Landscape Online – transdisciplinary journal bridging science, policy and practice
Supported by the International Association for Landscape Ecology and its community

Landscape Online
open access peer reviewed

Landscape Online | Volume 85 | 2020 | Pages 1-18 | DOI 10.3097/LO.202085

Submitted: 29 April 2020 | Accepted in revised version: 24 October 2020| Published: 05 November 2020

Landscape Signature as an Integrative View of Landscape Metrics: A Case Study in Brazil-French Guiana Border

Abstract

The present work presents an integrated view of landscape analysis through the construction of a signature system for the analysis of landscape types. These signatures were based on metrics that informed different patterns for each landscape type, which allowed the behavior of the landscape to be visually analyzed. The signature system was applied through a landscape classification developed through fieldwork to gather data on socioenvironmental categories combined with remote sensing data. The study site was the border region between Brazil and French Guiana. The results of this work showed that in situ landscape classification techniques can be supported by the analysis of quantitative metrics of landscape analysis, reinforcing the need for integrative and systemic studies in landscape geography.

Romero Silva[1]*, Sofia Zagallo[1], Anne-Elisabeth Laques[3], Carlos Saito[1,2]

[1)] University of Brasília, Center for Sustainable Development, Brasília, Brazil

[2)] University of Brasília, Ecology Department, Brasília, Federal District, Brazil

[3)] Research Institute for Development, Montpellier, France

*Corresponding author: University of Brasília, Center for Sustainable Development, Campus Darcy Ribeiro, 70910-900, Asa Norte, Brasília; Brazil. Email address: romerogomes1@hotmail.com

Keywords:
Amazon, landscape geography, landscape ecology, human geography, physical geography, field work

1 Introduction

Human and physical geography have been considered to be distinct fields. According to Tadaki et al. (2012), this separation occurred after the 1950s and 1960s, when the quantitative approach in many scientific disciplines and in geography led to growing specialization with the consequent separation of human and physical geography.

One of the results of this separation may is that traditional physical geography may have been led to a crossroads due to the erosion of some of its domains by other geosciences and the aging of its competencies and concepts (Kates, 1967). The notion that maps and cartography are the geographer's primary instruments, from the technological, methodological and language perspectives would now be questioned (Perkins, 2003). Even with modern computerized mapping, there is now great emphasis on the narrative understanding rather than on the cartographic understanding of the spatial dimensions of socioenvironmental phenomena (Wheeler, 1998).

In the past, the study of the landscape was a geography-centric topic, and it was seen as a unique synthesis of the natural, social and cultural characteristics (Antrop, 2000). As a consequence of the distance between physical and human geography, the restructuring of academic curricula crystallized this division, and regional geography, including the study of landscapes, was abolished or marginalized. According to Palka (1995), even before regional geography had also faded from widespread use, it became a focus of North American geographers in such a way that the landscape was no longer the basis of geography but rather a simple unit of study. Therefore, this would likely represent a paradigm shift in the way geographers are looking at space.

To advance the rapprochement between human geography and physical geography, one of the barriers to overcome is the idea that human geography approaches are fragile and subjective. The objectivity of geotechnologies and quantitative analysis are defended because they produce stronger evidence through the numerical data. A strong landscape analysis, according to this objectivity, should be based on landscape metrics.

Although the landscape is considered a unifying concept, the review by Simensen et al. (2018) of 54 characterizations of the contemporary landscape indicated that there is a clear division of the scopes (1: holistic analyzes; 2 geo-ecological properties related to land use and 3: biophysical characterization of the landscape by static analysis). For the authors, it is important to make an effort to integrate the different scopes for better planning and management of the landscape.

The objective of the present work was to propose an integrated view of landscape analysis and to demonstrate that landscape zoning produced in the field by human geographers is accurate and can be validated by the mathematical procedures used in landscape ecology. To do so, a graphic signature system was developed for the analysis of the types of landscapes based on metrics: this signature system creates different patterns for each landscape type that allow for visual analysis of the behavior of the landscape. The hypothesis was that the landscape map resulting from the observations and field research would present coherence that confirms the legitimacy and viability of the same, presenting the landscape as a mediator integrating physical geography and human geography.

2 Material and methods

2.1 Study area

The majority of the anthropic activities in the region (approximately 600 km2) are concentrated in the study area and specifically on the banks of the Oiapoque River; the study area included the urban centers of Saint Georges (four thousand inhabitants) in French Guiana and Oiapoque (25 thousand inhabitants) on the Brazilian side. On both sides of the river, most of the activities are linked to agricultural production, with the production of cassava associated with fruit cultivation (orange and banana) carried out by family farmers and indigenous people. Thus, the economic dynamics and the management of agriculture in the territory are reflected in the diversity of landscapes.

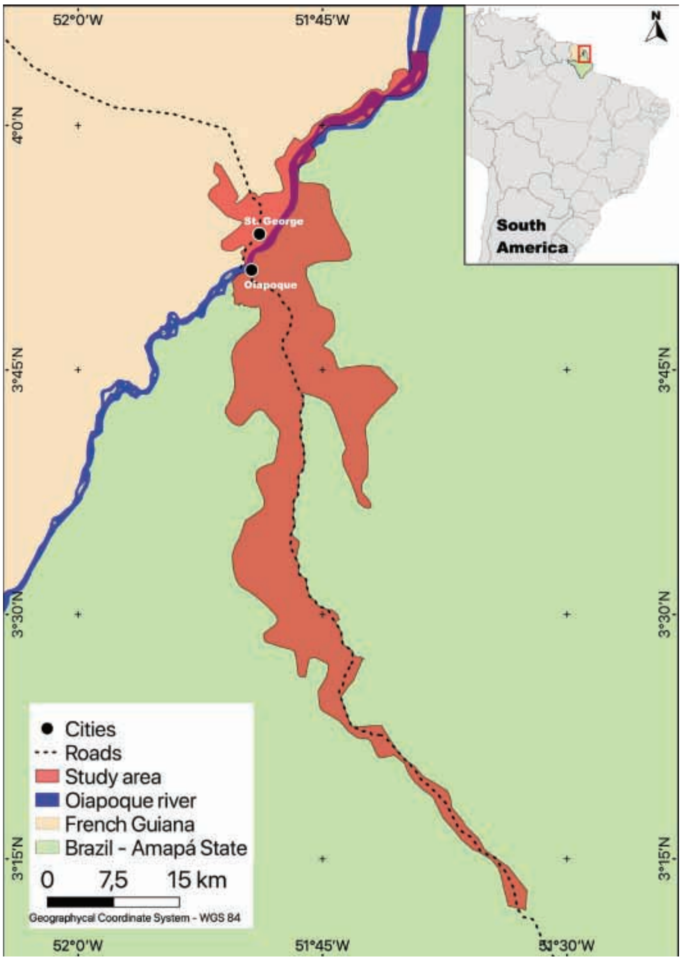

Figure 1: Location of the study area

Quantitatively, 90% of the study area was on the Brazilian side, where indigenous territories (named Uaçá and Juminã) and a rural settlement (delimited by Brazilian Agency of Agrarian Reform, or INCRA) are found. Although the French Guiana side does not have properly designated areas for the indigenous populations, it is worth mentioning that the Local Urbanism Plan (PLU) organized the land use zoning around Saint Georges. In this zoning, indigenous people live in urban or peri-urban areas and plant cassava in a specific area. Other small groups of indigenous people live in small villages beside the river.

2.2 Methodology

The validation of the landscape zoning produced in the field by human geographers was based on metrics from landscape ecology. The landscape types were first defined visually *in situ* from a human geography perspective. The metrics analysis was performed on the land use map for each type of landscape, which had been previously identified. Thus, the landscape metrics were applied to verify the existence of similarities or differences between the landscape types. To confirm the limits of the human geography perspective, it was expected that each landscape type differs in the behavior of the landscape metrics. A signature system was developed to register the patterns for each landscape type according to these landscape metrics, which allowed the behavior of the landscape to be visually analyzed.

