PFB
Pesquisa Florestal Brasileira
Brazilian Journal of Forestry Research
http://pfb.cnpf.embrapa.br/pfb/
e-ISSN: 1983-2605
Review Articles

Brazilian National Forest Inventory – a landscape scale approach to monitoring and assessing forested landscapes

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Index terms:
Spatial pattern
Forestry policy
Indices

Termos para indexação:
Padrão espacial
Política florestal
Índices

Received in 06/09/2017
Accepted in 24/04/2018
Published in 29/06/2018

doi: 10.4336/2018.pfb.38e201701493

Abstract - The strategic importance of forest resources, both at the national and global level, as well as the scarcity of reliable qualitative and quantitative information about Brazilian forests are among the motivations that led to the implementation of a new national forest inventory in Brazil (IFN-BR). Beyond traditional field survey through clustered sampling, the IFN-BR incorporates Landscape Sample Units (LSU) as a geospatial component of the inventory. Landscape indicators and indices are generated through the analysis of land use/land cover in the LSUs, which provide information about composition, morphology, mosaic patterns, adjacent habitat similarity, connectivity, fragmentation, and state of riparian zones. In the current study, we describe the indicators selected to assess landscape using pilot LSUs established in Paraná State, as well as the calculation and composition of indices and scores.

Inventário Florestal Nacional do Brasil - uma abordagem em escala de paisagem para monitorar e avaliar paisagens florestais

Resumo - A importância estratégica dos recursos florestais, tanto em escala nacional quanto global, assim como a falta de informações qualitativas e quantitativas confiáveis acerca das florestas brasileiras, está entre as motivações que levaram à realização de um novo Inventário Florestal Nacional do Brasil (IFN-BR). Além do tradicional levantamento de campo por meio de amostragem por conglomerados, o IFN-BR incorporou um componente geoespacial, as unidades amostrais de paisagem. A partir da análise do uso e cobertura da terra nessas unidades amostrais, são gerados indicadores e índices de paisagem, capazes de apresentar informações a respeito da sua composição, morfologia, padrão de mosaico, similaridade de habitats adjacentes, conectividade, fragmentação e situação das zonas ripárias. No presente trabalho são descritos os indicadores selecionados para avaliar a paisagem de amostras piloto no estado do Paraná, bem como sua forma de cálculo e composição de índices e scores.

Introduction

Brazil is a country that is predominantly forested, with approximately 57% of its territory covered in forests, occupying an area of 8.5 million km² (Serviço Florestal Brasileiro, 2013; FAO, 2015). Forests, in general, are one of the world's most valuable natural resources (Backes, 2009): they are centers of biodiversity, consisting of thousands of plant and animal species and microorganisms; they are important regulators of climate and drainage and effective protectors of the soil; and they are essential resources for humans, providing wood, cellulose, resins, tannins, and essential oils, among other non-wood forest products.

The strategic importance of forest resources, both on a national and global scale, as well as the lack of reliable qualitative and quantitative information about Brazilian forests, are among the motivations that led the Environmental Ministry (MMA) to propose a new national forest inventory (Freitas et al., 2010, 2016). The first and only national inventory was completed in the 1980s and was based on the standards of the era, which focused on wood production (Holmgren & Persson, 2002). Thus, the goal of the inventory was to provide information solely about the wood stock available from native and planted forests (Machado, 1984, Brena, 1996). Today, the National Forest Inventory of Brazil (IFN-BR), coordinated by the Brazilian Forest Service (SFB), aims to produce detailed information about forest resources across the country. As such, the IFN-BR provides information about forest stocks from native and planted forests, their composition, health and vitality, as well as patterns of change over time, comparing estimates from previous inventory cycles (Freitas et al., 2010). This information will support the development of public policies directed at the use, conservation, and restoration of forest resources (Freitas et al., 2010; Serviço Florestal Brasileiro, 2013).

Considering the size of a country such as Brazil, and its vast range of habitats, biodiversity and anthropogenic and economic environments, the most appropriate approach is to produce information about Brazilian forests based on a national system with a standardized and systematized methodology that considers the basic national and international requirements (Freitas et al., 2016). The methodology adopted by IFN-BR was developed through a participatory process enabling adaptations for the specificities of Brazilian biomes, ensuring the collection of biophysical, socioenvironmental, and landscape information. One of its components is, therefore, geospatial, referred to as Landscape Component (Serviço Florestal Brasileiro, 2013).

The Landscape Component involves the analysis of land use/land cover at a landscape scale and was included in the IFN-BR in response to increasing demand for reliable information about forest resources that considers biophysical and socioenvironmental factors, and information collected in the field. By enabling an evaluation of the dynamics of land use/land cover and the interactions between spatial patterns and ecological processes, including natural and anthropogenic processes, analyses at the landscape scale meet the general objectives of the National Environmental Policy in Brazil, which focus on preservation, improvement, and recuperation of the environment. As such, the planning and implementation of activities related to these objectives depend on the availability of diagnostic instruments and analyses that enable the mapping and evaluation of ecosystems and their respective services, both of which are spatially explicit. Hence, there is a need for the IFN-BR to consider spatial data and indicators in the analysis, with the ability to translate the results from technical-scientific approaches into accessible information that can be used to implement public policy and decision making.

In this context, the IFN-BR incorporates the use of Landscape Sample Units (LSUs): permanent plots distributed systematically throughout the entire Brazilian territory, that can enable both statistical analysis at a certain point time, as well as dynamic approaches, when time series data allows for the evaluation of landscape characteristics over time. As such, LSUs act as diagnostic and monitoring units to assess changes in land use/land cover. These analyses, based on land use/land cover mapping, enable an integrated diagnosis of each LSU, reflecting the biogeoclimatic (territorial or ecoregion class) characteristics and associated anthropogenic or natural influences occurring in that specific location.

Therefore, the objective of the landscape component of the IFN-BR is to analyze samples of the Brazilian territory through quantitative and qualitative indicators and produce information about the importance and quality of forest resources in relation to other land uses, highlighting their functions, quality and the pressures they are experiencing.

The objective of this paper is to describe the indicators selected to evaluate the landscape using pilot LSUs established in Paraná State, as well as to present the calculation and composition of indices and scores. Additionally, the results are showed in map-like visualisations and analyzed in the context of different landscape patterns observed across the state.

