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Status and trend of Amazon forest fragmentation from 2001 to 2022

Algorithm Theoretical Basis Document (ATBD)

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Contents

Abstract

This document describes the design process, definitions, and algorithmic implementation for an assessment of forest fragmentation across the Amazon. This study follows a request raised by the United Nations Food and Agricultural Organisation (FAO) to conduct an assessment on the state of the forests in the Amazon Region within the context of the Amazon Cooperation Treaty Organization and the EU-funded Amazonia+ Programme. The FAO-provided forest cover maps were analysed for forest fragmentation using a local neighbourhood of 100 km^2. Spatially explicit fragmentation maps and statistical summaries are derived for the years 2001, 2014, and 2022. The status maps are complemented by a fragmentation change map and statistics covering the time frame 2001 to 2022.

Foreword

This publication is a technical report by the Joint Research Centre (JRC), the European Commission's science and knowledge service. It aims to provide evidence-based scientific support to the European policymaking process. The scientific output expressed does not imply a policy position of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use that might be made of this publication. For information on the methodology and quality underlying the data used in this publication for which the source is neither Eurostat nor other Commission services, users should contact the referenced source. The designations employed and the presentation of material on the maps do not imply the expression of any opinion whatsoever on the part of the European Union concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

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1. Introduction

The Amazon Cooperation Treaty Organization (ACTO) is an intergovernmental organization formed by the eight Amazonian countries—Bolivia, Brazil, Colombia, Ecuador, Guyana, Peru, Suriname, and Venezuela—to promote the sustainable and harmonious development of the Amazon Basin through international cooperation. The ACTO countries have created many programs and established agreements to sustain biodiversity and promote conservation and resource management in the Amazon. International collaboration includes the United Nations Food and Agricultural Organization (FAO) and the EU-funded Amazonia+ programme with the objectives to improve the capacity of the countries of the Amazon basin to mitigate CO^2 emissions, adapt to the effects of climate change, significantly reduce deforestation and forest degradation, and improve their biodiversity.

The forest monitoring activities include the assessment of forest area and its degree in forest fragmentation, which is a key aspect in biodiversity, ecosystem services and the ever-increasing pressure from anthropogenic land use. Forest fragmentation may lead to the isolation and loss of species and gene pools, degraded habitat quality, and a reduction in the forest's ability to sustain the natural processes necessary to maintain ecosystem health. Connectivity can be seen as the complement to fragmentation, for example, if a forest is not fragmented at all, it would be fully connected. The metric FAD (Forest Area Density) quantifies the degree of connectivity within forested land cover. It describes structural connectivity within forest cover and can be derived at any suitable analysis scale, which is defined by the size of the local neighbourhood of interest. The result of a FAD analysis is a spatially explicit map and tabular summary statistics. At international level, the metric FAD was adopted in the US sustainability reporting under the international Montréal Process[1] (Riitters & Robertson, 2021), the United States Resource Planning Act Assessment[2], the FAO-UNEP SOFO 2020[3] report (Vogt et al. 2019a) and by Forest Europe in the State of Europe's Forests 2020[4] report (Vogt et al. 2019b).

For the upcoming State of the Forests in the Amazon Region report, and after discussions with the FAO coordinators, the forest fragmentation assessment scheme was refined to comply with the following key findings (**KF**):

— **KF1 - Data source:** FAO provided forest-nonforest raster maps for the years 2000, 2014, and 2022 and annual deforestation maps from 2001 to 2022.

  Motivation: The FAO-provided raster maps are based on a common definition of forest and boundaries of the Amazon region as agreed by the 8 Amazon+ countries.

1 https://montreal-process.org

2 https://research.fs.usda.gov/treesearch/66413

3 https://www.fao.org/documents/card/en/c/ca8642en

4 https://foresteurope.org/wp-content/uploads/2016/08/SoEF_2020.pdf

— **KF2 - Methodology:** the method "Forest Area Density" (FAD) at Fixed Observation Scale (FAD-FOS) was selected to best match the fragmentation assessment requirements stipulated by FAO. The FAD assessment is complemented by the reporting scheme "Accounting", providing geographic maps and derived statistics of six forest patch size classes.

Motivation: FAD is a widely accepted metric for forest fragmentation assessments. It is used by various international and national organisations and included in EU policy legislation, i.e. the Nature Restoration Regulation, Annex VI. The same methodology, as well as the Accounting reporting scheme, was also used in the FAO SOFO2020 report.

— **KF3 - Analysis scale:** a scale of ~ 100 km^2 (10,000 hectare) was selected.

Motivation: fragmentation is scale-dependent, and each scale has its merit. In the FAO SOFO2020 report, the global forest map with a spatial resolution of 100 m was analysed for fragmentation at a local scale of 100 km^2. For consistency, we use the same 100 km^2 analysis scale over the Amazon region. However, the higher spatial resolution of the Amazon forest maps (30 m) captures many fine-scale features such as roads, railway tracks, power lines and streams, leading to a more realistic assessment but consequently also to an increase in the degree of fragmentation when compared to the lower resolution global data used in the SOFO2020 report. For the FAD metric, and considering the 30 m forest map, a local analysis scale of 100 km^2 translates into a moving window size of 333 x 333 pixels (= 9990 x 9990 m).

— **KF4 - Fragmentation product:** the default FAD 5-class reporting style was selected.

Motivation: The degree in forest fragmentation is reported in five classes[5] : *Very High*, *High*, *Intermediate*, *Low*, *Very Low*. The spatial map shows the degree in fragmentation within the local neighbourhood of 10 km x 10 km around each forest pixel. The statistical summary lists the forest proportion in each fragmentation class and two single summary indices: FAD_AV - the average connectivity within the forest cover, and AVCON - the average connectivity within the reporting unit. These five fragmentation classes and their statistical summaries are intuitive to understand and easy to communicate. Because the georeferenced maps are in equal area projection the derived statistics provide forest area and fragmentation statistics in percentage as well as actual area in hectares, allowing for a comparative analysis across the Amazon. Accounting will be reported for each forest patch in six forest patch size classes [100; 1,000; 10,000; 100,000; 1,000,000; > 1,000,000] hectares.

— **KF5 – Fragmentation change:** provide a change map and change statistics for local forest fragmentation and forest patch size classes from the longest available time span.

Motivation: information of trends in forest fragmentation, particularly their spatial locations, is of critical importance in monitoring forest cover and its degradation.

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5 https://ies-ows.jrc.ec.europa.eu/gtb/GTB/psheets/GTB-Fragmentation-FADFOS.pdf

— **KF6 – Deforestation statistics:** provide a tabular summary of annual deforestation statistics including the number of deforestation patches, mean, standard deviation, median, and total area in hectare.

  Motivation: information of trends in deforestation statistics may provide insights in the temporal evolution of deforestation.

The FAO expert panel found that the combination of measuring local forest fragmentation (FAD) in five classes and Accounting in six patch size classes is well-suited to investigate the spatial integrity of forest land cover in the Amazon. The selected setup addresses key fragmentation aspects, such as the isolation of small fragments, number and extent of perforations, and large compact forest patches, and the distribution of patch size classes.

2. Implementation summary

This section provides an overview of the data source used, necessary pre-processing steps, details on the algorithms applied, details on the output format and other documentary information on the status and change product. All maps and statistics are available on the JRC public data portal (https://jeodpp.jrc.ec.europa.eu/ftp/jrc-opendata/FOREST/FAL/FAO_Amazon/VER2025).

