The potential of landscape metrics for assessing the impacts of selective logging in the Brazilian Amazon

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Abstract. This paper describes the application of spatial pattern analysis to assess the impacts of selective logging in the Brazilian Amazon based on forest/non-forest maps produced from a combination of object-based and pixel-based image classification approaches. Our test area is located in the central-northern part of Mato Grosso State, which has been heavily impacted by deforestation and selective logging activities. The research encompassed a stepwise approach for producing two different types of forest/non-forest maps (with and without selective logging) for the years 2000 and 2015. Then we applied different landscape analysis schemes from the free software GuidosToolbox and compared the impact on results when integrating information on logging areas. Our results indicate a reduction in the Core forest areas from 85% to 56% of the total area (edge width 300 m) from 2000 to 2015 due to deforestation. The results are considerably impacted when selective logging is added to the analysis, leading to an increased reduction in Core forest areas and increased fragmentation. As a complementary analysis, we tested the potential of Sentinel-2 images for improved mapping of logging areas. Sentinel-2 images allow for a better delineation of selective logging areas and thus are more suited to represent the impact and extent of logging activity.

Key words: forest fragmentation, selective logging, forest cover change, remote sensing, Brazilian Amazon.

1. Introduction

Forests in the Brazilian Amazon have been massively impacted by both deforestation and forest disturbances leading to degradation (e.g. selective logging) (Souza Jr. 2013, Asner et al. 2005), the latter still poorly assessed when compared to deforestation. The main processes in this region that cause forest degradation are selective logging, forest fires, and forest fragmentation, which occur in a synergistic and recurrent way, resulting in the loss of carbon stocks and biodiversity, changes in the forest structure, and in many cases in totally cleared areas (Souza Jr., 2013).

In this study, we focus on the relationship between selective logging and the changes in forest spatial patterns and fragmentation. Forest fragmentation involves both habitat loss and the breaking apart of the remaining forest areas (Fahrig, 2003), leading to an increase of forest edges and exposure of the forests to the deleterious consequences of edge effects (Laurance, 2000). Broadbent et al. (2008) presented selective logging as an important driver of forest fragmentation. Although the edges created by deforestation and selective logging are different - they refer to “hard” and “soft” edges to highlight the differences between the abrupt and subtler changes of deforestation and logging respectively – the authors point out that selective logging creates a fine-scale fragmentation. Moreover, these areas are subject to many edge-like effects such as increased susceptibility to wildfire and greater accessibility to forest interior, among others (Cochrane et al., 2002, Broadbent et al., 2008).

Historically the focus has been on mapping deforestation, while changes caused by selective logging for instance were mainly mapped as remaining forest, such as in PRODES project (INPE, 2008). This has changed and forest degradation has gained more attention; however, it remains poorly addressed (Pinheiro et al., 2016). Although still challenging and controversial, assessing these widespread subtler changes leading to forest degradation is critical to properly account for their environmental consequences (FAO, 2011). Thus, our main goal is to assess the potential of different landscape metrics to highlight the impacts of selective logging (combined with deforestation), as a driver of fragmentation and changes in the forest spatial pattern. Moreover, we assess the contribution of higher resolution images such as the Sentinel-2 images for improving the mapping of selective logging for the purpose of this work.

2. Methodological approach

2.1 Study area

The selected study area (Figure 1) is a subset of approximately 1530 km^2 of the Landsat scene path/row 226-068. It is located in the central-north of the Mato Grosso State, within the Brazilian Amazon biome (IBGE, 2004). This state has one of the highest annual deforestation rates in the Brazilian Amazon (INPE, 2008) and the study area is in a region with high occurrence of both legal and illegal logging activities (SEMA-MT, 2015).