Landscape Sample Units

Field data collection for the IFN-BR is based on systematic sampling, with the distribution of clusters (Field Sample Units - FSUs) in a 648-second grid spacing, which from the Equator corresponds to a grid of approximately 20 x 20 km between sample points (Freitas et al., 2010; Achard et al., 2017). Using the same structure, Landscape Sample Units (LSUs) are allocated with distances among them of 40 x 40 km, occupying an area of 10 x 10 km. The geometric center of the LSU corresponds to the location of a FSU (Figure 1), which is used in the mapping of land use/land cover and landscape spatial analysis (Freitas et al., 2006; Luz et al., 2015; Achard et al., 2017).

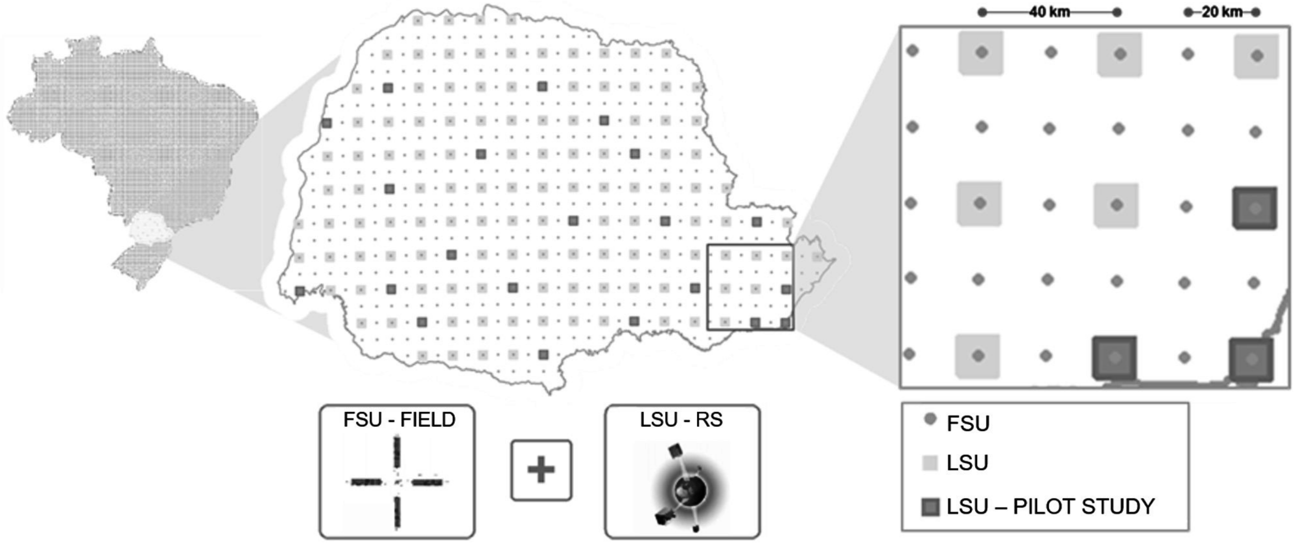

Figure 1. NFI-BR Field Sample Units (FSU) and Landscape Sample Units (LSU).

The development of this methodology for the analysis of LSUs is based on a pilot project implemented in Paraná State, which considered that the chosen areas should represent all phytogeographic variation that exists in the state (Luz et al., 2015).

Land use/land cover mapping

The basis from which we can calculate landscape indices is the land use/land cover map (LULC). Orthorectified images obtained by RapidEye (RE) Earth observation satellites were made available by the Environment Ministry to conduct this study. The images provided a foundation on which to develop the land use/land cover map using object-oriented image classification and analysis processes.

RapidEye images were segmented using a process tree developed by the Joint Research Centre of the European Commission (JRC), which guarantees the minimum mapping unit (MMU) of image objects. Using the software eCognition, a series of vegetation indices were calculated for objects generated during segmentation from the RE images to evaluate the software's potential to discriminate different land use and cover classes.

The thematic classes adopted in the present methodology can be divided into natural and anthropogenic areas, water bodies and non-observed areas. The latter includes areas with cloud cover or cloud shadow and they are designated as such when it is impossible to infer the land use class or substitute with another image. Natural areas include forests and grasslands, divided into the following classes: "natural forest"; "other wooded land"; "other land with tree cover" and "grasses and herbaceous plants". Natural areas without vegetation cover, including fluvial plains, rock outcrops or dunes are classified as "sand dunes and rock outcrop". The areas of anthropogenic activity were classified as follows: "agriculture and pasture"; "urban areas"; "planted forests" and "bare soil". Rivers, lakes, lagoons, reservoirs and the ocean were included in the class "surface water".

The classes were defined according to diverse criteria, beginning with the scale that could be adopted considering the spatial resolution of the images used to support the mapping and, in turn, the features that could be identified. The definition of classes also considered the objectives of the inventory, which prioritizes the collection of information on forest resources without discounting other types of land use/land cover, since the spatial-temporal interaction of landscape elements also constitutes a fundamental objective within the proposed methodology. Figure 2 shows a 5 x 5 km clip within a LSU classified for land use/land cover.

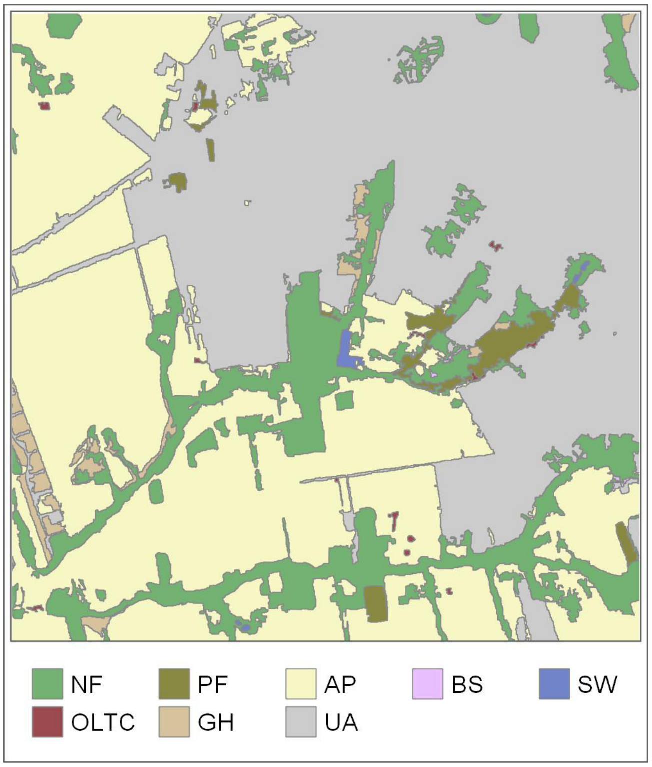

Figure 2. Detail of the classification of land use/land cover for a 25 km² area within a Landscape Sample Unit: NF: natural forest; GH: grass and herbaceous plants; OLTC: Other land with tree cover; PF: planted forest; AP: agriculture and pasture; UA: urban areas; BS: bare soil; SW: surface water.