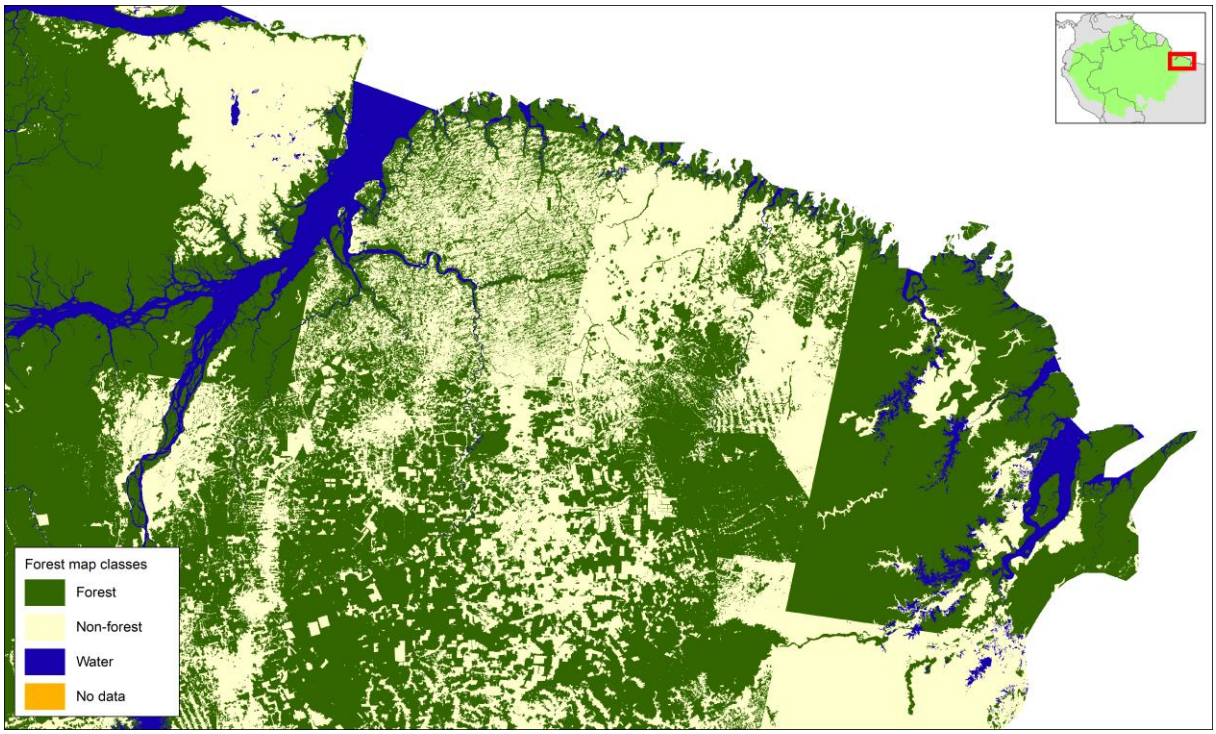
2.1. Input data source

This study utilized a comprehensive dataset of spatial information provided by FAO, comprising three forest-nonforest map layers for the years 2000, 2014, and 2022, as well as a layer detecting deforested areas on a yearly basis from 2001 to 2022. The spatial data encompass an extensive area of ~ 6,922,500 km^2, covering eight countries (Brazil, Suriname, Guyana, Venezuela, Colombia, Peru, Ecuador, and Bolivia).

The forest-nonforest maps, with a resolution of approximately 30 meters, categorize the land cover into four distinct classes: forest, non-forested land, waters, and missing data or clouds. These classes provide a detailed representation of the land cover dynamics over the study period.

Preliminary analysis of the data revealed some limitations and inconsistencies. Notably, the 2000 forest map exhibited significant artefacts in the western region, where forest cover was incorrectly detected (Figure 1).

Figure 1. Artefacts in the forest-nonforest map of the year 2000. The forest cover (in green) is incorrectly detected in large squares.



Source: JRC, 2025

Due to the substantial over-estimation of forest cover in the 2000 map, the 2014 forest map was used as a baseline and the deforested patches detected from 2014 backwards were added.

However, to maintain spatial accuracy, only the deforested patches from 2002 to 2014 were incorporated into the 2014 forest cover, effectively reconstructing the forest cover for the year 2001.

The assessment of forest fragmentation requires recoding the forest map layers (see Table 1) to be compliant with the fragmentation input data format required in the JRC software GuidosToolbox Workbench (GWB, Vogt et al., 2022) or GuidosToolbox (GTB, Vogt and Riitters, 2017).

Table 1. Reclassification of the FAO forest map value to the one required by GTB/GWB.

Land cover	FAO raster map value	Recoded raster map value
Non-forest	0	1
Forest	1	2
Water	4	3
Missing/clouds	3	0
No data	15	0

Source: JRC, 2025.

2.1.1. Forest map in WGS84 projection

The FAO-provided forest-nonforest maps are in the projection WGS84 (EPSG:4326), which is the standard projection for online visualization via map servers or standard geospatial applications such as GoogleEarth and Google Earth Engine. The three forest maps for the years 2001, 2014, 2022 are processed for fragmentation and the change map of fragmentation from 2001 to 2022 is derived in the projection WGS84. The result are geospatial fragmentation maps in the format GeoTIFF with the dimension 132,729 x 105,017 pixels for potential visualization on online web portals.

2.1.2. Forest map in equal area projection

Statistical analysis and related area estimates require geospatial maps in equal-area projection, which ensure that each map pixel has the same spatial extent. The forest maps in WGS84 projection were reprojected to the equal area projection Goode-Homolosine Land (EPSG:54052) with a pixel resolution of 30 m via the command in Box 1.

Box 1. Command to reproject the forest map from WGS84 to equal area Goode-Homolosine.

```
gdalwarp -s_srs EPSG:4326 -t_srs ESRI:54052 -tr 30 30 -dstnodata none -te -
8850000 -2050000 -4851000 1124000 -r near -ot Byte -of GTIFF -co "COMPRESS=LZW" -
co "BIGTIFF=YES" fmap2022.tif fmap2022_EA.tif
```

The file names of the equal area projection maps have the extension '_EA.tif' to distinguish them from the WGS84 maps. The three equal area forest maps for the years 2001, 2014, 2022 are processed for fragmentation and the change map of fragmentation from 2001 to 2022 is derived in the projection 54052. The result are geospatial maps in the format GeoTIFF with the dimension 133,300 x 105,800 pixels with a pixel resolution of 30 m. All fragmentation statistics are derived from the equal area projection maps.

2.1.3. Deforestation maps in equal area projection

Deriving spatial per patch statistics and related area estimates require geospatial maps in equal-area projection. The FAO-provided annual deforestation map in WGS84 projection was reprojected to the equal area projection Goode-Homolosine Land (EPSG:54052) with a pixel resolution of 30 m via the command outlined in Box 1.

2.2. Forest fragmentation

The methodology (**KF2**) to measure forest fragmentation combines the analysis of the degree in local forest fragmentation (FAD) with the assessment of forest patch size classes (Accounting).

2.2.1. Forest Area Density

The metric FAD (Forest Area Density) is defined as the area of all forest pixels in the local neighbourhood divided by the neighbourhood area, hence area density. FAD measurements are conducted over each forest pixel in the input map via a moving window algorithm to create a new map of FAD: the given local neighbourhood - a square window of size 333 x 333 pixels ~ 10,000 ha or 100 km^2 (**KF3**) - is centred over a given forest pixel, FAD within that neighbourhood is measured and assigned in a new map at the location of the subject forest pixel. This process is repeated for all forest pixels resulting in a new map of the same dimensions but showing FAD for the analysed neighbourhood. For each forest pixel, the FAD values in [0, 100] % are colour-coded into five classes (**KF4**) showing the degree of forest fragmentation as: *Very High* (FAD in [0, 10] %), *High* (FAD in [10, 40] %), *Intermediate* (FAD in [40, 60] %), *Low* (FAD in [60, 90] %), and *Very Low* (FAD in [90, 100] %).