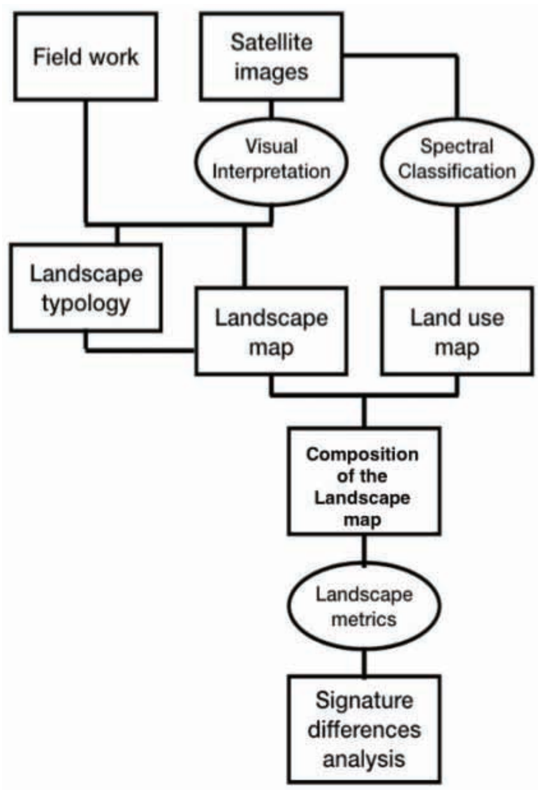

Figure 2: Overview of the methodological steps

2.2.1 Mapping coverage and land use

The mapping of land use in the study area was the first challenge of this work. The study area was very large (600 km2) and the official databases from the both countries do not match and complement each other. Furthermore, the large amount of clouds and shadows of all available images created additional difficulties to perform a uniform treatment to both countries areas. In addition, in the study area there is the presence of secondary vegetation in different successional stages, causing greater spectral confusion.

Due to this context, the following procedures were adopted. First, field work helped to determine the most important classes of land use present in different types of landscapes at both Brazilian and French Guiana sides. Seven classes of land use were determined: Forest, Urban, Water, Secondary Vegetation, Exposed Soil, Annual Agriculture / Pastures fields, and *Juquira* (cultivated areas of cassava abandoned).

Then, we concentrated efforts in the French Guiana side to conclude land use map (containing the seven classes) due to the reduced area (10% of the total area). To determine *juquira* class, manly, we utilized a SPOT 2014 image (scene 603/343, with 20 meters of spatial resolution) because there was no official land use data for this area and the limited area allowed a very focused and localized analysis. The mapping of land use with seven classes was performed by an unsupervised classification (by segmentation) using the ISOSEG method (Bins et al., 1996) available in the Spring software (Câmara et al., 1996), followed by visual regrouping of the classes with support of georeferenced photos obtained in the field.

For the Brazilian side, the situation was different. Besides the larger surface area (90% of the total area), the large amount of clouds and shadows of all available images made it impossible to replicate the same methodology on the Brazilian side. Thus, it was decided to get the Brazilian official land use database, prepared by the National Institute for Space Research (INPE - Brazil), known as TerraClass (base year 2014). This database is derived from the hierarchical classification of Landsat-TM images (30 meters of spatial resolution), carried out by a specialized team, with the purpose of generating twelve classes of land use with a low degree of ambiguity (Almeida et al., 2006). As the official map TerraClass follows the official borders drawn by Brazil, and thus it is limited to this country area. Thus, we chose to reclassify the polygons of the TerraClass base (Brazilian side) by photointerpretation within the scope of the seven classes mapped by SPOT (2014) image in French Guiana side.

It is true that the mapping from the SPOT image is more detailed, in terms of the spatial scale, but the refined techniques used to generate the TerraClass base reflect a greater number of classes (twelve), which enabled the reclassification of the final land cover and land use map in the seven classes. Thus, although Turner et al. (1989) alerted about the effect of changing scales (grain), we considered that the landscape type analysis was uniform in entire area, and the differences on resolution and scale was a very punctual analysis performed in 10% of the area corresponding to the French Guiana side where the concentrated presence of *juquira* determined the necessity of a more precise border identification to determine landscape type, which didn't occurred in Brazilian side according to field work. And resolution difference between the two images (20 to 30 meters) will not be so strong for the purpose.

2.2.2 Delimitation of the landscape types with the "field approach"

The mapping of the landscapes *in situ* was performed through a combination of observations in the field, photointerpretation of the satellite images available from Google Earth and interviews with local people. The landscape type was determined by considering the distinct combinations of the categories of patches (composition) and their configurations (spatial proportion, distribution and arrangement), with attention to *in situ* overall profile such as urban buildings and streets density, existence of scattered houses, centrality of cassava cultivation areas, language and cultural distinction, presence of gardens and fruit trees, detection of deforestation, proximity to river, roads etc. This means that landscape types were characterized after the production of the land cover and land use map of the entire study area, and mediated by the ground recognition by field trips in 2013 and 2016 within the scope of FEDER-OSEGuyamapa Project[1]. This empirical construction is a result of the integrated view of Human and Physical Geography. After the identification of landscape types, their delimitation procedures were performed by scanning the features of each type of landscape on the satellite images available from Google Earth, integrating knowledge previously acquired in the field.

1 Space Observatory Project of the French Guiana-Brazil border - Operational Program Amazônia and Regional Council of French Guiana. Partners: IRD, CNES, INPE.

2.2.3 Calculation and analysis of the landscape metrics

The first methodological step for the calculation of the landscape metrics was considered to be the identification of the land use class with the highest percentage coverage. After the definition of the matrices for each landscape type, the next step was the analysis of the landscape fragments (patches) through the use of the landscape metrics. This analysis corresponded to a quantitative scalar measure that summarized the landscape structure (McGarigal and Cushman, 2002). The authors of the cited study created a method that allowed the quantification of the structure of a landscape as they focused on the spatial distribution of the patches to find patterns. To understand these spatial patterns, several metrics have been developed to describe them and can be tested with the aid of remote sensing through satellite imagery or aerial photographs (Lafortezza, Corry, Sanesi and Brown, 2005).

Following the methodological framework of Cantwell and Forman (1993) and Lang and Blaschke (2007), the spatial configuration and the composition of the landscape elements was analyzed. Therefore, the choice of the metrics aligned with the size and complementarity of the relevant metrics in terms of the composition and configuration of the fragments or the matrix in the landscape. From this analysis, eight landscape metrics were chosen (Table 1).

Aiming at the practicality and replication of this method, this study applied the use of these eight metrics in a free and open source software QGIS. This software has the LecoS plug-in, developed by users (Jung 2016) that performs all the proposed metric calculations, based on land use mapping. This plugin generates the metrics chosen from a raster base (land use map). The numerical results were exported and tabulated in an .exl file, where they were analyzed and plotted on graphs.

Table 1: Types of metrics chosen

Types	Metrics
Composition	Number of classes
	Percentage of vegetation cover
	Percentage of patches in the landscape
	Total patches (fragmentation)
	Diversity index (Shannon-Weaver diversity)
Configuration	Patch size
	Patch adjacency (distance)
	Patch shape (form)

2.2.4 Landscape signatures

Each metric was described and then categorized into four classes. This categorization was used to generate ordering axes that were combined with each other to constitute the parameters of a classificatory space. The classificatory space was a conceptual model of the interactions of the landscape metrics, which were plotted on a graph for each type of landscape. These graphs, which are sometimes referred to as “landscape signatures” (Laques, 2009; Niesterowicz and Stepinski, 2016). The “landscape signature” consist of the values of landscapes metrics that are independent and together describe of the pattern for all possible patterns in an area Niesterowicz and Stepinski, 2016).