Landscape analysis

The management of forest patterns and fragmentation requires information at the landscape scale rather than at the stand or management unit scale (Haynes, 2002). The landscape analysis of the IFN-BR is based on landscape ecology concepts. Landscape ecology emphasizes the interactions between spatial patterns and ecological processes, that is, the causes and consequences of spatial heterogeneity in a range of scales (Turner et al., 2001). One of the central issues in landscape ecology is the relationship between landscape pattern and scale (Levin, 1992). Scale affects landscape patterns and in consequence landscape metrics (Benson & Mackenzie, 1995; Saura, 2004; Wu, 2004; García-Gigorro & Saura, 2005). Fragmentation indices, for example, present large differences in the values when derived from different spatial resolution images, given the different levels of detail (Saura, 2004). The large selection of sensors available allows for the characterization of land cover at multiple spatial scales. A multi-scale assessment is highly recommended in landscape patterns monitoring and characterization, since both pattern and process in ecological systems often operate on multiple scales (Wu, 2004). In order to compare indices obtained in different scales, one alternative is data up or downscaling. Upscaling refers to aggregating fine-scale information to a coarser scale, while downscaling means generating patterns at a resolution below the one of the data without auxiliary information (Jenerette & Wu, 1997). These techniques are not encouraged and should be used carefully, since discrepant results were obtained using these techniques when compared to real data (Saura, 2004; Wu, 2004; García-Gigorro & Saura, 2005).

The use and combination of more than one group of indicators and indices is highly recommended to obtain more detailed information for landscape conservation (Lindenmayer et al., 2008), since the mapping of land use/land cover alone, and the quantification of the respective landscape covers, do not provide information about the pattern of the forest landscape, or its fragmentation and connectivity. In fact, no single measure analyzed in isolation can completely capture the complexity of the spatial arrangement of forest fragments in a landscape (Estreguil et al., 2014). As such, the combination of indices provides a tool for strategic landscape planning and the possibility to quantify progress in the implementation of specific policies focused on territorial management and the use and conservation of forests.

Estreguil et al. (2014) note that the indices must be organized within components of landscape patterns that are ecologically significant and easily understood. As such, the selected landscape indicators for the analysis of LSUs consider their composition (percentage of surface occupied by the land use/land cover class), morphology (categorization of forested areas based on location, i.e., in the interior, edge, or linear portions of the fragment), mosaic (identification of the predominant land use classes in the neighboring region of the forest fragment), similarity with adjacent habitats (percentage of fragment edge interface with other land use/cover classes), connectivity (intra- and inter-connectivity), fragmentation (degree of forest fragmentation) and riparian zones (information related to the presence of forest in, and anthropogenic pressure on, riparian areas). The indices can be provided individually for each LSU or summarized by strata by considering different ecoregions or political-administrative units, for example.

Landscape composition

The landscape composition indices are taken directly from the land use/land cover map (Figure 2).They are expressed in percentage values ranging from 0 to 100% and represent: i) the sum of the proportions of forest or shrub cover (natural forest; other wooded land; other land with tree cover); and ii) the sum of other natural (grass and herbaceous plants) or semi-natural areas (planted forest) for each LSU. The importance of these indices lies in the assessment of the availability of habitats in each landscape.

Morphological spatial pattern analysis

The morphological spatial pattern analysis (MPSA), developed by Soille & Vogt (2009) and applied using the open software Graphical User Interface for the Description of Image Objects and their Shapes GuidosToolbox (Vogt, 2016), consists of a sequence of mathematical morphological operators focused on the description of the geometry (size and shape) and connectivity (fragmentation classes) of components in an input image.

The MPSA analysis uses four previously defined parameters: a) foreground connectivity (8 pixels), b) edge width (30 pixels), c) transition (On) and d) intext (On).

The approach is based on the segmentation of objects in the foreground of a binary image. Foreground objects are divided into seven generic MSPA classes (Soille & Vogt, 2009; Wickham et al., 2010), grouped into four morphological pattern indices, that are dimensionless and expressed as a percentage ranging from 0 to 100%: i) *Core*, corresponds to the internal pixels located at a distance greater than the specified edge width parameter – areas belonging to natural classes with tree or shrub cover, located at a distance of at least 30 m from the edge of other non-natural classes (background); ii) *Islets*, are very small, isolated groups of foreground pixels that are not contained in the core area – areas of natural vegetation that are potentially vulnerable to disappearance due to their shape and size (generally small and/or elongated, thin, and isolated). Depending on the landscape context in which they are found, islets can serve as stepping stones for pollination and species dispersion between central fragment areas; iii) *Edge* incorporates perforation and edge classes, which are formed by pixels representing transition zones between core areas and the background in internal areas of the foreground (internal perimeter of a foreground object) and between core and background areas (external perimeter of a foreground object), respectively – areas more vulnerable to invasive species penetration and likely include edge effects that in turn can affect interior habitats; iv) *Connectors and branches* is formed by the grouping of the classes loop (pixels that connect a core area to itself), bridge (pixels that connect two or more disconnected core areas), and branch (extensions of pixels in a core area that do not connect with other areas). These represent structural connections between the internal parts of a fragment which can act as corridors for biodiversity. A clip of a pilot LSU with the respective MPSA classes used as input for other analyses is shown in Figure 3.

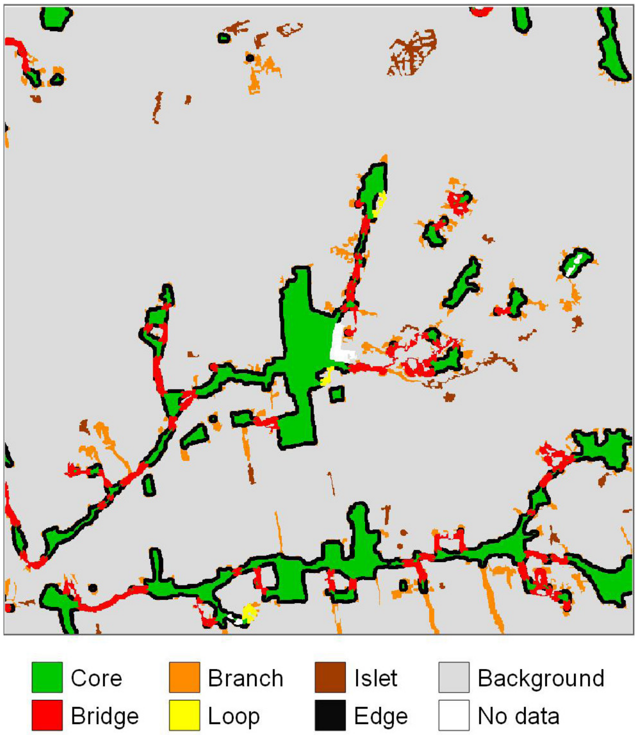

Figure 3. Detail of morphological spatial pattern analysis segmentation for a 25 km² area within a Landscape Sample Unit.