The statistical summary of a forest fragmentation map, which is only derived for the equal area projection maps, lists: the reporting unit area, forest area, forest proportion, the proportion of forest cover in the five fragmentation classes, FAD_AV - the average connectivity within the forest cover, and AVCON - the average connectivity within the reporting unit.

The degree of local forest fragmentation is assessed by processing the forest input maps with the GWB_FRAG module using the default settings and the five-class reporting scheme.

2.2.2. Accounting

Accounting is designed to provide a concise summary of the location and size class distribution of forest patches in a forest map. The methodology provides a map product together with a statistical summary for a series of forest patch size classes (**KF2**). Following the decision for the SOFO2020 report, FAO suggested to use the same six forest patch size classes: [100; 1,000; 10,000; 100,000; 1,000,000; > 1,000,000] hectares, or [1; 10; 100; 1,000; 10,000; > 10,000] km^2. The distinction into these six classes describe the forest patch size class distribution at a given point in time.

Mapping and statistics of the six patch size classes are derived by processing the 30 m resolution forest input maps with the GWB_ACC module using the default settings and the five area thresholds [1111, 11111, 111111, 1111111, 11111111].

2.3. Fragmentation change

Fragmentation change (**KF5**) is derived via two perspectives. Comparing the accounting statistics over time, shifts in proportion and total number of forest patches between the six accounting classes provides insights into fragmentation processes at the reporting unit level. At local level, this analysis is complemented by calculating the difference between two FAD status maps having the same spatial resolution, map projection, map extent, and analysis scale. Pixels in the FAD change map can then be either forest cover at both times, non-forest at both times, forest cover at one time only (forest loss or forest gain), or coded as missing, for example if the pixel is within cloud cover, or outside of the reporting unit at either time. The change class water is assigned to pixels that are marked as inland water in the input map at either time. Change in forest fragmentation is constrained to those pixels that have forest cover at both times. Like the status product, the FAD change product consists of a spatially explicit change map, a change histogram, and plain text files listing the change matrix between the five fragmentation classes including common background at both times, and differences in all other status indices. Any change statistics are derived from the equal area product only.

Mapping and statistics of local forest fragmentation (FAD) are derived by processing the change between the FAD status maps for 2001 and 2022 with the GWB_FOSCHANGE module.

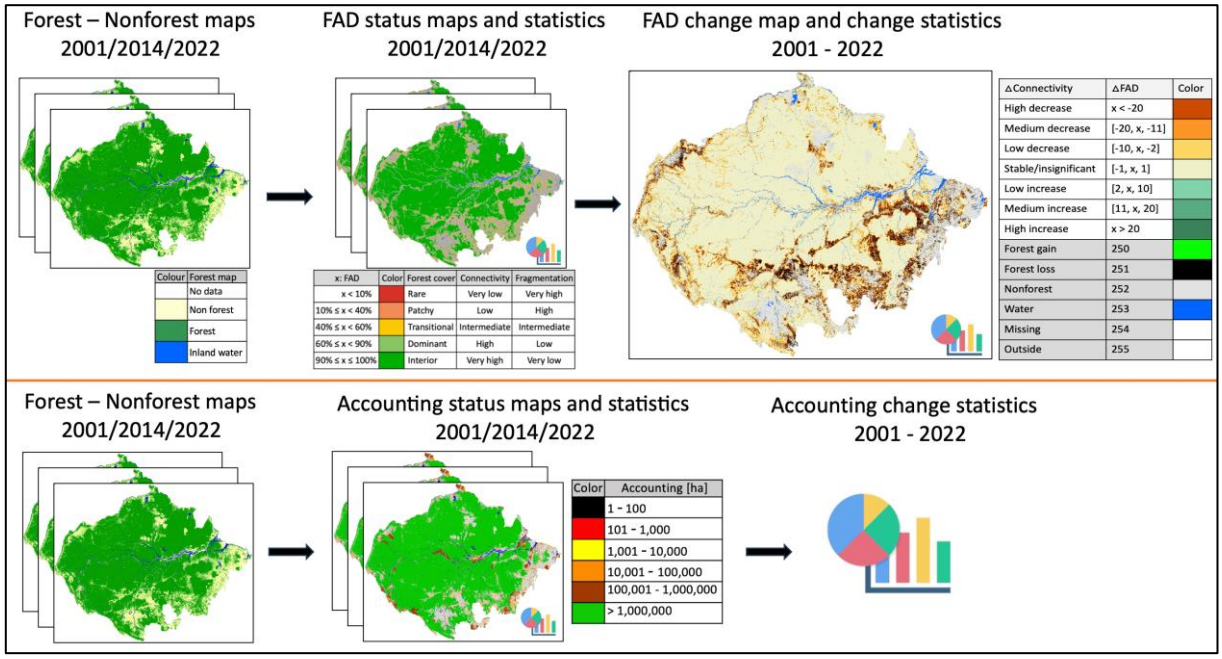
2.4. Deforestation patch statistics

A small custom script was setup to derive annual deforestation statistics (**KF6**). The equal-area projected deforestation map is masked by year, a blob-labelling procedure with 8-connectivity delineates individual deforestation patches, which are then analysed for the requested statistical properties number of patches, mean patch size, standard deviation, median patch size, and total area. This process is conducted in a loop, and the result is written to a single spreadsheet output.

2.5. Implementation flowchart

Figure 2 provides an overview of the processing chain to derive the forest fragmentation maps and statistics. The top panel shows the sequence for processing the local fragmentation FAD status and change maps. The bottom panel shows a similar sequence but for deriving the Accounting status maps and statistics. Change in Accounting is derived by comparing the status statistics from the assessment years 2001 and 2022.

Figure 2. Flowchart to derive forest fragmentation maps and statistics.



Source: JRC, 2025

Details on the file hierarchy and the input and output file data assignments are summarised in the Annex at the end of this document.