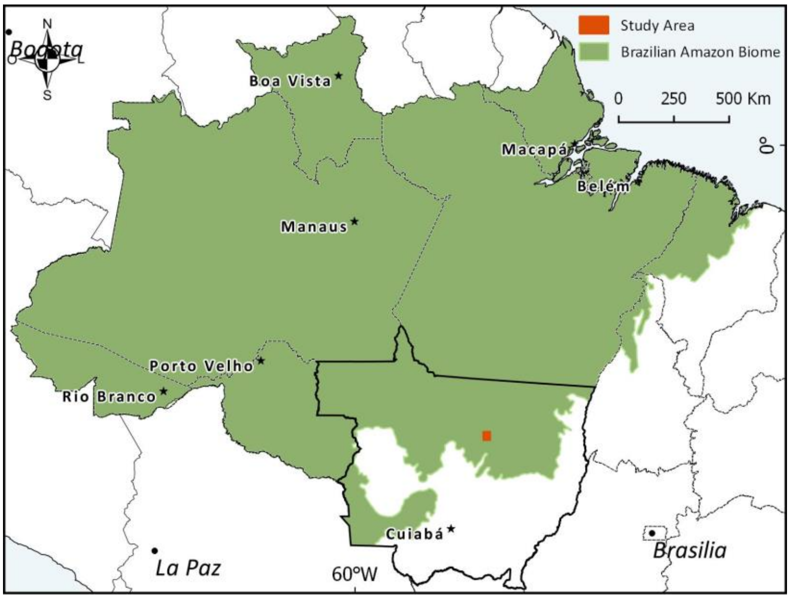

Figure 1. Location of the study area

2.2 Building the forest masks

Adapting the methodology used by Shimabukuro et al. (2014), we built forest masks, which allowed to assess forest changes within a 15-year time interval. Landsat images ETM+ and OLI for the years 2000 and 2015, respectively, were used. The images were converted to top of atmosphere (TOA) reflectance using the JRC IMPACT Toolbox (Simonetti et al., 2015) and then an object-based classification approach was applied using the eCognition®

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software to map forest and non-forest areas. In this first step, logging areas are kept within the forest patches as they correspond to very small clearings surrounded by forest.

Next, logging features (e.g. logging decks, logging roads) within the forest areas (mapped in previous step) were identified from soil fraction images, obtained through a Linear Spectral Mixture Analysis - LSMA (Shimabukuro and Smith, 1991), by the application of an empirically defined threshold (soil fraction >= 10%). This information was integrated with the previous forest/non-forest mask to produce a map with the following classes: ‘forest’, ‘non-forest’ and ‘logging’. Logging and non-forest were combined to generate the forest mask including logging. The baseline forest mask (year 2000) was evaluated through a comparison with PRODES results (INPE, 2008). In addition, we used a subset (11kmx4km) of a Sentinel-2 image (from 12-02-2016) and a Landsat 8 image from the closest possible date (03-04-2016) to compare the results in a nearby area and thus to evaluate the contribution of this higher resolution image to logging assessment. We applied the same soil fraction approach for extracting logging within the forest in this area.

2.2 Applying landscape metrics

We used the forest masks produced in previous steps (with and without logging features) as input to apply “landscape metrics" available in the free software GuidosToolbox (http://forest.jrc.ec.europa.eu/download/software/guidos). In order to capture the changes in the landscape, we tested the potential of the different analysis schemes. First, we used the Morphological Spatial Pattern Analysis - MSPA (Soille and Vogt, 2009), which consists in the segmentation of a binary forest/non-forest input mask and results in seven mutually exclusive morphometric forest feature classes (Core, Islet, Perforation, Edge, Loop, Bridge, and Branch). The Core class corresponds to interior forest areas beyond a stipulated distance to the forest border (Edge Width). The MSPA analysis was conducted with Edge Widths of 100m and 300m, which are common distances for edge effects in the study region (Broadbent et al., 2008). The proportion in each MSPA class ranges between 0% and 100%. We combined these classes as Core and Non-Core forest areas, which may be used as a proxy for forest areas vulnerable to degradation (Bucki et al., 2012). We also used the Fragmentation analysis, conducted via the concept of spatial entropy, which may serve as a descriptor for spatial fragmentation (Vogt, 2015). Finally, the Distance analysis, which calculates the Euclidean distance from the forest edge.

A summary of the main steps is presented in Figure 2.