Landscape mosaic

The landscape mosaic (LM) model is derived from the indicator landscape pattern type (LPT), developed by Wickham & Norton (1994), that was adapted for landscape pattern assessment in large areas using land use/land cover maps based on remote sensing (Riitters et al., 2000, 2009a, 2009b; Yemshanov et al., 2015) and implemented in the GuidosToolbox by Vogt (2016). This model is defined by a tripolar classification (Figure 4), where for each input map pixel a class is attributed according to the composition of the types of land use/ land cover of a predefined neighboring area, creating a landscape mosaic map (Riitters et al., 2009b).

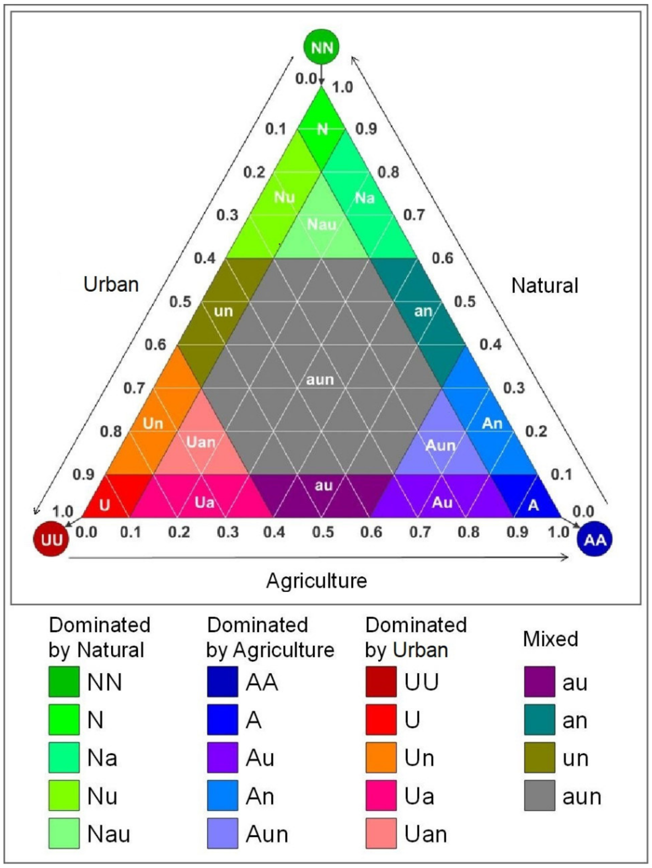

Figure 4. Tripolar classification triangle of the landscape mosaic, generating 19 classes from the proportion of natural, agricultural and urban (artificial) land use/land cover types (Amended from Vogt, 2016).

The software parameter to be defined in this case refers to the dimension of the moving window used to analyze the image, that is superimposed on each input image pixel and the selected metric is calculated for the area occupied within the window. The result is thus reassigned for the central pixel in the superimposed window in the output image (Vogt, 2016). In the present methodology, we established a window with dimensions of 13 columns by 13 lines, which corresponds to an area of approximately 0.42 ha.

The focus of the IFN-BR is on forest or shrub cover (natural forest; other wooded land and other land with tree cover). Therefore, a thematic stratification was used in which the LM map was intersected with the original LULC map, to extract the LM pixel values correspondent to the focal classes only, as implemented by Riitters et al. (2009a) in USA. The indices originating from this analysis are calculated as the sum of percentages of landscape mosaic class occupation, grouped into three categories, as proposed by Estreguil & Mouton (2009), and expressed as dimensionless percentage values ranging from 0 to 100%: i) *Natural forest landscape pattern*, represents forests with a minimum of 80% natural/semi-natural cover (and less than 10% anthropogenic or agriculture and pasture areas) in the surrounding area. For forest habitats and species living within this type of landscape, no edge effect related to agricultural or anthropogenic land use is considered, since the interface zones of the forest with other land use types are natural; ii) *Mixed forest landscape pattern,* represents forests with 60 to 89% natural/semi-natural forest cover, and more than 10% anthropogenic or agricultural land use in the surrounding region. Forest habitats and the species living within this mixed landscape pattern (mixed interface zones) are potentially suffering edge effects due to the presence of agricultural or anthropogenic areas; iii) *Some natural forest landscape* represents forests with less than 60% natural area and the remaining made up of agricultural and/or anthropogenic land use in the surrounding area. In this case, they are considered forest habitats inserted into predominantly non-forest landscapes and are very likely experiencing dominant edge effects from agricultural and/or anthropogenic land use. In Figure 5, a LSU clip shows landscape mosaic classes.