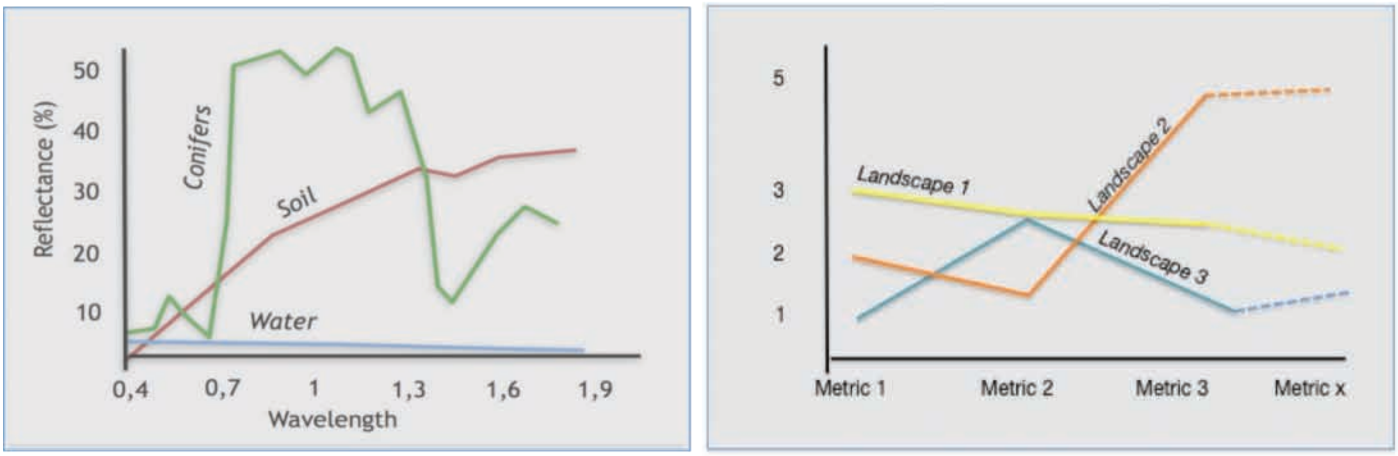

Figure 3: (a) Hypothetical example of a spectral signature (b) Hypothetical example of a “landscape signature”

For Laques (2009), its construction can resemble a "spectral signature" in remote sensing. This approach considers that each object on the surface of the Earth has a spectral signature, which is the amount of energy reflected as a function of the wavelength, that is unique and that allows it to be identified in satellite images - Figure 3(a). In this perspective, Bellón et al. (2017), produced a map of the different land use systems (in particular, cropping systems) at regional scale (Brazil) based on the spectral responses resulting from vegetation indexes (in this case, NDMI). In the present study, each landscape was thus described from a series of variables that, when combined into a graph, established a unique "landscape signature" - Figure 3(b).

3 Theory and calculation of the metrics

Landscapes represent a spatial continuum that is observable both in the field and from satellite images or aerial photographs. To identify landscapes, three spatial perspectives should be considered (Béringuier et al., 1999): the landscape element (Élément Paysager, in French), patches (Composant Paysager, in French), matrix and the landscape itself (Paysage, in French). Therefore, each landscape presents a unique configuration of the landscape components (Béringuier et al., 1999). However, landscapes are not only a structural arrangement of visible patches since the existence of the landscape does not necessarily imply that it can be visually identified (Béringuier et al., 1999).

For more than a century, the analysis of landscape patterns has been considered a helpful tool for the description of landscapes (O'Neill et al., 1988; Lang and Blaschke, 2007). Troll (1939) pioneered the methodological framework of using aerial photographs to map the patterns and arrangements of landscape units.

In the early 1990s, Turner (1989) already stated the spread of numerous GIS software that performed metrics analysis based on land use maps (derived from satellite images) to analyze landscape patterns. In addition to proprietary software, Turner (1989) cited numerous programs developed by users themselves to meet specific demands in the analysis of the landscape by metrics. Regardless of the software and the satellite image, some concepts are important to be taken up.

To do so, when analyzing the arrangement of the landscape units, it is important to define the landscape matrix. The matrix is understood here as the dominant unit in terms of spatial cover; that is, it one of the parts of the landscape that covers the greatest area (Forman and Godron, 1981). Metzger (2001) considered the matrix to be the most important element for analyzing and understanding the structure of a landscape because it was the dominant unit controlling the dynamics of the landscape in most cases.

The landscape element corresponds to the smallest object recognizable by landscape analysis in the field. This object is not always detectable in satellite images (e.g., trees, house, and lakes) because is the visibility of objects in images is very dependent on the image resolution.

Patches are the smallest combinations of elements that are recognizable by landscape analysis in the field and from images. Similarly, patches (such as gardens, grasslands or water bodies) represent pieces of a puzzle that need to be assembled to create a more compelling large-scale picture. From an ecological point of view, this picture represents an ecological unit that has distinguishable structures, functions, geomorphology and disturbance regimes (Forman and Godron, 1986). From a geographic and remote sensing point of view, this level corresponds to land use classes.

Landscapes are associations of patches, and the composition of the patches defines the type of landscape. However, landscapes are more than combinations of patches, and the configuration of the patches is important. Two landscapes may have the same patches (identical composition) but with a different spatial proportions, distributions and arrangements (specific configuration). Likewise, two landscapes may have different categories of patches (different compositions), even though they have similar proportions, distributions and spatial organizations (similar configurations). Thus, both the composition and the configuration of the patches should be considered for the elaboration of "landscape signature" (Niesterowicz and Stepinski, 2016). The metrics chosen (present in the LecoS plugin of the QGIS software) for the present work and their classes of information are presented below.

3.1 Composition metrics

3.1.1 Number of Classes

The numbers of the classes refer to the number of land uses present in each type of landscape. The numbers of land use classes ranged from 1 to 7, which included water, forest, agriculture/pasture, exposed soil, urban area, secondary vegetation and *juquira* (cultivated areas abandoned in the previous year; in this case, cassava cultivation systems). The heterogeneity of the matrix was indicated by the number of classes that were present; the larger the number of classes was, the more heterogeneous the landscape. For Turner (1989), in ecological processes, a greater number of classes is usually related to increased fragmentation, which creates more patches, while fewer classes indicated reduced levels of landscape fragmentation as some land use classes were eliminated.

3.1.2 Percentage of Vegetation Cover

This metric was related to the percentage of natural vegetation cover of the landscape and helped to analyze the degree of human intervention associated with the intact landscapes (McIntyre and Hobbs, 1999; Riitters and Costanza, 2018; Riitters et al., 2002). Pearson et al. (1996) used the percentage of vegetation cover to describe four landscape states: intact (vegetation cover greater than 90%), varied (vegetation cover between 60 and 90%), fragmented (vegetation cover between 10 and 60%) and relictual (vegetation cover less than 10%). In the present study, a modified analysis of the percentage of landscape cover was applied to each 25% of the vegetation cover intervals to maintain the standardization of the landscape signatures. The following land use classes were considered vegetation cover: forest, *juquira* and secondary vegetation.

3.1.3 Percentage of patches in the landscape

According to Forman and Godron (1981), for landscape analysis, it is essential to determine the number of patches in at least four categories. In the present study, this metric was calculated for each landscape type from the accumulated area (in percentage) of the patches. The same value is defined by excluding the percentage area of the landscape matrix. The metric expresses the abundance of fragments of a specific type of landscape.

3.1.4 Total number of patches (fragmentation)

In addition to the number of patches per type of landscape, it was also decided to analyze the number of patches in relation to the total average number of patches of all types in the landscape. Cabral et al. (2018) argued that the number of patches indicates the extent of anthropogenic impact: higher numbers of patches suggests intense deforestation processes. In the present work, the number of patches of each type of landscape was summed; next, the number of patches of all types of landscape was summed. This result was divided by the total number of patches in all landscape types to obtain the average of the total number of patches in the landscape. The final value was then calculated as a percentage by the mean number of fragments of each landscape type in relation to the total average number of fragments.

3.1.5 Shannon-Weaver Diversity (H') Index

The diversity was calculated with the Shannon-Weaver diversity index (H'). This is one of the most used indexes for measuring the diversity of categorical data; it was developed by Shannon and Weaver (1949) and is usually used for the measurement of species diversity. In the context of landscape analysis, this index expresses the degree to which the land use classes are equally represented on the map (McGarigal and Marks, 1995), as the following (Eq 1):

$$\text{Shannon-Weaver Index } (H') = -\sum_{(i=1)}^{m} Pi \ln Pi \qquad (1)$$

Where Pi represents the fraction of a study area occupied by class i and m the total number of classes.

The higher the index (H'= 1) was, the more diverse the landscape. Thus, the maximum diversity is achieved when all land use classes of are represented in equal proportions. In the present work, the values refer to average values of diversity of the set of sampling points for the respective landscape types.

3.2 Configuration Metrics

3.2.1 Patch size

The size of the patches is a fundamental attribute that is used for characterization (McGarigal, 2014). Since the types of landscapes are not the same size and the number of fragments is variable, the simple calculation of the average size of the fragment for each type of landscape can be incongruous. This way, to establish an ordering scale (patches: small, medium to large) for a set of landscape types, it was necessary to relate to the average size of the fragments of the total landscape. Thus, first, to calculate the patch size, the sum of the mean patch areas of the fragments of each type of landscape were calculated, excluding the matrix class. Next, the number of patches was summed, and the sum of the average landscape type area was divided by the sum of the number of fragments of each type. These values were summed for all landscape types and then divided by the total landscape number. The final result was then calculated as a percentage by dividing the mean size of the fragments of each type of landscape in relation to the total average number of patches of the landscape, which was calculated previously.