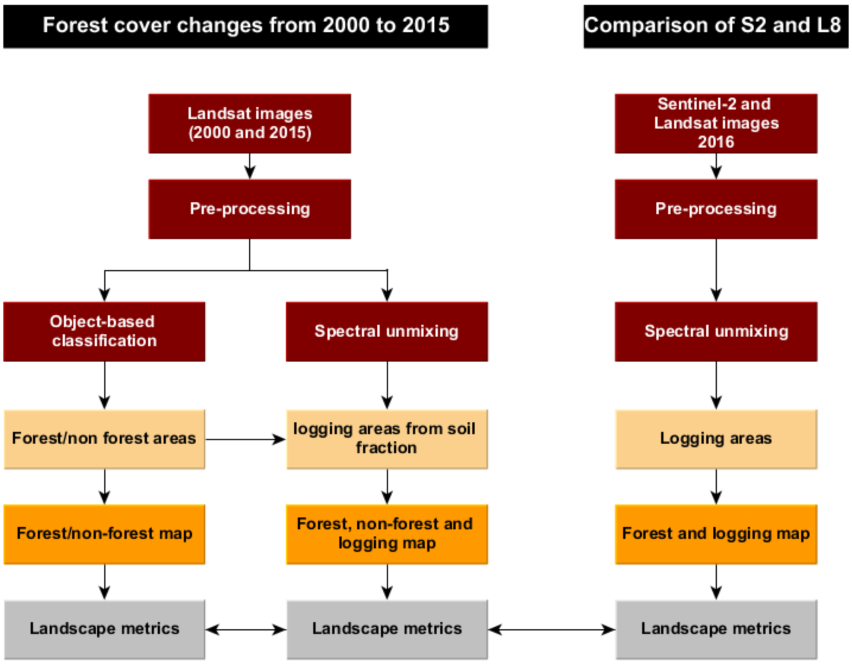

Figure 2. Flowchart of methodological steps used in this research

3. Results

Our results show that from 2000 to 2015 and for an Edge Width of 100m, the percentage of interior forest was reduced from 90% to 68% due to deforestation only. When considering an Edge Width of 300m, the percentage of interior forest decreased from 85% to 57%. Including selective logging in each year, the changes were more pronounced. Here, the interior forest areas were considerably reduced in both years (2000 and 2015), especially if a larger Edge Width is considered. They changed from 50% in 2000 to ~35% in 2015 (see Table 1 as well as the MSPA examples in Figure 3).

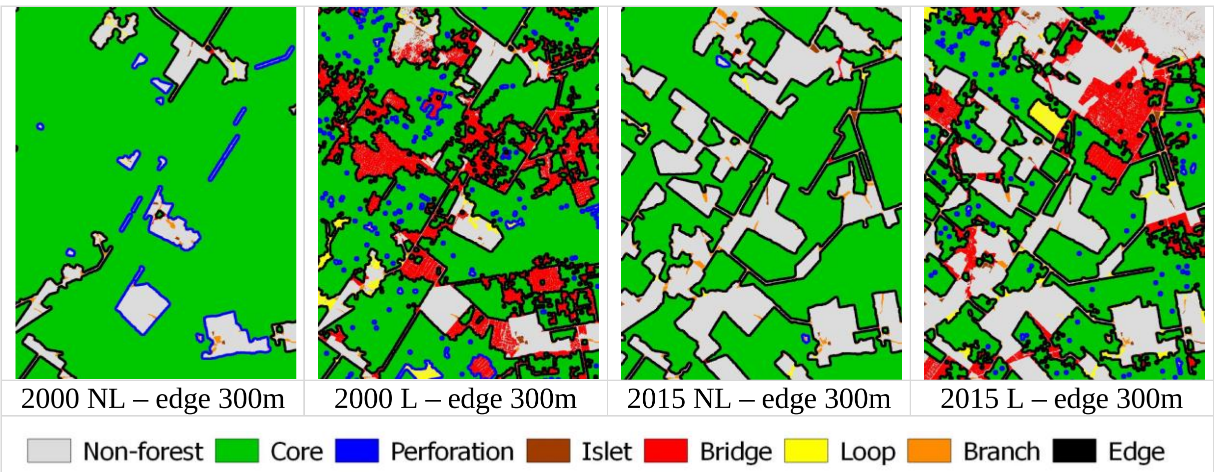

Figure 3. MSPA – pattern results for years 2000 and 2015, using forest masks with (L) and without (NL) logging.

Another way of looking at the forest cover changes is to build the ratio of Core by Non-Core forest areas (Figure 4). This ratio shows a dramatic reduction of Core areas in this period, especially if selective logging and an Edge Width of 300m are considered (in this scenario, Core areas are equivalent to the amount of Non-Core forest areas).