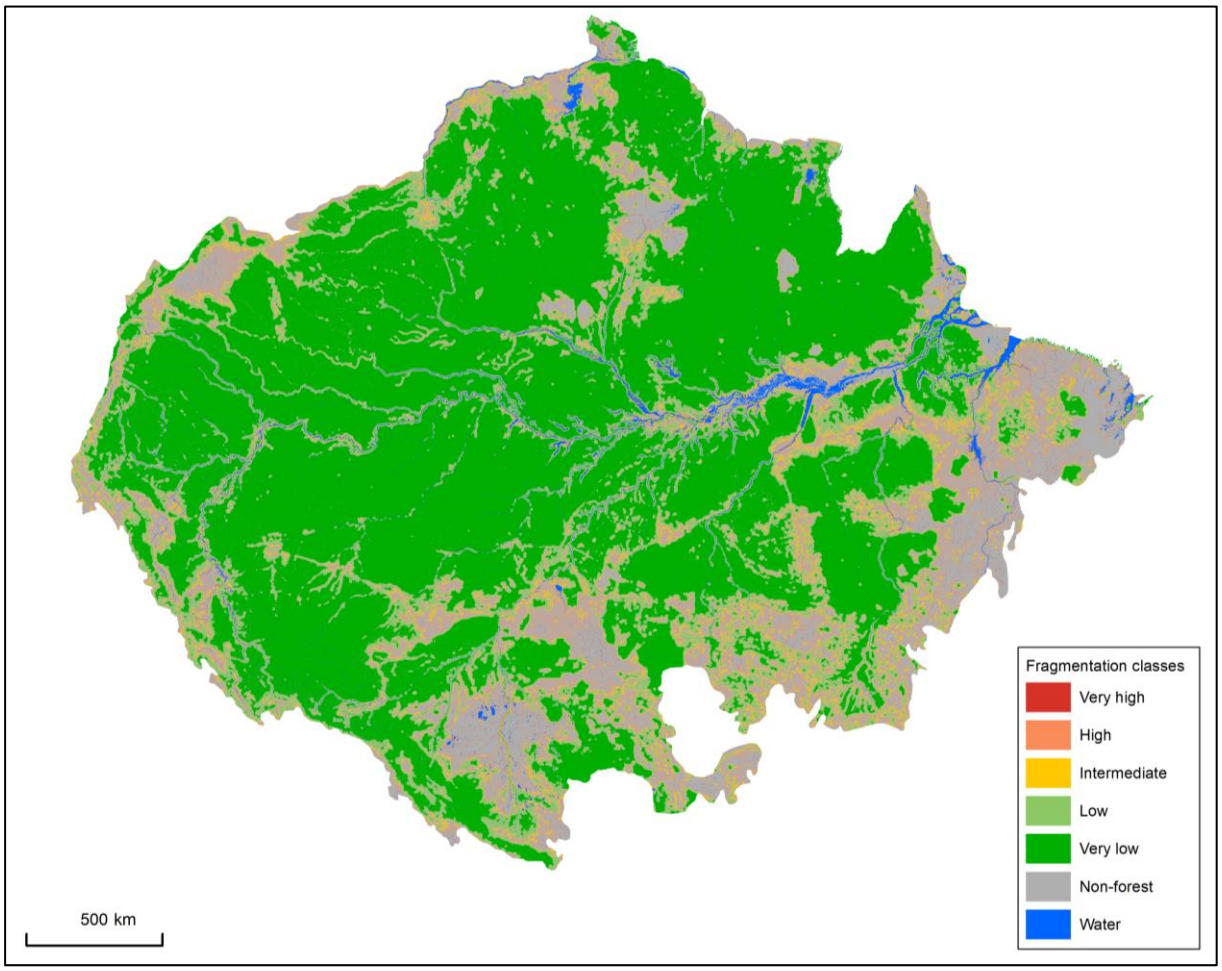
3. Results

This section provides example maps and explanatory notes of the resulting products. Additional technical details are provided in the Annex at the end of this document.

3.1. Status and change of FAD

The degree of forest fragmentation in the year 2022 across the Amazon region is shown in Figure 3. The five colour-coded ranges indicate that most of the forest area within a local neighbourhood of 100 km^2 is in the fragmentation class *very low* (dark green). Regions with higher degree in fragmentation are found in the north, west and particularly the south-eastern part of the Amazon.

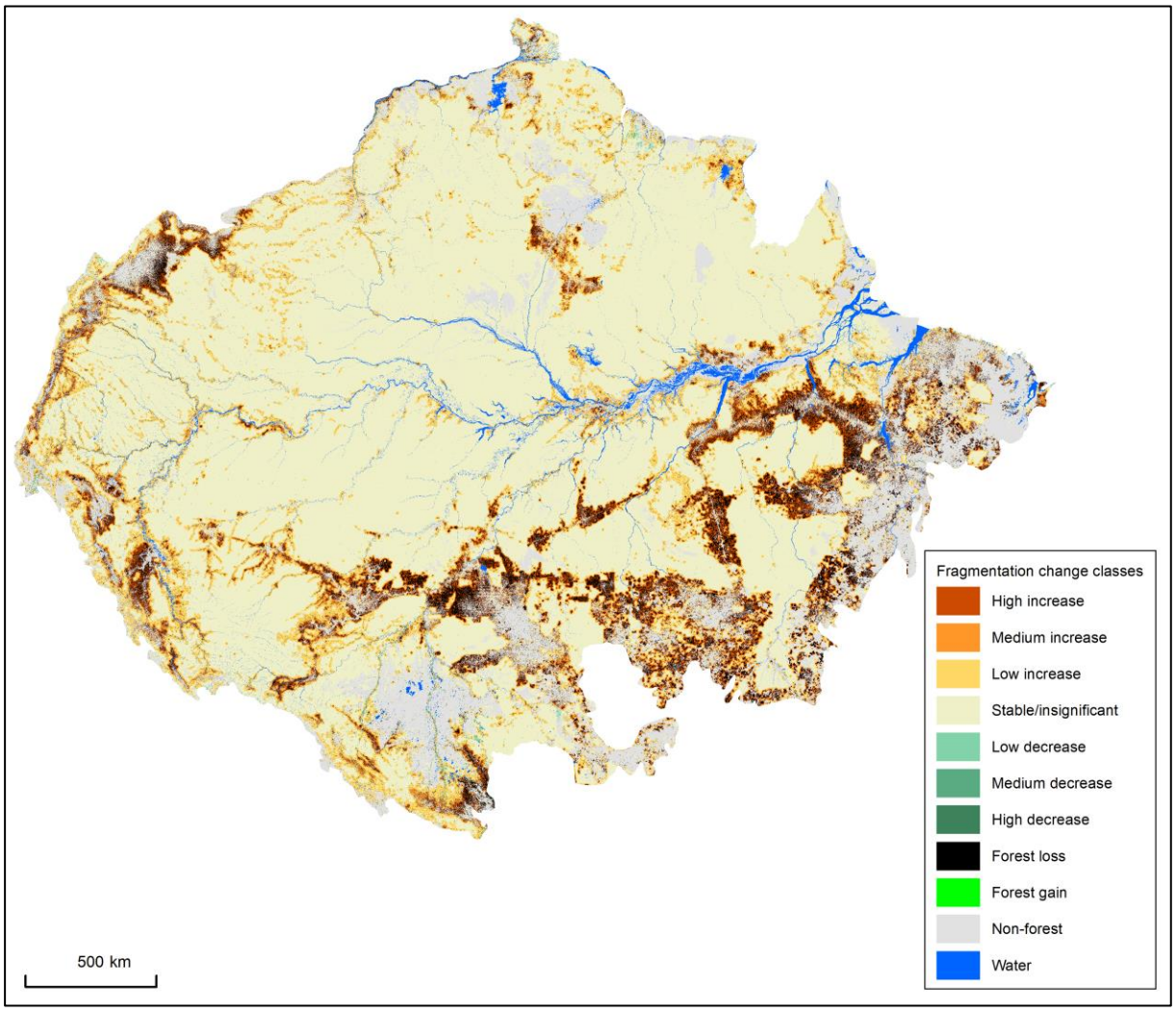
Figure 3. FAD status map of 2022.



Source: JRC, 2025

Changes in forest fragmentation for the period 2001-2022 are shown in Figure 4. Virtually all changes denote fragmentation increase (orange to dark red), which very often is found in the vicinity of forest loss areas (black). The map also delineates areas with no change in forest fragmentation (beige) and very few areas with a fragmentation decrease (green), which may result from forest regrowth or newly planted forest.