3.2.2 Patch adjacency (distance)

There are several ways to calculate the distance between the fragments in a GIS environment (Euclidean distance, average distance, etc.). In the LecoS plugin, the function that refers to the distance is called Like adjacency. This metric provides information on the degree of aggregation of the fragments that compose the land use classes in the landscape (McGarigal and Marks, 1995) as the following (Eq 2):

$$\text{LikeAdjacency}=\left(\frac{g_{ij}}{\sum_{k=1}^{m} g_{ik}}\right)*(100) \qquad (2)$$

Where g_{ij} is the number of adjacencies between cells of class i and g_{ik} is the number of adjacencies between cells of class i and k.

Thus, this metric can be useful to assess the fragmentation of the landscape in terms of distance, that is, the more aggregated the fragments the smaller the distance and vice versa. This metric is calculated from the adjacency matrix, which shows the frequency with which different pairs of patch types (of the same class) appear side-by-side on the map. For this index, the degree of adjacency of the fragments ranged from 0 to 100. Values close to 0 indicated that a fragment did not have contact with another fragment of the same class (they were distant), and values close to 100 indicate the maximum level of contact between fragments of the same class (they were in close proximity).

3.2.3 Patch shape Index (form)

The complexity of the shape is related to the geometry of the patches; they can be simple and compact or irregular and curled. To calculate the shape metric, the fractal dimension index (McGarigal and Marks 1995) was used as the following (Eq 3).

$$\text{Fractal Dimension Index}=\frac{2\ln(0.25*p_{ij})}{\ln*a_{ij}} \qquad (3)$$

Where pij is perimeter (m) of patch ij and aij is the area (m^2) of patch ij.

The calculation of this metric is based on the perimeter-area ratio, which quantifies the degree of complexity of the shapes. The importance of this

Table 2: Categorization (four classes) of the chosen metrics

Metrics	Class 1	Class 2	Class 3	Class 4
Number of classes	1 and 2	3 and 4	5 and 6	7
Vegetation cover (%)	(0 to 25]	(25 to 50]	(50 to 75]	(75 to 100]
Patches in the landscape (%)	(0 to 25]	(25 to 50]	(50 to 75]	(75 to 100]
Total patches (%)	(0 to 25]	(25 to 50]	(50 to 75]	>75
Diversity index (%)	(0 to 0,25]	(0,25 to 0,50]	(0,50 to 0,75]	(0,75 to 1]
Patch sizes (%)	(0 to 25]	(25 to 50]	(50 to 75]	>75
Patch adjacency (%)	(0 to 25]	(25 to 50]	(50 to 75]	(75 to 100]
Patch shapes Index (%)	(1 to 1,25]	(1,25 to 1,50]	(1,50 to 1,75]	(1,75 to 2]

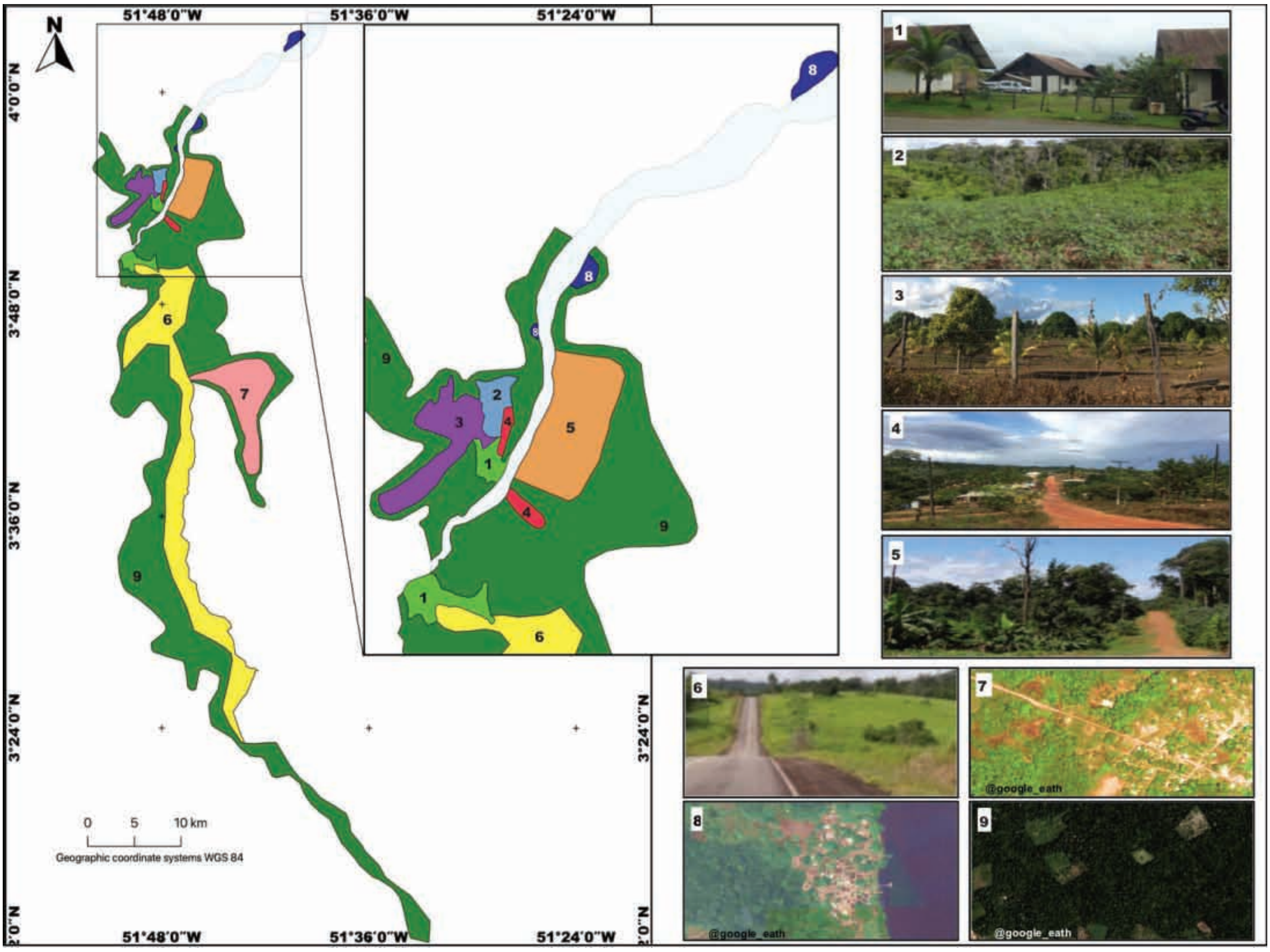

Figure 4: Types of landscape in the study area

variable to environmental analysis was described by Diamond (1975). In the present study, the index was averaged for all patches of all classes except for the matrix. The index value ranged from 1 to 2, and whenever the values were closer to 1, the complexity of the fragment was lower.

4 Results

Nine types of landscapes were identified after the field surveys in 2013 and 2016. Figure 4 and Table 3 show the types of landscape with brief descriptions. The analysis of the land use map in each type of landscape revealed the patch presence and distribution, and the definition of the matrix for each type of landscape (defined as the land use class with the highest percentage). Table 3 also presents the classes that were considered matrices for each type of landscape. In this work, it the remaining elements after the exclusion of the landscape were defined as patches.

The landscape signatures were generated according to the metrics for each type of landscape (Table 4 and Figure 5). The signatures in blue indicate the types of landscape that occurred in French Guiana and those in green indicate landscape types on the Brazilian side. These landscape signatures reflect the behaviors of the set of metrics for each landscape type. The visual analysis of the signatures (Figure 5) generally showed that the landscapes are different. This supports, for the first time, the delimitation of the landscape types performed with the geographic approach.