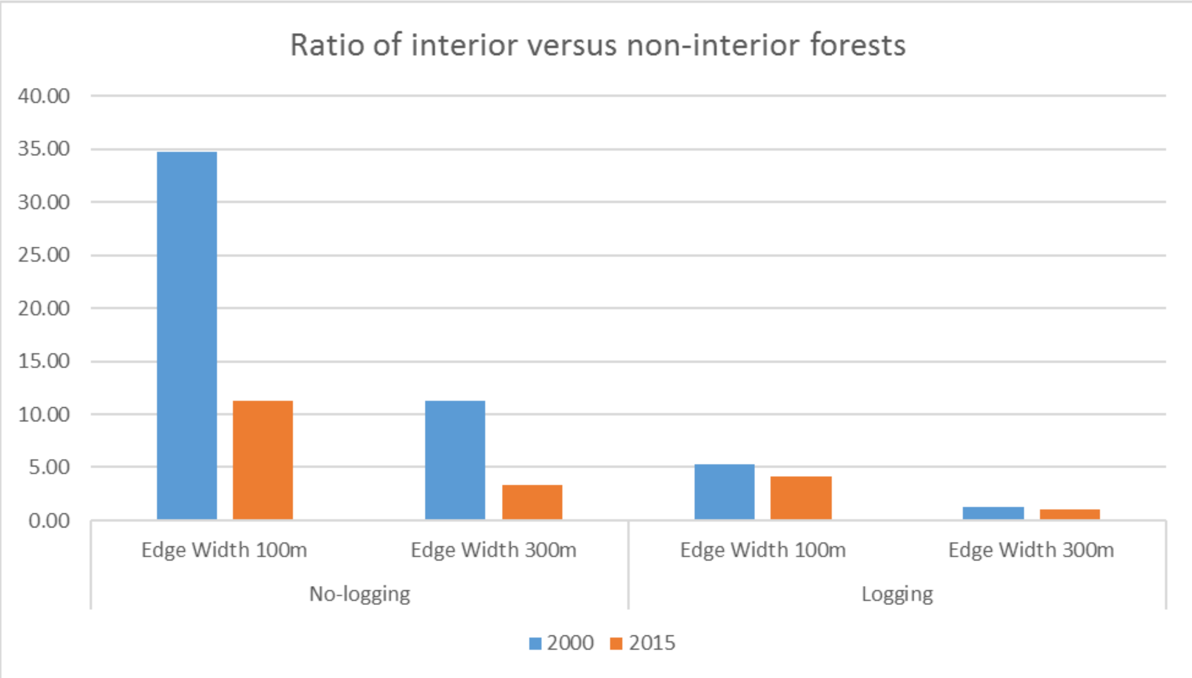

Figure 4. Ratio of interior (Core) forests versus non-interior forest areas for the different scenarios.

Table 1. MSPA classes considering the different scenarios (NL: forest mask without logging/ L: forest mask with logging):

year 2000	**NL (100m)**		**L (edge 100m)**		**NL (edge 300m)**		**L (edge 300m)**	
classes	% forest	% area	% forest	% area	% forest	% area	% forest	% area
interior forest	97.19	90.01	84.12	76.15	91.81	85.02	54.82	49.63
islets	0.02	0.01	0.09	0.08	0.05	0.05	0.19	0.17
edge forest	2.61	2.41	13.62	12.34	7.49	6.94	31.71	28.7
connectors	0.17	0.16	2.18	1.97	0.64	0.6	13.29	12.03
non-forest	-	7.39	-	9.47	-	7.39	-	9.47
year 2015	**NL (edge 100m)**		**L (edge 100m)**		**NL (edge 300m)**		**L (edge 300m)**	
classes	% forest	% area	% forest	% area	% forest	% area	% forest	% area
interior forest	91.83	67.82	80.49	56.57	76.94	56.83	49.69	34.93
islets	0	0	0.27	0.19	0.22	0.16	0.65	0.45
edge forest	7.66	5.65	16.19	11.38	20.82	15.38	34.22	24.06
connectors	0.5	0.37	3.05	2.14	2.02	1.49	15.43	10.85
non-forest	-	26.14	-	29.71	-	26.14	-	29.71

The overall fragmentation almost doubled due to deforestation from 2000 to 2015 (Figure 5). When selective logging is added to the analysis, fragmentation is even higher in both years, but not very different from 2000 to 2015. This can be explained by the fact that selective logging is many times a transitory change as it can recover and be mapped as forest again. The index helps to highlight spatial hotspots, presenting higher fragmentation values in areas more impacted by selective logging.

