,859,089	20.97
IBGE (2019)	NV trimmed	31.45	1,711,606	34,805,009	20.33
Dinerstein et al. (2017)	FV not trimmed	26.7	1,796,063	32,173,468	17.91
Dinerstein et al. (2017)	FV trimmed	26.67	1,834,102	32,133,736	17.52
Dinerstein et al. (2017)	NV not trimmed	33.97	1,767,078	40,934,679	23.17
Dinerstein et al. (2017)	NV trimmed	33.92	1,821,027	40,870,573	22.44

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