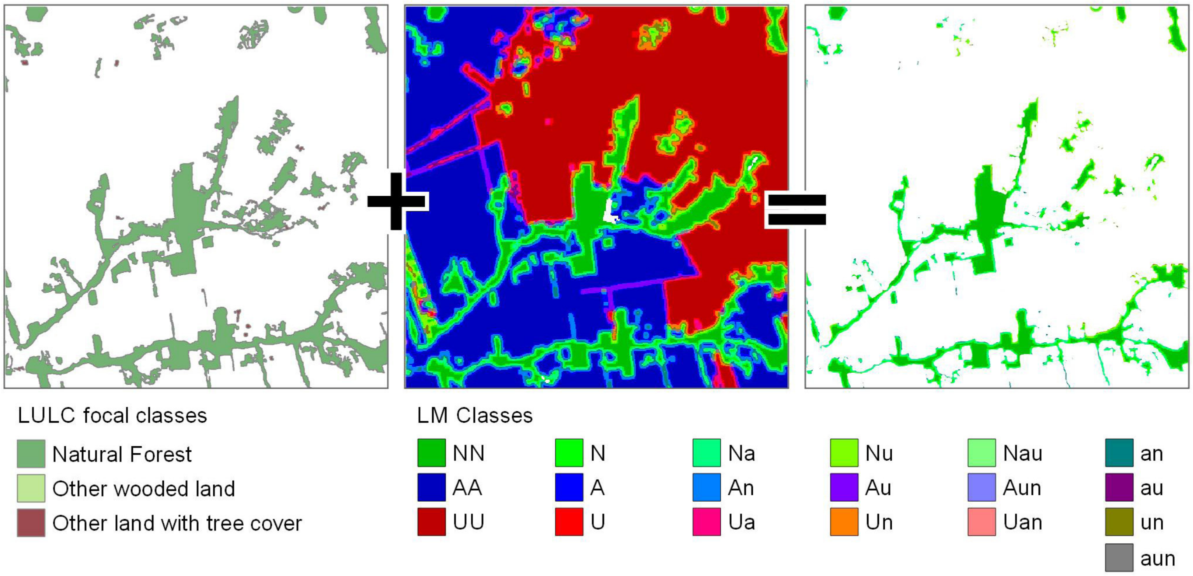

Figura 5. Illustration showing the process to obtain the landscape mosaic (LM) indices by integrating focal classes from the original land use/land cover (LULC) map with the LM map, and the final intersected result for a 25 km² area within a Landscape Sample Unit.

Edge interface model

The edge interface model adopted in this study, developed by Estreguil et al. (2014), integrates the LM with the MSPA (Figure 6). In this approach, the edge interfaces are differentiated by their morphology (interior edges, connector and branch as linear features and islets) and characterized according to the similarity between adjacent habitats, as focal habitat edges along natural/semi-natural lands as natural edge interface, and edges along more anthropogenic (i.e., agricultural and/or artificial) lands as artificial edge interfaces (Estreguil et al., 2014).

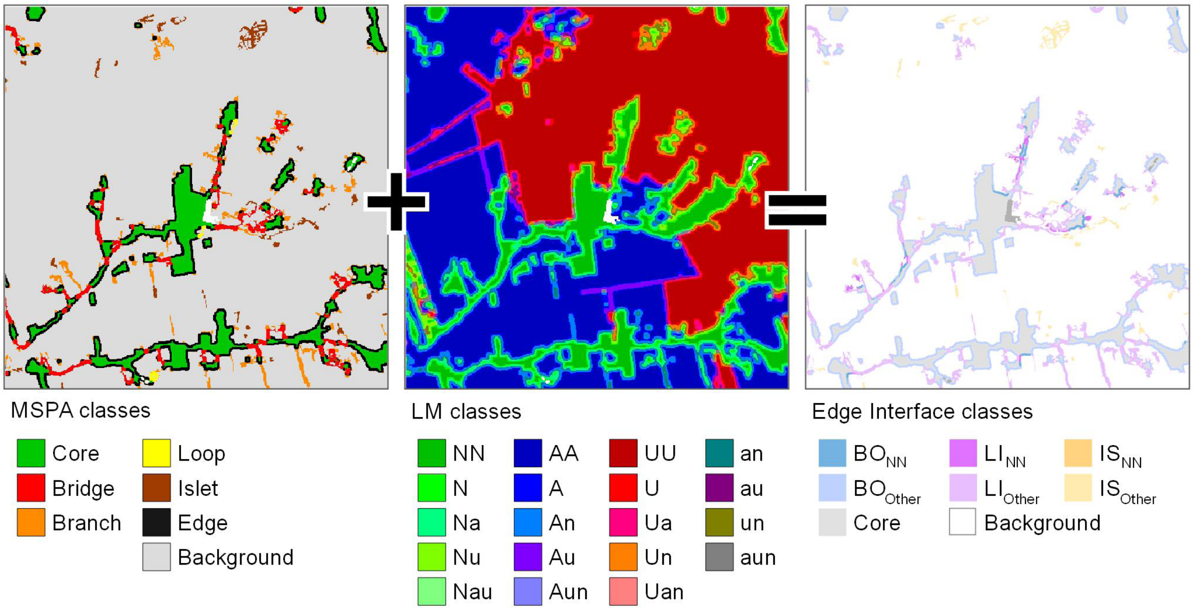

Figure 6. Illustration showing the process to obtain the edge interface model by integrating the morphological spatial pattern analysis (MSPA) with landscape mosaic (LM), and the final result for a 25 km² area within a Landscape Sample Unit. Edge interface classes proportion: BO_{nn} - with natural interface; BO_{other} - with artificial interface; LI_{nn} - linear connectors and branches with natural interface; LI_{other} - linear connectors and branches with artificial interface; IS_{nn} - vegetation islands with natural interface; and IS_{other} - vegetation islands with artificial interface.

The importance of this analysis resides in the fact that fragmentation is influenced by changes in LULC in areas adjacent to forest remnants. Therefore, this indicator assesses the susceptibility of fragment edges to anthropogenic pressure imposed by other types of land use. The permeability of interface zones for species dispersion depends on the similarity of adjacent habitat types and is likely greater in the case of natural edge interfaces. As such, indices of the proportion of edges, connectors and branches, and islets of vegetation with greater natural interfaces represent more favourable conditions.

From this analysis, we have six dimensionless indicators expressed as a percentage ranging (proportion) from 0 to 100%: i) edges with natural interface; ii) edges with artificial interface; iii) connectors and branches with natural interface; iv) connectors and branches with artificial interface; v) vegetation islands with natural interface; and vi) vegetation islands with artificial interface. The spatialization of edge interface classes can be observed for a pilot LSU in Figure 6.

Connectivity

The MSPA analysis can be converted into a network for subsequent analysis in the Conefor application (Saura, 2006), which is based on graph theory. A network is composed of nodes (core class in MPSA segmentation) and connections (bridge class in MPSA), while the other MPSA classes are disregarded (Figure 7). A set of connected nodes and their connections are called components. In GuidosToolbox, after MPSA segmentation, the following network analyses can be undertaken: network components, node/link importance, network component connectors, and MSPA Conefor inputs.

From these analyses, five indicators are generated: i) *total dPC value*, represents the sum of the importance of all nodes and connections that exist in the landscape (expressed as a percent); ii) *habitat dPC value*, corresponds to the sum of the importance of all interior habitat areas (nodes) present in the landscape (expressed as a percent); iii) *connector dPC value*, provides the sum of importance of all existing connections in the landscape (expressed as a percent); iv) *probability of connectivity index* (*PC*), indicates the probability that two points, placed randomly within a landscape, would be located in areas that are accessible to each other (interconnected), given a set of *n* fragments and connectors (direct connections) between them (Saura, 2006); v) *Equivalent connected area* (*EC*(*PC*)), corresponds to a general connectivity index, similar to PC, which can be defined as the size of a single, maximally connected fragment (area of interior habitat) that would provide the same value of the PC index as the actual pattern of fragments in the landscape. The greater the PC and EC(PC) values, the greater the importance of the existing connections in the landscape.