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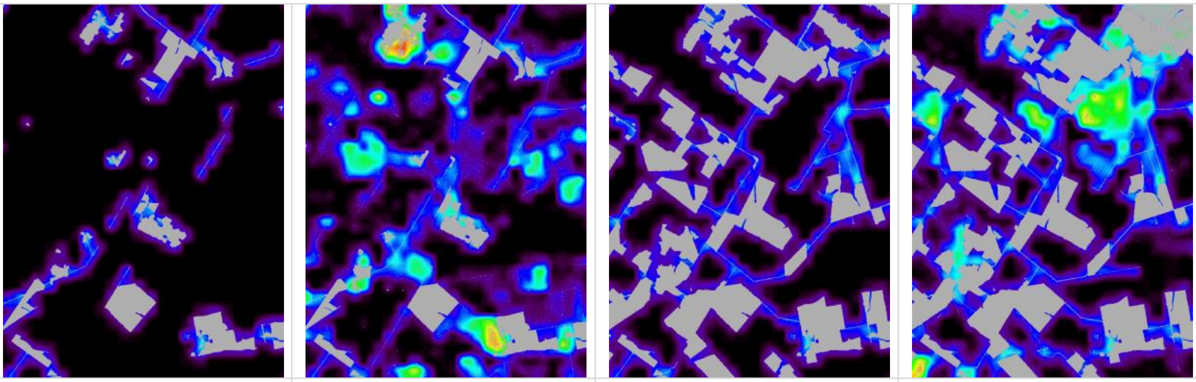
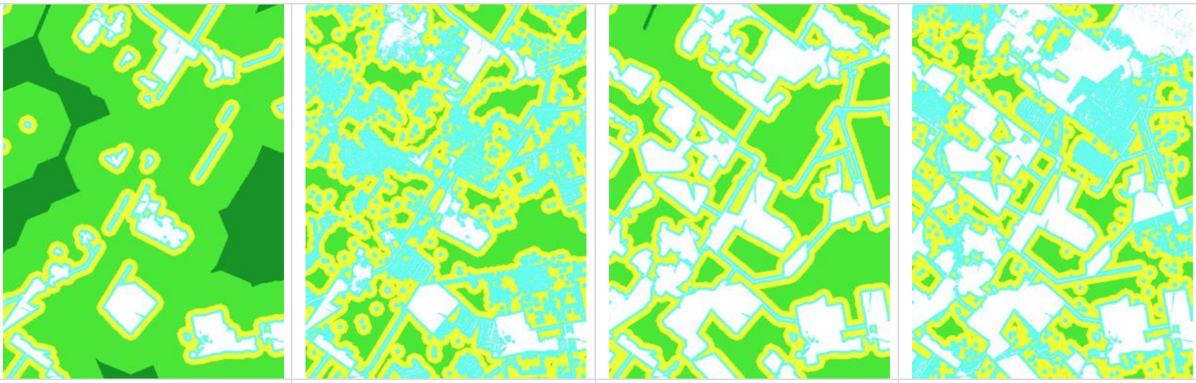


2000 NL	2000 L	2015 NL	2015 L
Overall frag 3.9 Range: [0,30]	Overall frag 12.0 Range: [0,69]	Overall frag 7.9 Range: [0,33]	Overall frag 13.6 Range: [0,65]

Figure 5: Spatial distribution of fragmentation for the years 2000 and 2015 using forest masks with and without logging

When assessing distances from forest edge (Figure 6) we observed that in 2000, as cleared areas were more isolated and reduced in area, the majority of the forests areas were farther than 1000m from forest edges (predominance of classes 1000-5000m and > 5000m) (Figure 6a). However, this changes after adding the disturbance pixels from selective logging. In this case, we no longer find forests that are farther than 5000m from the edge and the forest areas within 300m of the edges increase significantly (Figure 6b). In 2015, as non-forest areas became widespread and occupied a larger area, we no longer have forest areas farther than 5000m from the edge (Figure 6c). Moreover, when considering selective logging, the distances from edge up to 300m and from 300m to 1000m predominate, while from 1000m to 5000m are considerably reduced (Figure 6d).



(a) 2000 Distance NL | (b) 2000 Distance L | (c) 2015 Distance NL | (d) 2015 Distance L

0 - 300 m | 300 - 1000 | 1000-5000 | > 5000 m

Figure 6. Euclidian distance from forest edge - results for years 2000 and 2015 using forest masks with and without logging.