Table 3: Descriptions of the landscape types

Type	Name	Descriptions	Matrix
1	Urban	Paved streets in a dense urban center. Typically includes fenced houses with small gardens.	Urbanized area
2	Peri-urban indigenous area	Cassava planting in a rotation system conducted by indigenous people who generally live in the urban areas of Saint Georges.	Agriculture and Pasture
3	Crioulos garden	Farmhouses used for recreation and small-scale fruit production.	Forests
4	Peri-urban	Unpaved streets; houses are more distant from each other.	Agriculture and Pasture
5	Rural settlement	Large land plots for settled families; presence of forests, areas of agriculture and fruit trees.	Forests
6	Pastures and agriculture	Large deforested areas (for pasture and agriculture), near to roads. Usually in a geometric format.	Forests
7	Indigenous village	Village with houses and unpaved streets. Cassava is planted in a rotation system around the village.	Forests
8	Indigenous riverside	Small indigenous villages where the houses are scattered near the Oiapoque River.	Forests
9	Small forestry openings	Deforested areas, generally in a geometric format, for planting cassava. When the areas are large, deforested areas are designated as pasture.	Forests

Table 4: Landscape metrics for each landscape type

	Class		Vegetation Cover		Patches		Fragmentation		Diversity		Size		Distance		Form	
Types (polygon) / categorization	nº	Categ.	%	Categ.	%	Categ.	Index	Categ.	Index	Categ.	%	Categ.	%	Categ.	Index	Categ.
Urban - Fr. Guiana	7	4	9,46%	1	13,80%	1	16,43%	1	0,28	2	7,17%	1	90,75%	1	1,18	1
Urban - Brazil	4	2	6,47%	1	10,37%	1	16,11%	1	0,31	2	2,49%	1	96,78%	1	1,09	1
Peri-urban Indig. area - Fr. Guiana	7	4	17,18%	1	53,83%	3	21,26%	1	0,74	3	0,02%	1	93,90%	1	1,13	1
Creoles Garden - Fr. Guiana	6	3	59,01%	3	65,32%	3	74,42%	3	0,79	4	6,85%	1	97,62%	1	1,12	1
Peri-urban - Brazil	4	2	16,77%	1	41,13%	2	5,15%	1	0,75	4	329,04%	4	99,05%	1	1,08	1
Peri-urban - Fr. Guiana	5	3	40,66%	2	59,49%	3	9,02%	1	0,72	2	90,74%	3	98,09%	1	1,08	1
Rural Settlement - Brazil	6	3	88,44%	4	20,37%	2	29,64%	2	0,42	2	6,30%	1	92,14%	1	1,10	1
Pasture	7	4	58,86%	3	53,60%	3	144,64%	4	0,58	3	0,11%	1	82,77%	1	1,19	1
Indig. Riverside - Brazil	5	3	93,71%	4	10,54%	1	15,14%	1	0,29	2	620,32%	4	96,68%	1	1,08	1
Indig. Riverside - Fr. Guiana (A)	4	2	83,14%	4	46,61%	2	5,80%	1	0,73	3	35,30%	2	97,98%	1	1,08	1
Indig. Riverside - Fr. Guiana (B)	4	2	80,47%	4	37,95%	2	5,48%	1	0,69	3	198,28%	4	98,62%	1	1,06	1
Small Forestry opening - Fr. Guiana	7	4	80,02%	4	30,21%	2	250,95	4	0,56	3	0,04%	1	90,79%	1	1,12	1
Small Forestry opening - Brazil (A)	7	4	87,73%	4	16,80%	1	123,70%	4	0,35	2	0,05%	1	85,95%	1	1,14	1
Small Forestry opening - Brazil (B)	7	4	26,76%	4	13,83%	1	25,00%	4	0,28	2	0,03%	1	98,32%	2	1,15	1