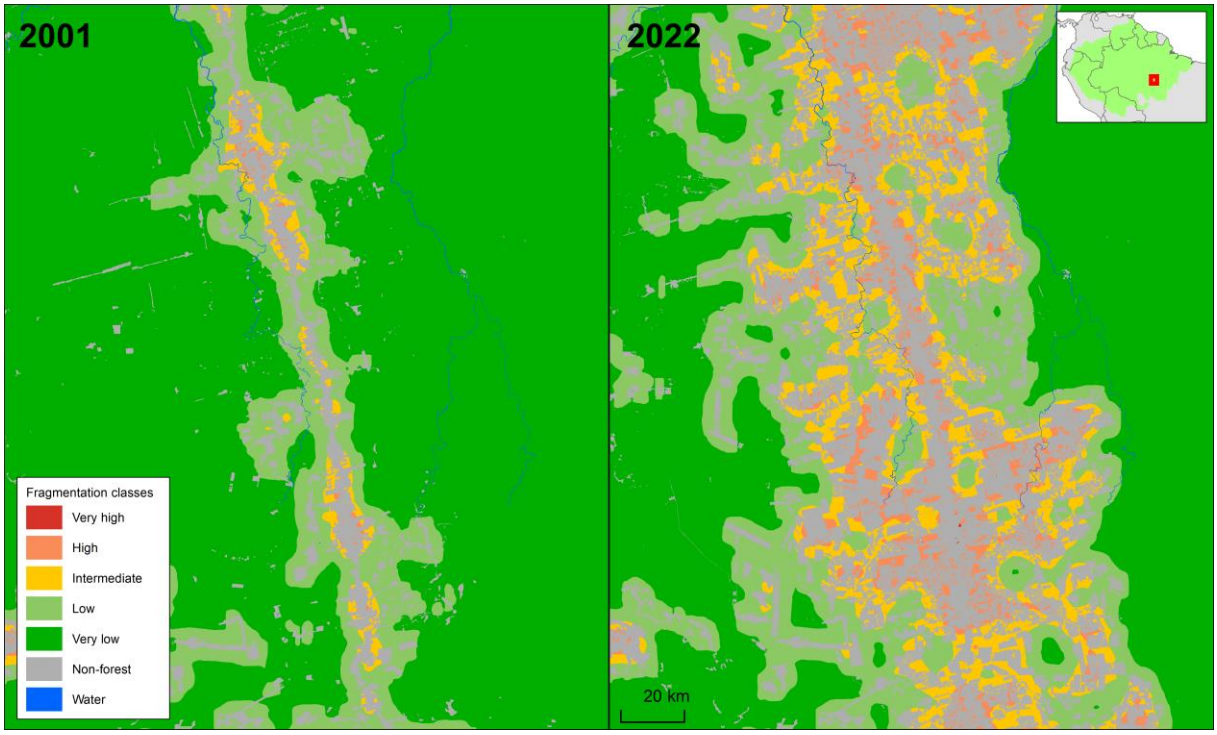
Figure 4. FAD change map from 2001-2022.



Source: JRC, 2025

The previous two maps show the overall situation, but more informative details become apparent when zooming in to regional and local level. Figure 5 shows a comparative extract of the FAD status maps for 2001 and 2022 in South Altamira Municipality (Pará, Brazil). The degree of forest fragmentation within a local neighbourhood of 100 km^2 is colour-coded in five classes, ranging from *very high* (red) to *very low* (dark green). Non-forest pixels are shown in grey and water pixels in blue colour. The temporal evolution shows increasing deforestation on both sides of the highway 163 resulting in increased fragmentation for the remaining forest cover in 2022.

Figure 5. Extract of FAD status maps in 2001 and 2022 along the highway 163 in South Altamira Municipality (Pará, Brazil).



Source: JRC, 2025.

An extract of the statistical summary for the entire Amazon reporting unit and the years 2001 to 2022 is shown in Table 2. Over the entire Amazon area all fragmentation classes, besides the class *very low*, show a continuous increase in forest area becoming more fragmented. Forest cover in the least fragmented class (*very low*) is the only one showing a continuous decline.

Table 2. Fragmentation classes and forest cover proportion.

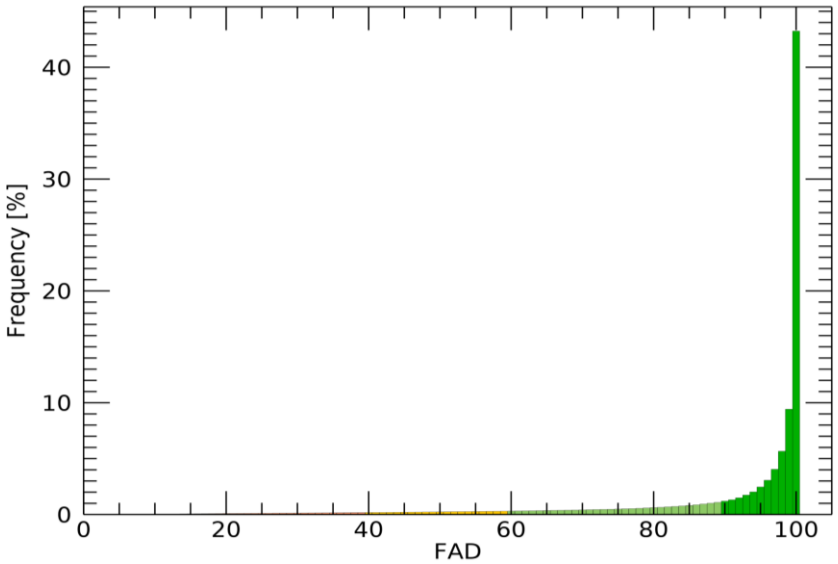
Fragmentation class	FAD [%]	Forest cover proportion [%]			Change 2001-2022 [%]
		2001	2014	2022	
Very high	0-10	0.10	0.15	0.16	+0.06
High	10-40	1.91	2.65	3.09	+1.18
Intermediate	40-60	3.57	4.24	4.62	+1.05
Low	60-90	15.08	15.99	16.46	+1.38
Very Low	90-100	79.35	76.97	75.67	-3.68

Source: JRC, 2025.

Since the FAD fragmentation status maps show the degree of fragmentation within the local neighbourhood of each forest pixels, an alternative summary description is to show the histogram distribution across all forest pixels (Figure 6). Compared to the typically used average patch size, this histogram provides a more detailed view on the distribution of the degree of fragmentation

across all forest pixels. In line with Table 2 most forest pixels are in the fragmentation class *very low* with FAD values within the range [90, 100] %.

Figure 6. Histogram of FAD occurrence frequency in the year 2022.



Source: JRC, 2025.

Additional details from the statistical summary files from 2001 to 2022 are presented in Table 3. In the analysed time frame the overall forest cover proportion is decreasing resulting in a loss of 4.77% of Amazon forest, equivalent to a total area of 33,045,443 ha. This loss is accompanied by a significant increase in the number of forest patches and a corresponding decrease in the average patch size. Collectively, these metrics indicate that the Amazon forest exhibits a continuous increase in forest fragmentation.

Table 3. Fragmentation status and trend statistics.

Index	2001	2014	2022	Absolute Difference 2001-2022	Relative Difference 2001-2022
Forest cover	572,042,383 ha	549,627,971 ha	538,996,940 ha	-33,045,443 ha	-5.78 %
Forest cover	82.59 %	79.36 %	77.82 %	-4.77 %	-5.78 %
Number of forest patches	1,034,763	1,384,467	1,862,997	+828,234	80.04 %
Average forest patch size	552.82 ha	397.00 ha	289.32 ha	-263.50 ha	-47.66 %
FAD_AV	92.35 %	91.15 %	90.48 %	-1.87 %	-2.02 %
AVCON	76.28 %	72.33 %	70.41 %	-5.87 %	-7.70 %

Source: JRC, 2025.