We also compared the results derived from Landsat-8 and Sentinel-2 images in a nearby area. From this analysis, we can see that the results obtained from Sentinel-2 allow for a better delineation of selective logging areas and thus a better representation of the extent of the impacts through the metrics (Figure 7).

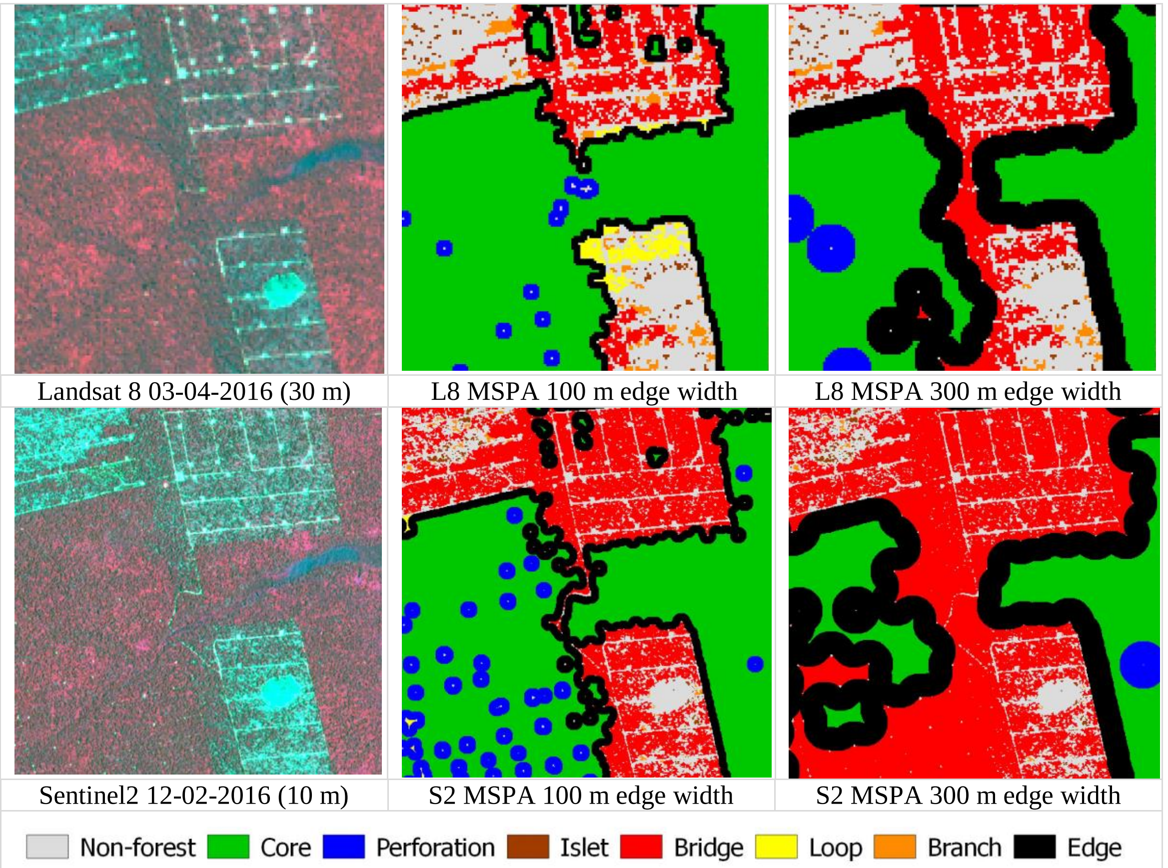


Figure 7: Comparison of Landsat 8 and the higher spatial image resolution of Sentinel-2 and its impact on MSPA pattern classes.

4. Conclusions

Our approach has shown the potential of three different landscape analysis schemes to monitor and assess the impact of selective logging on forested areas in the Amazon basin. Selective logging was found to produce considerable changes in the forest structure, resulting in increased forest fragmentation and reducing ecological highly valuable interior core forest areas. The proposed analysis schemes, available within a free software, may be easily used in a reproducible way to describe and measure landscape patterns (e.g. assessing areas under reduced-impact and conventional logging). The quantitative assessment of the described methodologies is a pre-requisite for a reliable and meaningful comparison of different areas as well as quantifying temporal changes over a given site and as such provides an essential toolset for monitoring and assessing the extent of logging activities.

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