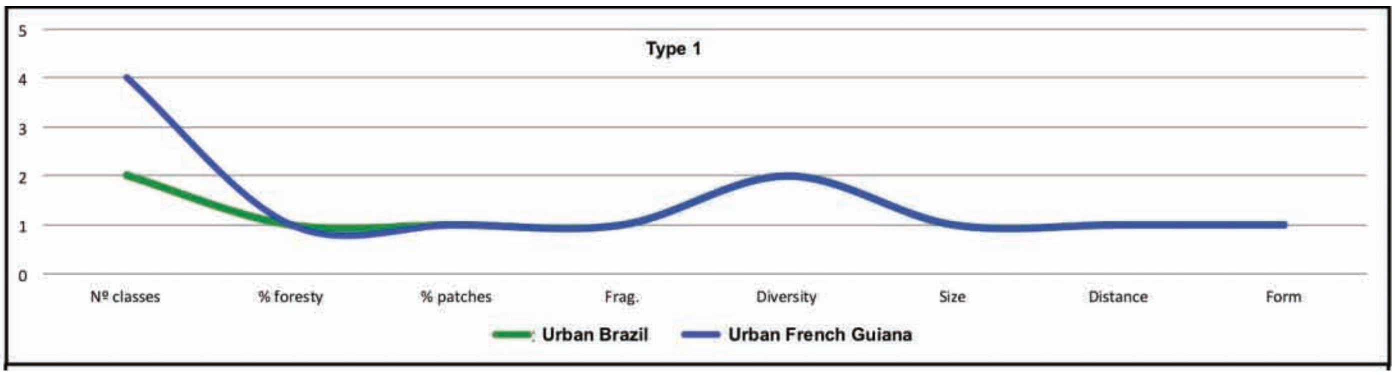

Figure 5. Signatures of the landscape types

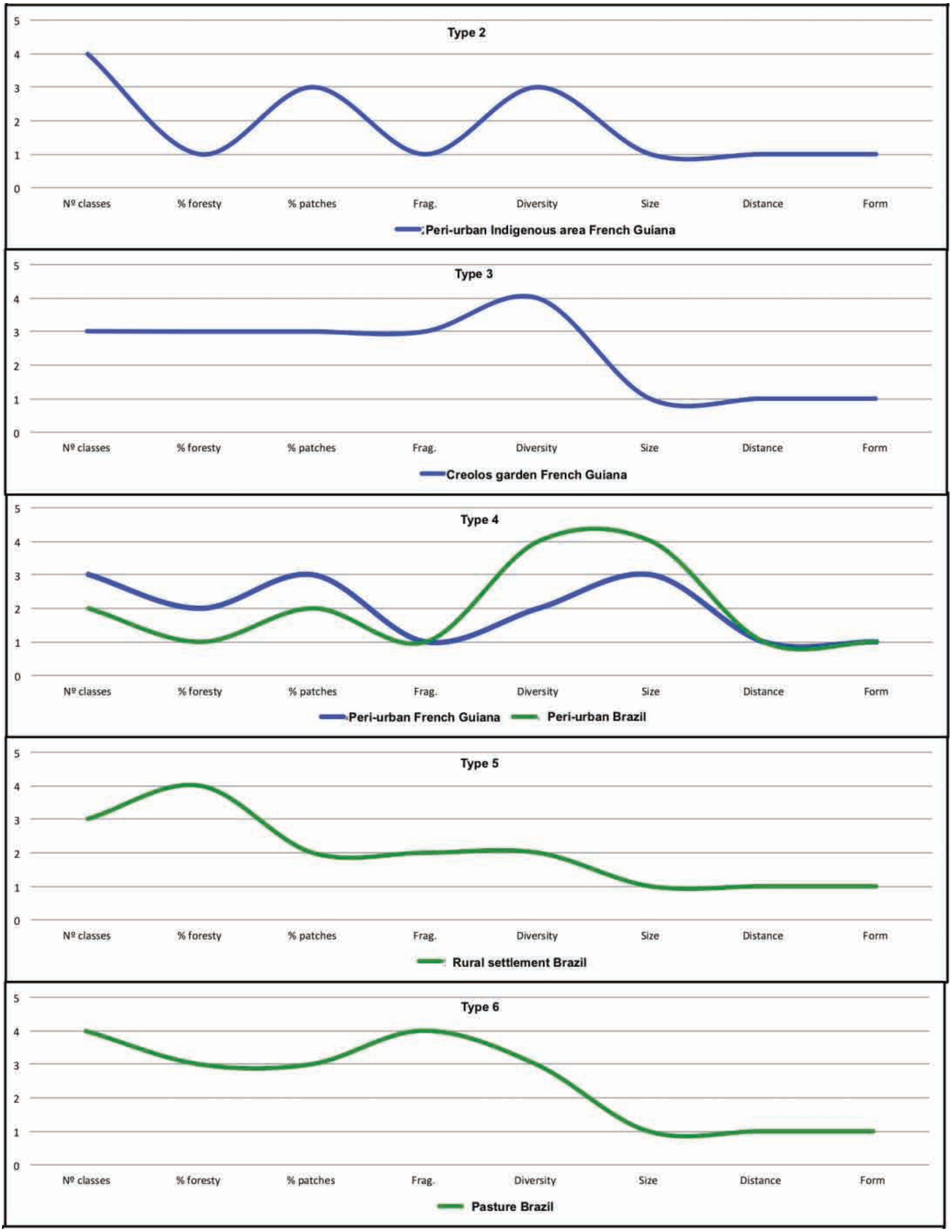

Figure 5. Signatures of the landscape types

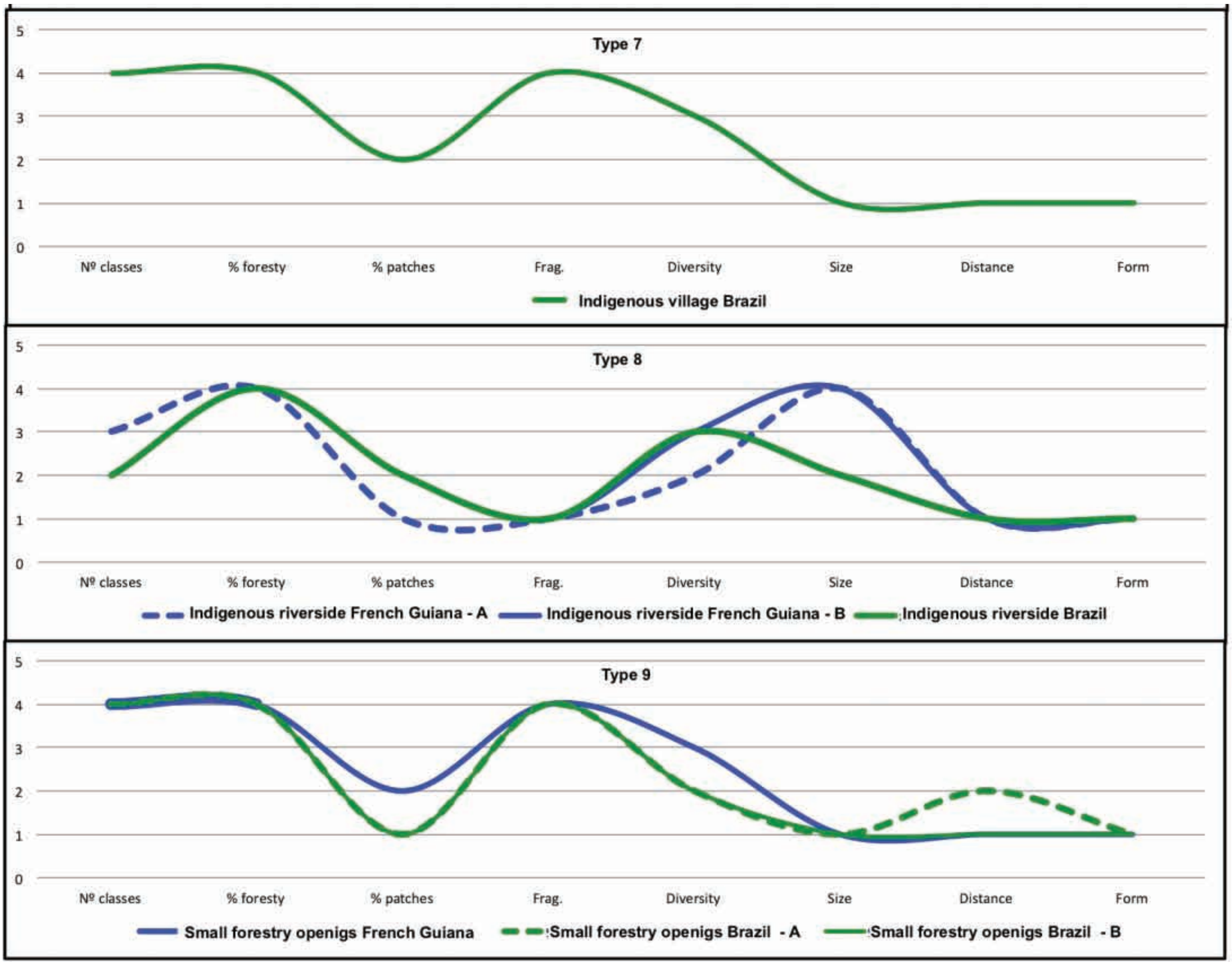

Figure 5. Signatures of the landscape types

5 Discussion

The discrimination of the different landscape units at the landscape scale requires the identification of the boundaries of the different landscape types from a geographical view based on the interrelationships between the anthropic uses and the environment (Guillaumet et al., 2013). Concerns about the structural aspects of the landscape elements and their limits cannot, however, obscure the analysis of the functions of the landscape. It is necessary to maintain a holistic perspective (Saito, 1998) to avoid misuse of landscape indices that hinders the establishment of relationship between patterns and processes (Li and Wu, 2004). Therefore, it is important to know how to interpret the land use indicators in the landscape through knowledge of history of the main dynamics of a specific land use type. In doing so, it is helpful to understand the role of geophysics and ecology on these dynamics and leads to the establishment of spatial patterns in different landscapes, which helps to map each of the landscapes (Laques, 2009).

An important step is the identification and quantification of the spatial patterns present in the landscape structure (Turner, 1989), with attention to the interactions, flows, and transfers among the landscape units. As a result of the composition of patterns (Risser et al., 1984), the shapes and boundaries of the units need to be investigated and compared.

Most studies that relate the behavior of metrics to one type of landscape make use of statistical tests and a wide variety of existing metrics. In the study of Neel, McGarigal and Cushman (2004), for example, which examined the nonlinear behavior exhibited by many metrics in different landscape types, the authors envisioned the use of several metrics distributed into behavioral groups to characterize one type of landscape. Similarly, Peng et al. (2010) reported that it was important to evaluate the complexity of the various components of the spatial patterns, as in the present study, rather than analyzing the metrics separately. The present proposal of the joint analysis of a set of landscape metrics allows this integrative perspective (Figure 5).

In the types 1 (urban), 4 (peri-urban), 8 (indigenous riverside) and 9 (small forestry openings) more than one curve was generated to represent the landscape signature; one signature was generated for each existing polygon. For the urban landscape type, for example, only one metric (number of classes) was inconsistent between the polygons.

As for the peri-urban and the indigenous riverside landscape types, it is important to note that they presented the smallest areas among all landscape types delimited in this work. Study by Liu et al. (2016) and Gustafson (1998) indicated that the landscape metrics were very sensitive to the variations in spatial scale, either through the resolution of land use and coverage map or in the extent of the area that was analyzed. This made the analysis of the metrics more sensitive to variations in the composition and configuration of the landscape fragments. How Kupfer (2012) explain, the spatial scale poses a problem to analyze landscape metrics because their values are based on static classifications of land-cover data that are provided at scales that may be different or inappropriate. Therefore, these variations in the signatures were expected.

In the specific case of the peri-urban type, Gonçalves et al. (2017) emphasized that peri-urban areas do not have clear boundaries, either geographically or conceptually. The authors pointed out that this type of landscape is intrinsically variable and complex, which makes it difficult to characterize since it includes several patterns of settlements in the intermediate space between urban and rural areas. This variability was seen *in situ*, and it was verified that the peri-urban type was difficult to delimit due to, above all, the similarity of the urban streets and houses. However, peri-urban areas have sparser houses with larger plots of land, where small gardens are grown in backyards. Thus, the landscape signatures confirmed the need to separate the urban and peri-urban types.

Despite the effectiveness of the proposed method, it was necessary to consider the limitations of this analysis. As reported by Satterfield et al. (2013), the measurements and extents of landscape data are complex and involve ecological and social dynamics but are generally reduced to static measures. Similarly, Naveh (2000, p.24) stated “present methods for the categorization of organized landscape complexity are based chiefly on simple regularities of Euclidean Geometry for the description of formal structures and their mechanistic interpretation”. It can be said that this form of analysis was applied in the present analysis; the landscape signatures showed a static image and did not incorporate the cultural or historical contexts and their evolutions.

In this sense, it is important to stick to the historical and cultural contexts that exist beyond the (ir) regularities of the landscape metrics (Naveh, 2000). This confirms the importance of the integration of the geographical (field) perspective in the analysis of the landscape signatures.