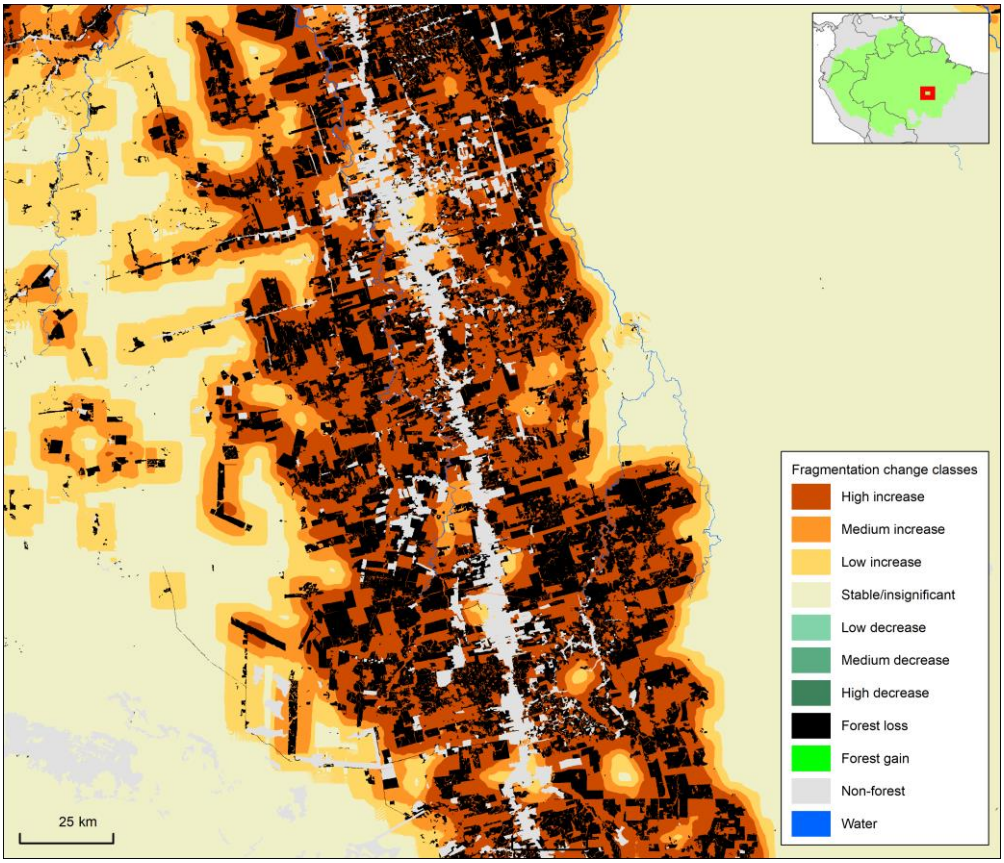
Furthermore, this fragmentation increase is corroborated by the observed decline in the two summary indices, FAD_AV, the average FAD value across all forest pixels, and AVCON, the average FAD value across all pixels in the reporting unit.

FAD_AV is based on the total forest cover area and, as such, its value is influenced by changes in forest area. AVCON is derived by building the average FAD value across all pixels in the reporting unit, where non-forest pixels are assigned a FAD value of zero. Because the reference area for AVCON is the reporting unit area, which is consistent over time, AVCON is more meaningful for temporal trend assessments. In addition, and in contrast to FAD_AV, AVCON accounts for the forest loss, making it a more realistic descriptor for forest fragmentation.

While each statistic measure is focused on a specific fragmentation feature, they all convey the same key message of increasing forest fragmentation from 2001 to 2022.

Tabular statistics of fragmentation and its change provide a succinct summary for reporting. However, tabular statistics exclude geospatial information and as a result they cannot provide any information on spatial features such as mapping hotspots of change. Progress monitoring and spatial planning require a spatially explicit fragmentation change map. The example in Figure 7 shows change in fragmentation derived by building the difference of the two FAD status maps shown in Figure 5. This figure highlights areas of forest loss and locations with varying degree in forest fragmentation increase, spreading out of the highway 163 resulting from human activities from 2001 to 2022.

Figure 7. Change in fragmentation between 2001and 2022 along the highway 163 in South Altamira Municipality (Pará, Brazil).

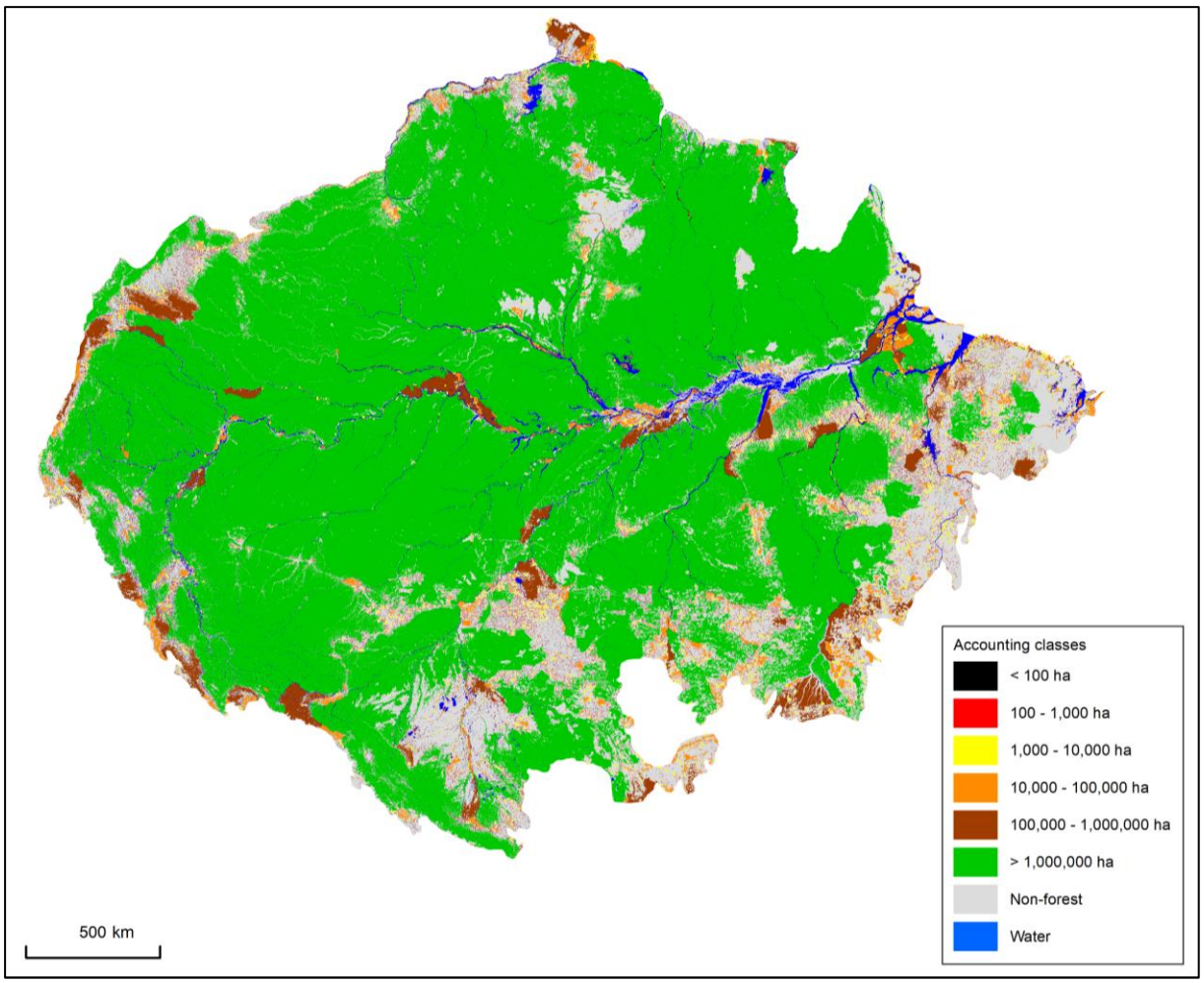


Source: JRC, 2025.