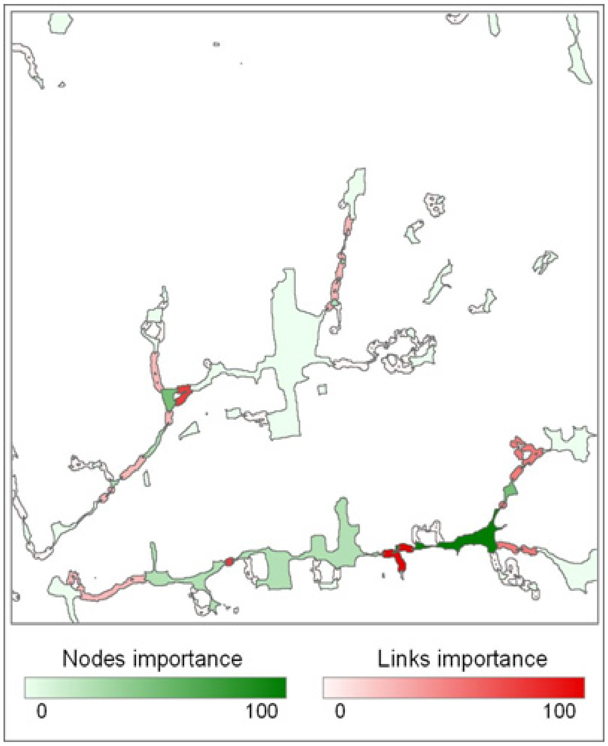

Figure 7. Results for the importance of landscape nodes and connectors for a 25 km² area within a Landscape Sample Unit.

Hypsometric fragmentation

Fragmentation can be seen as an aspect of spatial heterogeneity, or the spatial composition and arrangement of objects in the foreground of an image, considering the number of objects and the distance between them, thus addressing characteristics of the first and second planes at the same time. Due to its holistic nature, the description of fragmentation is highly complex. In the case of landscapes, fragmentation is normally defined based on a certain species (animal or vegetal) of interest and as such can be very specific. Furthermore, existing definitions of fragmentation are only descriptive and as such do not allow for quantification of the fragmentation degree or changes to fragmentation for a given image.

To quantify fragmentation, we included concepts in the methodology that differ from those used traditionally.

Along with quantifying the state of fragmentation in a determined area, this index allows for the comparison of the degree of fragmentation in different locations, quantification of changes to fragmentation, monitoring over time, as well as the assessment of the implementation of planning programs and policy guidelines.

Fragmentation, applied through the GuidosToolbox, provides three hypsometric fragmentation indices, with their values normalized to an interval of 0-100%: i) *Foreground fragmentation*; ii) *Background fragmentation*; iii) *Fragmentation*, defined by the weighted sum of *foreground* and *background fragmentation* (Figure 8).

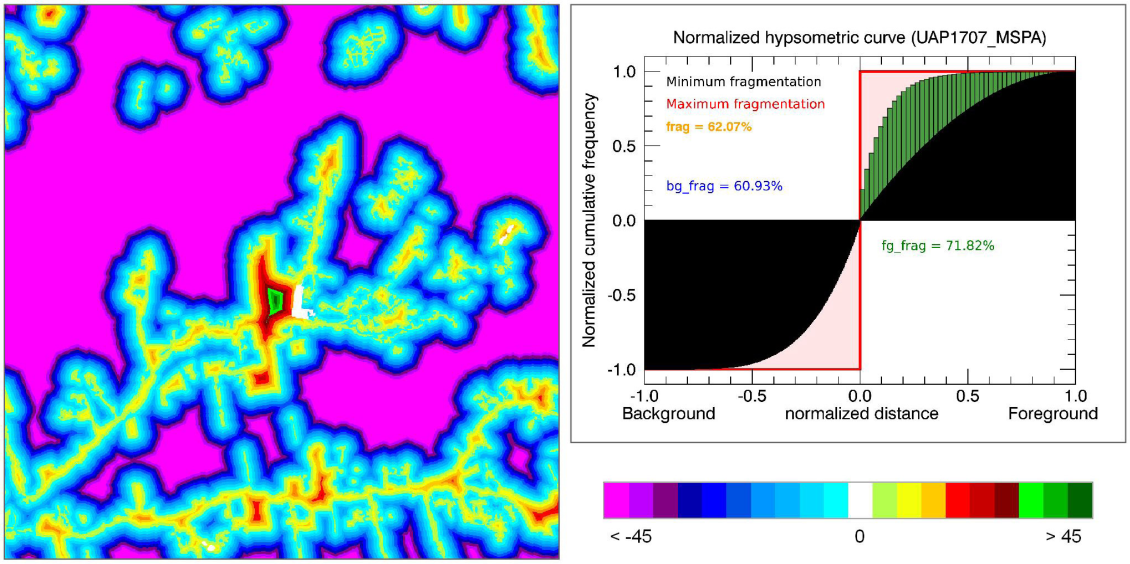

Figure 8. Image generated through the calculation of Euclidean distance for a 25 km^2 area within a Landscape Sample Unit, resulting in the hypsometric fragmentation index, as well as the normalized hypsometric curve for the minimum (black), maximum (red), and the current state of fragmentation for the foreground (green) and background (blue).

Riparian zones

In the context of landscape scale analyses included in the IFN-BR, the methodology adopted to evaluate riparian zones was based on the structural connectivity of these environments as vegetation corridors, the degree of anthropogenic pressure acting on them, and the simulation of scenarios for the protection of riparian zones. After transformation to scores, integrated indices were calculated to provide a ranking that enables the identification of priority areas for landscape conservation or restoration, as implemented in Europe by Clerici et al. (2011).

For the assessment of riparian areas in LSUs for the IFN-BR, the methodology developed by Clerici et al. (2011) was modified because a comprehensive map of riparian zones for Brazil was not available. As such, we established a fixed value to delimit riparian areas – as proposed by Ivits et al. (2009) – considering the maximum buffer required by law number 12.651 of Brazilian Forest Code (Brasil, 2012), which is 500 m along each bank for rivers wider than 600 m in unconsolidated areas.