Thus, Palang et al. (2017) highlighted as both interdisciplinary and transdisciplinary methods as key tools for an integrative approach to landscape analyze. Stephenson (2008) and Naveh (2000) reported the need for science to establish new methods for analyzing the landscape more holistically and as a dynamic system. In this context, the effectiveness and simplicity of the presented methodology is emphasized since the signatures for the analysis of the landscape types included a set of metrics distributed on a graph, which allowed the behavior of the landscape signature to be analyzed visually.

The methodological strategy of differentiating among the types of landscapes with the signatures of the landscape metrics has also indicated to be a useful method for analyzing the landscape, in addition to validating the geographic *in situ* analysis. In this case, using the landscape metrics and composing the signatures of the metrics for each type of landscape *a posteriori* can be a valid procedure for confirming the *in situ* data or slightly adjusting to its delimitations.

Therefore, the present work had similar concerns to those of Antrop and Van Eetvelde (2000), who asked whether maps of landscape metrics, which are presumed to reveal spatial patterns, correspond to the landscape units defined by holistic approaches based on human perception. However, the present work differs from the work of Antrop and Van Eetvelde (2000) in the application of the metrics to the landscape units defined *in situ* and then evaluating the level of differentiation between the two datasets, whereas Antrop and Van Eetvelde (2000) used a holistic approach by adopting their own metrics as a starting point for defining the landscape units and compared their boundaries with those derived from the visual interpretation of the images.

Thus, the present work aligned with that of Burnett and Blaschke (2003), who defended the survey the whole picture (holistic), which is precisely the concept of a landscape. As in Messerli and Rey (2012), we also argued in favor of the study of regional landscapes as the location and scale are suitable for enacting the necessary integration of human geography and physical geography. During the approximation process, the concept of a landscape was reexamined, stimulated by George Bertrand, who contributed to reshaping the conceptual basis of landscapes for "reconciliation" between the natural sciences and the social sciences for socioenvironmental issues (Bertrand, 1978). This physical geography-human geography rapprochement movement basically sought an integrated and interdisciplinary approach for determining the notion of complexity. This is in accordance with the work of Burnett and Blaschke (2003), and the present work aligns with this epistemological objective.

Additionally, when discussing the search for new approaches, it is pertinent to mention Brown et al. (2014), who presented a set of "social metrics" capable of measuring both the composition and configuration of the human perceptions of landscapes using empirical data based on participatory GIS. For future work, the possibility of integrating these data, which are considered subjective, to landscape signatures is suggested. It is possible that they will be more sensitive to sociocultural issues, making the landscape signatures more robust. On the possibility of integrating "subjective" data with the digital data obtained by GIS, the work of Sahraoui et al. (2016) concluded that each of the two approaches could contribute with its own information that was complementary and not redundant.

Finally, we discussed not only the validity of the signatures or the limitations of the methodology for analyzing the types of landscapes but, above all, the necessity of integrating the geographical perspective with technical knowledge. In the present study, the landscape signatures were effective since the delimitations of the types of landscape used were not built from the Cartesian or formal points of view but mainly from fieldwork grounded on historical and cultural knowledge.

6 Conclusion

It is important to point out that the results of the signatures indicated that, on one hand, the metrics could point to the adjustment of the methodology for the identification of the types of landscapes with a geographical view *in situ*. On the other hand, the signatures also revealed that these metrics alone were capable only of capturing the structure of the landscapes at the times that the remote sensing instruments allowed a classification of the land use and land cover.

The fact that the landcover classification and use of the ground based only on the images obtained by the remote sensing instruments represented an instantaneous picture also indicates that in this classification, cultural and historical aspects may be absent from the remote sensing data. The geographic *in situ* view can represent a valid methodological path for promoting the understanding of the landscape as a whole, in a holistic way, through combination of the structural and sociocultural aspects.

Thus, the present work concluded that landscape-scale analysis and the integration concept is valuable and has been revitalized, which was supported by metrics. Additionally, the landscape should be highlighted because it can produce an integrative view that unifies the field of geography and opposes both methodologically and epistemologically the artificial division established between physical geography and human geography.

References

Almeida, C.A., Coutinho, A.C., Esquerdo, J.C.D.M., Adami, M., Venturieri, A., Diniz, C.G., Dessay, N., Durieux, L, and Gomes, A.R. 2016. High Spatial Resolution Land Use and Land Cover Mapping of the Brazilian Legal Amazon in 2008 Using Landsat-5/TM and MODIS Data. Acta Amazonica 46 (3): 291–302, DOI: 10.1590/1809-4392201505504

Antrop, M. 2000. Geography and Landscape Science. Belgeo. Revue Belge de Géographie, nº. 1-2-3–4:9–36, DOI: 10.4000/belgeo.13975

Antrop, M. and Van-Eetvelde, V. 2000. Holistic Aspects of Suburban Landscapes: Visual Image Interpretation and Landscape Metrics. Landscape and Urban Planning 50 (1):43–58, DOI: 10.1016/S0169-2046(00)00079-7

Bellón, B., Bégué, A., Lo Seen, D., De Almeida, C. A., and Simões, M. 2017. A remote sensing approach for regional-scale mapping of agricultural land-use systems based on NDVI time series. Remote Sensing, 9(6), 600, DOI: 10.3390/rs9060600

Béringuer, P., Dérioz, P. and Laques, A.E. 1999. Les paysages français. Collection Synthèse, série Géografie, Paris: Armand Colin.

Bertrand, G. 1978. Le Paysage Entre La Nature et La Société. Revue Géographique Des Pyrénées et Du Sud-Ouest 49 (2):239–58, DOI: 10.3406/rgpso.1978.3552

Bins, L.S.A., Fonseca, L.G., Erthal, G.J., Ii, F.M. 1996. Satellite imagery segmentation: a region growing approach. Brazilian Remote Sensing Symposium, 8(1996), 677-680.

Brown, G., Weber, D. and De Bie, K. 2014. Assessing the Value of Public Lands Using Public Participation GIS (PPGIS) and Social Landscape Metrics. Applied Geography 53:77–89, DOI: 10.1016/j.apgeog.2014.06.006

Burnett, C. and Blaschke, T. 2003. A Multi-Scale Segmentation/Object Relationship Modelling Methodology for Landscape Analysis. Landscape Theory and Landscape Modelling 168 (3):233–49., DOI: 10.1016/S0304-3800(03)00139-X

Cabral, A.I.R., Saito, C., Pereira, H. and Laques, A.E. 2018. Deforestation pattern dynamics in protected areas of the Brazilian Legal Amazon using remote sensing data. Applied Geography 100:101–115. DOI: 10.1016/j.apgeog.2018.10.003

Câmara, G., Cartaxo, R.M.S., Freitas U.M., Garrido, J. 1996. SPRING: Integrating Remote Sensing and GIS with Object-Oriented Data Modelling. Computers e Graphics, 20(3), 395-403, DOI: 10.1016/0097-8493(96)00008-8

Cantwell, M.D. and Forman, R.T.T. 1993. Landscape graphs: Ecological modeling with graph theory to detect configurations common to diverse landscapes. Landscape Ecology 8 (4): 239-255, DOI: 10.1007/BF00125131

Diamond, J. 1975. The Island dilemma: Lessons of modern biogeographic studies for the design of Natural Reserves. Biological Conservation 7(2):129-146, DOI: 10.1016/0006-3207(75)90052-X

Forman, R.T.T. and Godron, M. 1986. Landscape Ecology. New York: John Wiley and Sons, DOI: 10.1017/S0376892900008766

Forman, R.T.T. and Godron, M. 1981. Patches and Structural Components for a Landscape Ecology. BioScience 31 (10): 733–40, DOI: 10.2307/1308780

Gonçalves, J., Gomes, M. C., Ezequiel, S., Moreira, F. and Loupa-Ramos, I. 2017. Differentiating Peri-Urban Areas: A Transdisciplinary Approach towards a Typology. Land Use Policy 63 (Supplement C):331–41, DOI: 10.1016/j.landusepol.2017.01.041.

Guillaumet, J. L., Laques, A. E., Léna, P. and Robert, R. 2013. La Spatialisation de La Biodiversité: Pour La Gestion Durable Des Territoires. Latitude 23. Marseille - FR: IRD Éditions.