3.2. Status and change of Accounting

The Accounting status map (Figure 8) indicates that approximately 90% of the forest area in 2022 is found in forest patches that are larger than 1 million ha (green colour).

Figure 8. Accounting status map of 2022.



Source: JRC, 2025.

The statistical summary of the forest patch size class distribution (Table 4) shows a continuous increase in forest cover proportion of all but the largest Accounting class. The latter is the only one which decreases over the time from 2001 to 2022. The dissection from larger to smaller-sized patches, a typical aspect of fragmentation, is particularly evident for the total number of forest patches (see Table 3), that increased from 1,034,763 to 1,862,997, or by 80.04% over the assessment period. Accounting status maps for the years 2014 and 2001 have a similar visual appearance as Figure 8 when displayed at the full Amazon map area extent.

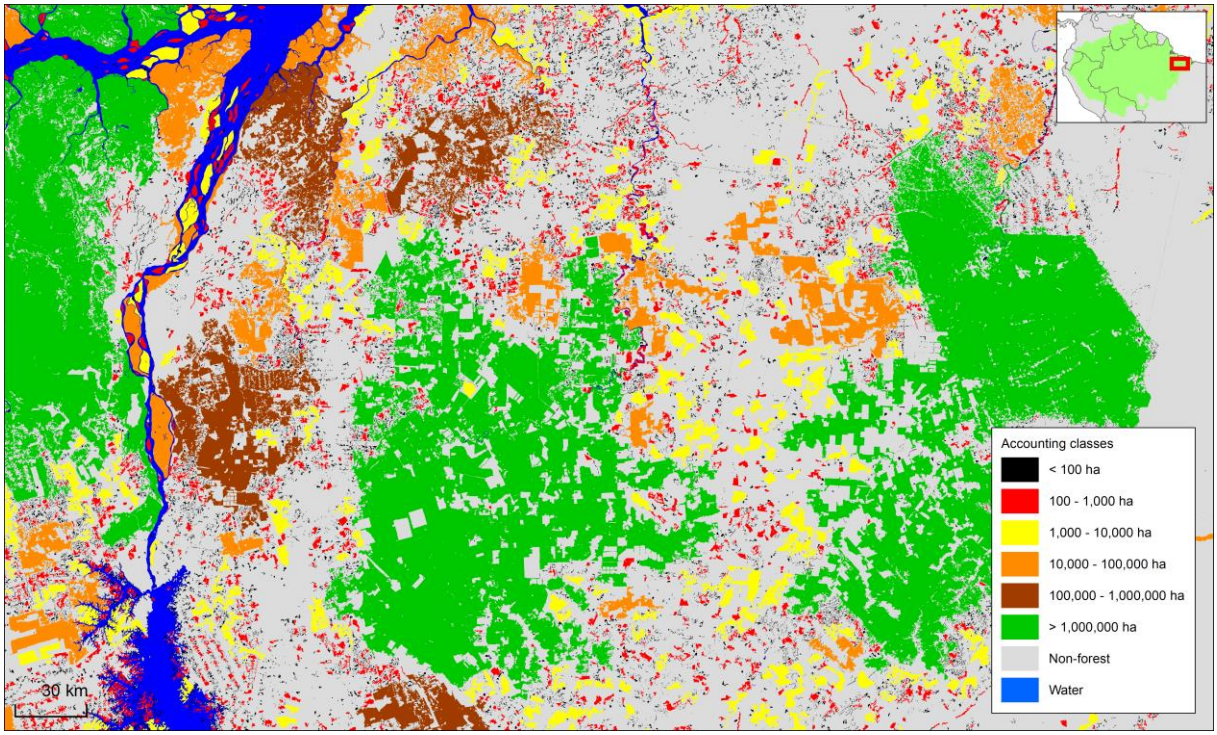
Table 4. Accounting classes, forest area proportion, and change from 2001 to 2022.

Accounting class [ha]	Forest cover proportion [%]			Change 2001-2022 [%]
	2001	2014	2022	
< 100	0.56	0.83	1.04	+0.48
100 – 1,000	0.81	1.08	1.21	+0.40
1,000 – 10,000	1.26	1.60	1.76	+0.50
10,000 – 100,000	1.75	2.17	2.29	+0.54
100,000 – 1,000,000	2.35	2.89	3.57	+1.22
> 1,000,000	93.26	91.43	90.13	-3.13

Source: JRC, 2025.

More spatial details, especially on the smaller Accounting classes, are evident when zooming in on the status maps at regional or local scale as exemplified in Figure 9.

Figure 9. Extract of the Accounting map for the year 2022 in the western area of Pará State (Brazil).



Source: JRC, 2025.

Note that spatially explicit maps of Accounting change are not meaningful because Accounting only measures the area of patches but not their change in spatial location.

3.3. Annual deforestation patch statistics

The statistical summary of annual deforestation patches from 2001 to 2022 across the Amazon region is shown in Table 5.

Table 5. Annual deforestation patch statistics from 2001 to 2022.

Year	Number of patches	Mean [ha]	Sdev [ha]	Median [ha]	Total area [ha]
2002	1,059,550	3.94	42.63	0.09	4,174,054
2003	1,026,022	3.02	59.47	0.09	3,096,263
2004	1,255,643	4.12	39.41	0.09	5,166,504
2005	1,541,447	1.98	23.52	0.09	3,057,330
2006	1,147,651	2.31	19.12	0.09	2,651,337
2007	1,066,959	1.45	20.02	0.09	1,548,382
2008	1,359,700	2.29	20.19	0.18	3,118,977
2009	1,110,050	0.87	7.85	0.09	960,964
2010	1,503,022	1.31	10.28	0.09	1,971,367
2011	1,236,184	0.79	7.37	0.09	982,070
2012	1,432,213	1.12	11.16	0.09	1,597,933
2013	1,279,235	1.16	12.87	0.09	1,488,482
2014	1,704,474	1.03	11.19	0.09	1,751,685
2015	1,368,408	1.22	11.67	0.09	1,663,378
2016	1,430,132	1.20	11.52	0.09	1,719,980
2017	1,534,060	1.04	10.56	0.09	1,589,844
2018	1,580,628	1.11	13.29	0.09	1,760,669
2019	1,568,104	1.26	13.52	0.09	1,982,773
2020	1,847,568	1.18	16.17	0.09	2,171,288
2021	1,603,970	1.34	14.67	0.09	2,154,572
2022	1,691,625	1.41	19.63	0.09	2,377,478

Source: JRC, 2025.

In the 21-year time span, the number of annual deforestation patches is always more than 1 million and shows an increasing number for the past 10 years. The total area of deforestation shows high amounts of deforestation up to 2008, followed by a decline and then an increase in deforested area from 2011 onwards (Figure 10).

Figure 10. Trend in total deforested area from 2002 to 2022.

Source: JRC, 2025.

The years 2009 and 2011 are the only years where the deforested area is less than 1 million hectares. The same years also show the lowest average deforestation patch size (< 1 ha) and the lowest standard deviation (< 10 ha). The highest value of deforested area is found for the year 2004 with more than 5 million hectares. The median, or most often encountered deforestation path size is 1 pixel, equivalent to 0.09 ha, which suggests that most deforestation activity addresses clearing of forest remnants. The total deforested area is approximately 47 million hectares, which is more than the 33 million hectares reported in Table 3. A part of this difference is due to forest regrowth and new plantation forest setup from 2001 to 2022.

4. Conclusions

This report provides an assessment of forest fragmentation in the Amazon region from 2001 to 2022. The approach is based on measuring the Forest Area Density (FAD) and the Accounting indices. FAD quantifies the connectivity, while the Accounting methodology provides a concise summary of the location and size-class distribution of forest patches in a forest map. The combination of these two metrics allows for a detailed analysis of the fragmentation process and its trends over time.