The structural connectivity analysis is realized using a polygon grid with cells of 100 m x 100 m over the entire LSU area and a mask corresponding to the riparian zones (buffer width of 500 m along river banks). All subsequent analyses consider only the area within these masks and the indices are calculated for each 1 ha cell.

From this analysis, three indicators of riparian corridors and structural connectors in the landscape (Clerici & Vogt, 2013) are provided, standardized to a scale that ranges from 0 to 1: i) *Structural corridors* (SC_c) – represents the total proportion of the surface occupied by the presence of structural corridors in each 1 ha cell *c*. The quantity of riparian corridors represented by this index is directly proportional to the extent of riparian zones present in cell *c*. Therefore, large SC_c values occur in areas with conditions that permit the presence of riparian zones, i.e., areas with a large proportion of natural/semi-natural cover and a dense fluvial network;

ii) *Structural corridors under pressure* (CP_c) – integrates the SC_c with information about the proportion of non-natural cover (anthropogenic and agricultural areas) present in the cell. The value of this index is larger when a large proportion of the cell area is occupied by anthropogenic and agricultural land use. From a conservation and management perspective, cells with the highest values indicate the most critical situations for riparian zones; iii) *Structural corridors under pressure protection index* (UCP_c) – this index incorporates the proportion of structural corridors under anthropogenic pressure with information about the proportion of the area under some form of environmental protection. For LSUs, riparian protection zones correspond to limits established in the Brazilian Forest Code for the restoration of permanent protection areas (APPs) in consolidated areas, following the methodology presented by Jesus & Souza (2016). This index allows us to identify which areas contain corridors that do not have adequate levels of protection. If there are few protected areas, the total value of the index will increase. Large UCP_c values correspond to a large ranking attributed to the cell, indicating a significant presence of structural riparian corridors experiencing anthropogenic pressure, with little or no protection. Cells with large UCP_c scores represent potential priority areas for the conservation and management of riparian corridors, an example of which can be seen in Figure 9.

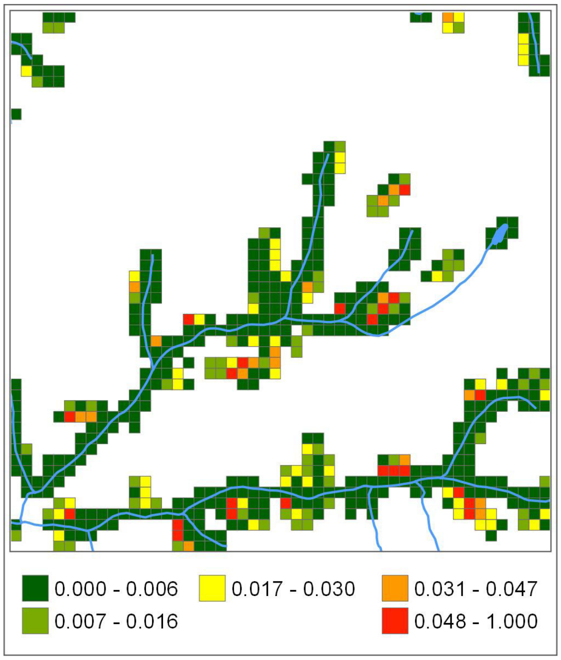

Figure 9. Distribution of the *Structural corridors under pressure protection index* (UCP_c) index considering the permanent protection areas along waterways for a 25 km² area within a Landscape Sample Unit.

Final diagnosis: quality of forest landscape

The spatial quality of LSUs is evaluated through indicators, represented by seven groups of indices (Figure 10). The linear combination of selected indices, with different weights, generates a unique score per LSU which enables comparisons among them and the development of restoration, maintenance, or improvement activities for certain aspects of the landscape. The most representative indices selected within each group are as follows:

Landscape composition: the sum of the proportion of forest and/or shrub cover (natural forest, other wooded land and other land with tree cover) and other natural (grass and herbaceous plants) or semi-natural areas (planted forest) for each LSU;

Morphological spatial pattern analysis: the proportion of core areas; areas belonging to natural classes with forest and/or shrub cover, located at least 30 m from the edges of other non-natural classes (background);

Landscape mosaic: proportion of natural forest landscape pattern; areas where at least 80% of forest/shrub habitats are surrounded by natural/semi-natural habitats and less than 10% are surrounded by anthropogenic or agricultural/pasture areas;

Edge interface model: proportion of edges with natural interface;

Connectivity: Probability of connectivity index (PC); probability that two points placed randomly within a landscape are inter-accessible;

Foregound fragmentation: normalized foreground fragmentation*;*

Riparian zones: Structural corridors under pressure and legal protection (UCP_c); proportion of structural corridors under anthropogenic pressure with some form of protection (APP).

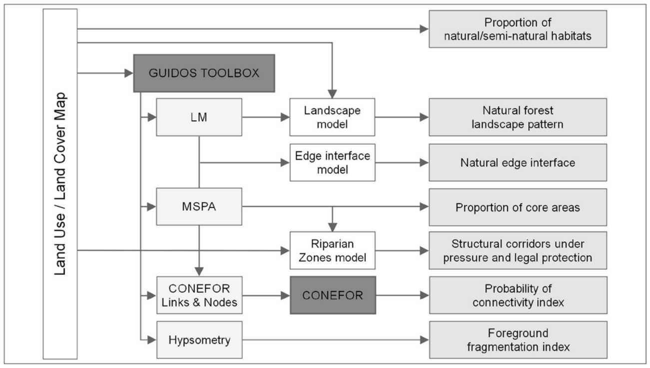

Figure 10. Flow of data and information for the proposed indices calculation.

Each index was submitted to a "minimum-maximum" standardization using Equation 1.

$$x_{pad} = \frac{x_i - x_{min}}{x_{max} - x_{min}} \qquad (1)$$

Where: $xpad$: new value, standardized for variable x; xi: original value of variable x; $xmin$ and $xmax$: minimum and maximum value of variable x, respectively, for the set of data.

For each LSU, the sum of the normalized value for the seven variables (indices) were calculated (Equation 2). The final score was calculated through the rescaling of these sums on a scale of 0 to 10.

$$S = (\alpha * 1.5) + b + c + (d * 1.5) + e + (1 - f) + (1 - g) \qquad (2)$$

Where: α: sum of the indices; : proportion of forest and/or shrub cover, other natural and semi-natural areas for the LSU; b: proportion of core areas; c: proportion of natural forest landscape pattern; d: proportion of edges with natural interface; e: probability of connectivity index; f: foreground fragmentation; g: structural corridors under pressure protection index .