Gustafson, E.J., 1998. Quantifying landscape spatial pattern: what is the state of the art? Ecosystems 1, 143–156. DOI: 10.1007/s100219900011

Jung, M., 2016. LecoS - A python plugin for automated landscape ecology analysis. Ecological informatics 31: 18-21, DOI: 10.1016/j.ecoinf.2015.11.006

Kates, R.W. 1967. Links between Physical and Human Geography: A Systems Approach. Association of American Geographers Commission on College Geography Publication 5 (1967): 23-30.

Kupfer, J.A. 2012. Landscape ecology and biogeography: rethinking landscape metrics in a post-FRAGSTATS landscape. Progress in Physical Geography 36, 400–420. DOI: 10.1177/0309133312439594

Lafortezza, R., Corry, R.C., Sanesi, G. and Brown, R.D. 2005. Quantitative approaches to landscape spatial planning: clues from landscape ecology. WIT Transactions on Ecology and the Environment, 84 (1): 239-250, DOI: 10.2495/SPD050241

Lang, S. and Blaschke, T. 2007. Landschaftsanalyse Mit GIS. 8547 vols. Germany: Ulmer Stuttgart.

Laques, A.E. 2009. Paysage, Image et Observatoire: Lire et Diagnostiquer Les Territoires Amazoniens. Mémoire de Recherche Inédit, HDR. Avignon: Université d'Avignon et des Pays de Vaucluse.

Li, X., Mander, Ü. 2009. Future options in landscape ecology: development and research. Prog. Phys. Geogr. 33, 31–48. DOI: 10.1177/0309133309103888

Liu, Y., Wei, X., Li, P. and Li., Q. 2016. Sensitivity of Correlation Structure of Class- and Landscape-Level Metrics in Three Diverse Regions. Ecological Indicators 64 (Supplement C):9–19, DOI: 10.1016/j.ecolind.2015.12.021.

McGarigal, K. and Marks, B.J. 1995. Spatial Pattern Analysis Program for Quantifying Landscape Structure. Gen. Tech. Rep. PNW-GTR-351. US Department of Agriculture, Forest Service, Pacific Northwest Research Station.

McGarigal, K. 2014. FRAGSTATS Help. Documentation for FRAGSTATS 4.

McGarigal, K. and Cushman, S.A. 2002. The gradient concept of landscape structure: Or, why are there so many patches. Available at the following website: http://www.umass.edu/landeco/pubs/pubs. [Accessed 16 May 2018].

McIntyre, S. and Hobbs, R. 1999. A Framework for Conceptualizing Human Effects on Landscapes and Its Relevance to Management and Research Models. Conservation Biology 13 (6): 1282–92, DOI: 10.1046/j.1523-1739.1999.97509.x

Messerli, P. and Rey, L. 2012. Integrating Physical and Human Geography in the Context of Mountain Development: The Bernese Approach. Geographica Helvetica 67 (1/2):38–42, DOI: 10.5194/gh-67-38-2012

Metzger, J.P. 2001. O Que é Ecologia de Paisagens? Biota Neotropica Vol 1 (Num 1/2):1–9, DOI: 10.1590/S1676-06032001000100006

Naveh, Z. 2000. What Is Holistic Landscape Ecology? A Conceptual Introduction. Landscape and Urban Planning 50 (1): 7–26, DOI: 10.1016/S0169-2046(00)00077-3

Neel, M.C., McGarigal, K. and Cushman, S.A. 2004. Behavior of Class-Level Landscape Metrics across Gradients of Class Aggregation and Area. Landscape Ecology 19 (4): 435–55, DOI: 10.1023/B:LAND.0000030521.19856.cb

Niesterowicz, J., and Stepinski, T.F. 2016. On using landscape metrics for landscape similarity search. Ecological indicators, 64, 20-30. DOI: 10.1016/j.ecolind.2015.12.027

O'Neill, R.V., Krummel, J.R., Gardner, R.H., Sugihara, G., Jackson, B., DeAngelis, D.L., Milne, B.T., Turner, M.G., Zygmunt, B., Christensen, S.W., Dale, V.H. and Graham, R.L. 1988. Indices of landscape pattern. Landscape Ecology 1 (3): 153-162, DOI: 10.1007/BF00162741

Palang, H., Soini, K., Printsmann, A. and Birkeland, I. 2017. Landscape and Cultural Sustainability. Norsk Geografisk Tidsskrift - Norwegian Journal of Geography 71 (3):127–31, DOI: 10.1080/00291951.2017.1343381.

Palka, E.J. 1995. Coming to Grips with the Concept of Landscape. Landscape Journal 14 (1):63–73, DOI: 10.3368/lj.14.1.63

Pearson, S.M., Turner, M.G., Gardner, R.H. and O'Neill, R.V. 1996. An Organism-Based Perspective of Habitat Fragmentation. Biodiversity in Managed Landscapes: Theory and Practice, 77–95.

Peng, J., Wang, Y., Zhang, Y., Wu, J., Li, W. and Li, Y. 2010. Evaluating the Effectiveness of Landscape Metrics in Quantifying Spatial Patterns. Ecological Indicators 10 (2): 217–23, DOI: 10.1016/j.ecolind.2009.04.017

Perkins, C. 2003. Cartography: Mapping Theory. Progress in Human Geography 27 (3):341–51, DOI: 10.1191/0309132503ph430pr

Riitters, K. and Costanza. J. 2018. The Landscape Context of Family Forests in the United States: Anthropogenic Interfaces and Forest Fragmentation from 2001 to 2011. Landscape and Urban Planning, DOI: 10.1016/j.landurbplan.2018.04.001

Riitters, K.H., Wickham, J.D., O'neill, R.V., Bruce Jones, K., Smith, E.R., Coulston, J.W., Wade, T.G. and Smith, J.H. 2002. Fragmentation of Continental United States Forests. Ecosystems 5 (8): 0815–22, DOI: 10.1007/s10021-002-0209-2

Risser, P.G., Karr, J.R. and Forman, R.T.T. 1984. Landscape Ecology: Directions and Approaches (Champaign, IL: Illinois Natural History Survey).

Sahraoui, Y., Youssoufi, S. and Foltête. J.C. 2016. A Comparison of in Situ and GIS Landscape Metrics for Residential Satisfaction Modeling. Applied Geography 74:199–210, DOI: 10.1016/j.apgeog.2016.07.011

Saito, C.H. 1998. O Estruturalismo na Ecologia da Paisagem. Brazilian Journal of Ecology 2 (1):47–56.

Satterfield, T., Gregory, R., Klain, S., Roberts, M. and Chan, K.M. 2013. Culture, Intangibles and Metrics in Environmental Management. Journal of Environmental Management 117 (Supplement C):103–14, DOI: 10.1016/j.jenvman.2012.11.033.

Shannon, C. E. and Weaver, W. 1949. The Mathematical Theory of Communications–Univ. Illinois Press, Urbana.

Simensen, T., Halvorsen, R., Erikstad, L. 2018. Methods for landscape characterization and mapping: A systematic review. Land use policy, 75, 557-569. DOI: 10.1016/j.landusepol.2018.04.022

Stephenson, J. 2008. The Cultural Values Model: An Integrated Approach to Values in Landscapes." Landscape and Urban Planning 84 (2):127–39, DOI: 10.1016/j.landurbplan.2007.07.003.

Tadaki, M., Salmond, J., Le Heron, R. and Brierley, B. 2012. Nature, Culture, and the Work of Physical Geography. Transactions of the Institute of British Geographers 37 (4):547–62, DOI: 10.1111/j.1475-5661.2011.00495.x

Troll, C. 1939. Luftbildplan Und Ökologische Bodenforschung. Ihr Zweckmäßiger Einsatz Für Die Wissenschaftliche Erforschung Und Praktische Erschließung Wenig Bekannter Länder. Zeitschrift Der Gesellschaft Für Erdkunde Zu Berlin 1939 (7, 8): 241–98.

Turner, M.G. 1989. Landscape Ecology: The Effect of Pattern on Process. Annual Review of Ecology and Systematics 20:171–97.

Turner, M.G., O'Neill, R.V., Gardner, R.H. and Milne, B.T. 1989. Effects of changing spatial scale on the analysis of landscape pattern. Landscape Ecology 3 (3, 4): 153-162, DOI: 10.1007/BF00131534

Wheeler, J.O. 1998. Mapphobia in Geography? 1980-1996. Urban Geography 19 (1):1–5, DOI: 10.2747/0272-3638.19.1.1