The results of this assessment show a continuous increase in forest fragmentation. From 2001 to 2022, the Amazon forest experienced a loss of more than 33 million hectares, equivalent to 4.77% of the total forest cover, resulting in a significant decline in the average forest patch size and an 80.04% increase in the number of forest patches. This change is well-reported by the AVCON index, which measures the average FAD value in the reporting unit and has decreased by 7.70% over 21 years. These findings are confirmed by the Accounting analysis, which show a decrease of 3.13% in the proportion of forest cover for forest patches larger than 1 million hectares from 2001 to 2022. Additionally, the FAD status and change maps provide a detailed visualization of the fragmentation process, highlighting areas where deforestation is occurring and its effects on adjacent forest patches. The analysis of annual deforestation patches shows a decrease in total deforested area from 2009 to 2014 but despite this decreasing rate in deforestation the overall fragmentation rates did not decrease in time, because deforestation became more disperse. From 2011 onwards, the number of deforested patches, as well as the deforestation area show a continued increase.

When interpreting the results, it is essential to consider the settings and potential limitations of the methods and indices used. The FAD metric is specific to the choice of local neighbourhood, which is set at 100 km^2 in this study. Furthermore, the analysis is limited to the reporting unit and does not account for adjacent forest coverage outside of the Amazon boundary, which influences both metrics, particularly the Accounting methodology. This implies that forest patches in the vicinity of the reporting boundary may extend beyond the reporting unit boundary but can only be partially considered in the Accounting classes. Another limitation of the assessment is related to the computation of the forest map for 2001. This forest map was computed by using the forest map of 2014 and adding the forest losses that occurred between 2001 and 2014. However, this approach does not consider any potential forest gains that may have occurred during the same period, which should be removed. This can lead to an overestimation of the forest area in 2001 and, consequently, an underestimation of the fragmentation increase between 2001 and 2022.

Despite these limitations, the FAD and Accounting methods are widely accepted and have been used in various international and national organizations, including the Food and Agriculture Organization (FAO), such as in the FAO SOFO2020 report. The GuidosToolbox Workbench (GWB) software, which was used to conduct all processing, is available on the FAO's cloud computing platform SEPAL.

Overall, this report provides a contribution to the understanding of forest fragmentation in the Amazon region. The results of this report could be used to inform conservation and forest management planning and may provide evidence in the policy design and monitoring process.

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List of abbreviations and definitions

Abbreviations	Definitions
ACTO	Amazon Cooperation Treaty Organization
Amazonia+	Amazonia+ Global Gateway flagship programme
ATBD	Algorithm Theoretical Basis Document
AVCON	Average connectivity within the reporting unit
BDAP	JRC Big Data Analytics Platform
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAD	Forest Area Density
FAD_AV	Average connectivity across all forest pixels
GIS	Geographic Information System
GTB	GuidosToolbox
GWB	GuidosToolbox Workbench
JRC	European Commission Joint Research Centre
NRR	Nature Restoration Regulation
SEPAL	System for Earth Observation Data Access, Processing and Analysis for Land Monitoring

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Annexes

Annex 1. File hierarchy and data format

This section describes the file hierarchy and output formats in the various sub-directories of the base directory **AMAZON2025**. Files are shown in *italics* and directories in **bold**.

— **4326:** fragmentation status maps and change map in projection EPSG:4326.

- *fmap<year>_acc.tif*: accounting status maps.
- *fmap<year>_fos-fad_5class_333.tif*: fragmentation status maps.
- *fragchange2001_2022.tif*: fragmentation change map.

— **54052:** fragmentation status maps and change map in equal area projection EPSG:54052.

— *deforPPY.csv:* annual deforestation patch statistics.

- **fmap<year>_EA_acc:** accounting status product.
  - *fmap<year>_EA_acc.csv*: summary of accounting classes.
  - *fmap<year>_EA_acc.tif*: accounting status map.
  - *fmap<year>_EA_acc.txt*: detailed accounting summary statistics.
- **fmap<year>_EA_fos-fad_5class_333:** fragmentation status product.
  - *fmap<year>_EA_fos-fad_5class.csv*: summary of FAD classes.
  - *fmap<year>_EA_fos-fad_5class.txt*: detailed FAD summary statistics.
  - *fmap<year>_EA_fos-fad_5class_333.png*: FAD histogram summary.
  - *fmap<year>_EA_fos-fad_5class_333.sav*: FAD indices for change analysis.
  - *fmap<year>_EA_fos-fad_5class_333.tif*: FAD status map.
- **fragchange_EA2001-2022:** fragmentation change product.
  - *fragchange_EA2001-2022.csv*: fragmentation class change matrix.
  - *fragchange_EA2001-2022.png*: ΔFAD histogram of forest change pixels.
  - *fragchange_EA2001-2022.tif*: ΔFAD fragmentation change map.
  - *fragchange_EA2001-2022_hist.csv*: detailed FAD change histogram table and FAD change summary statistics.

Note: the original forest – nonforest and annual deforestation maps are not included.

All map products are provided in GeoTIFF format and in the data type Byte. Details of the geo-header information can be retrieved with the 'gdalinfo' command or by any GIS application.

The output pixel assignment in the fragmentation status map, *fmap<year>_fos-fad_5class_333.tif* is as follows:

Value	Colour	RGB colour code	FAD description
[0, 9]		215/50/40	Forest pixels in fragmentation class: very High
[10, 39]		250/140/90	Forest pixels in fragmentation class: high
[40, 59]		255/200/0	Forest pixels in fragmentation class: intermediate
[60, 89]		140/200/100	Forest pixels in fragmentation class: low
[90, 100]		0/175/0	Forest pixels in fragmentation class: very low
101		175/175/175	Non-forest land
102		255/255/255	Missing or outside of reporting unit
105		0/100/255	Inland water

The output pixel assignment in the fragmentation change map, *fragchange*.tif* is as follows:

Value	ΔFAD	Colour	RGB colour code	ΔFAD description
[200, 121]	[-100, -21]		205/75/0	High increase in fragmentation
[120, 111]	[-20, -11]		255/150/40	Medium increase in fragmentation
[110, 102]	[-10, -2]		255/215/100	Low increase in fragmentation
[101, 99]	[-1, 1]		240/240/200	Stable/insignificant change
[98, 90]	[2, 10]		130/210/170	Low decrease in fragmentation
[89, 80]	[11, 20]		90/170/130	Medium decrease in fragmentation
[79, 0]	[21, 100]		60/130/90	High decrease in fragmentation
250	-		0/255/0	Forest gain
251	-		0/0/0	Forest loss
252	-		225/225/225	Nonforest at both times
253	-		0/100/255	Water at either time
254	-		255/255/255	Missing at either time
255	-		255/255/255	Outside of reporting unit at either time

The output pixel assignment in the accounting status map, *fmap<year>_acc.tif* is as follows:

Value	Class	RGB – Colour Code		ACC Description
0	Background	220/220/220		Nonforest land cover
103	Size class 1	0/0/0		Forest patches: 1 ≤ 100 ha
33	Size class 2	255/0/0		Forest patches: 101 ≤ 1,000 ha
65	Size class 3	255/255/0		Forest patches: 1,001 ≤ 10,000 ha
1	Size class 4	255/140/0		Forest patches: 10,001 ≤ 100,000 ha
9	Size class 5	160/60/0		Forest patches: 100,001 ≤ 1,000,000 ha
17	Size class 6	0/200/0		Forest patches: ≥ 1,000,001 ha
129	Missing	255/255/255		No data or outside reporting unit
105	Water	0/0/255		Inland waters

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