Figure 11 shows the ranking of the pilot LSUs for Paraná State considering the calculated score from these seven indices. Large values represent LSUs where the landscape pattern reflects a more privileged situation in terms of forest conservation, notably in the eastern (Serra do Mar) and extreme west of the state (Iguaçu National Park). The northeast region – typically an agricultural area – shows smaller scores, indicating the need for habitat restoration activities. In the south central and northeast region – where the scores have intermediate values – we note the presence of Araucaria Forest remnants as well as large areas of planted forests that, although considered semi-natural, help to increase the indices.

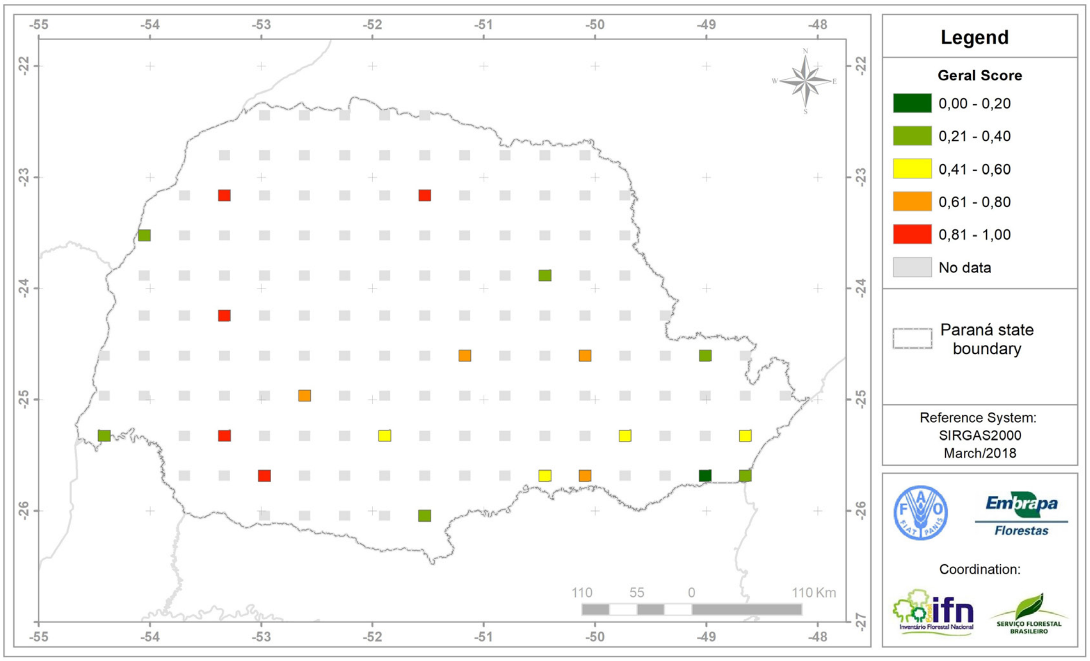

Figure 11. Ranking of pilot Landscape Sample Units of the IFN-BR in Paraná state considering the score calculated from seven indices of forested landscape quality.

Final considerations and future directions

This article presents a generic, concise and reproducible methodology to characterize habitat patterns that is based on a harmonized mathematical description, incorporating known indices and suggesting new ones as logical additions. It also promotes the application of a small, simple and integrated set of indices that are easily customizable depending on the focus and needs of the user (Estreguil et al., 2014). This methodology is based on the premise that there is a strong connection between the patterns, functions, and processes that occur within a landscape, which is particularly relevant for the development of public reports on habitat patterns, fragmentation and connectivity of forests in the Brazilian landscape.

In the context of the Brazilian National Forest Inventory (IFN-BR), the landscape can be considered a group of heterogeneous ecosystems occurring in different and interacting types of land use/land cover. As such, the methodology presented herein, developed specifically for the analysis of Landscape Sample Units (LSU) in the IFN-BR, brings innovative aspects to the analysis of spatial landscape patterns, mosaics of land use/land cover, as well as habitat fragmentation, connectivity, and interfaces. It was developed to be used at a fixed observer scale, the one constrained by the available remote sensing spatial resolution data, although techniques can be applied to any type of raster data at any spatial resolution. This is a restriction of this methodology given the need of standardization and simplicity necessary to a national forest inventory. One has to keep in mind that comparison with data generated at different scales, in the future, is not possible in a strict sense or has to be carefully conducted and analysed, considering the restrictions related to the comparison of multi-scale landscape indices discussed previously.

Since the 1980s, several studies have explored the use of spatial metrics in landscape analysis, and as a result the number of indices have proliferated (Estreguil et al., 2012). Thus, there is a need to define standardized guidelines for landscape analyses, particularly in the context of the IFN-BR. The models presented herein were revised, combined and integrated, to provide new, spatially explicit indices that represent both the composition as well as the configuration of the landscape.

This methodology incorporates not only traditional indicators, such as landscape composition, but also includes a new way of assessing fragmentation by adopting a normalized index and enabling comparisons based on the total Euclidean distance of the habitat. Another approach includes the assessment of riparian zone quality, based on the structural connectivity of these environments as vegetation corridors and the degree of anthropogenic pressure they are experiencing (Clerici & Vogt, 2013), while also considering the priority of these areas for conservation. This approach is particularly important considering the recent changes in Brazilian forest legislation (Brasil, 2012) to the extent of forest vegetation to be maintained or restored along rivers and waterbodies (Freitas et al., 2016; Achard et al., 2017).

The results generated through the application of this methodology to LSUs of the IFN-BR will be used to support federal and state government strategic planning as well as to improve reporting to international agencies. This includes the global evaluation of forest resources (Global Forest Resources Assessment from Food and Agriculture Organization of the United Nations - FRA/FAO), as well as the requirements for information about forests for international conventions regarding climate change, as United Nations Framework Convention on Climate Change (UNFCCC). More specifically, this information will be used to identify priority areas for the protection and restoration of forests, as well as the analysis and planning of landscapes, aiming to reduce forest fragmentation through restoration. Furthermore, our objective was to provide the public with data and information, making it available for use in the development of research and education, both in the private sector and non-governmental institutions (Freitas et al., 2016).

Acknowledgements

The authors would like to thank the fellow researchers and experts from Joint Research Centre of the European Commission (JRC) René Beuchle, Dario Simonetti and Peter Vogt for their constant technical support, without which this work and the Landscape Component of the Brazilian National Forest Inventory would not be the same.

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