[AM-03-054] Landscape Metrics

Abstract

Landscape metrics are algorithms that quantify the spatial structure of patterns – primarily composition and configuration - within a geographic area. The term "landscape metrics" has historically referred to indices for categorical land cover maps, but with emerging datasets, tools, and software programs, the field is growing to include other types of landscape pattern analyses such as graph-based metrics, surface metrics, and three-dimensional metrics. The choice of which metrics to use requires careful consideration by the analyst, taking into account the data and application. Selecting the best metric for the problem at hand is not a trivial task given the large numbers of metrics that have been developed and software programs to implement them.

Keywords: composition, landscape metrics, measurement, patch, quantifying landscapes, spatial patterns

Author & citation

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Explanation

1. Definitions
2. Overview of Landscape Metrics
3. Emerging Directions

1. Definitions

Landscape metrics: algorithms to quantify the spatial structure of patterns (typically land cover) within a defined geographic area.

Composition: the number, amount, and area of patch types without considering the spatial characteristics of the individual patches or their placement and location in the landscape.

Configuration: the spatial arrangement and distribution of the different classes.

Patch: homogenous areas of the landscape.

Patch Mosaic Model (PMM): represents landscapes as mosaics of discrete land cover patches situated within a background matrix.

Gradient Surface Model (GSM): represents landscapes as environmental gradients using ratio data to capture the intensity of a phenomena across space.

Graph-based approaches – represent landscape as a network using nodes connected by

edges.

2. Overview of Landscape Metrics

2.1 Elements

Landscape metrics—also known as spatial pattern metrics, spatial pattern indices, or landscape pattern metrics—are algorithms that quantify the spatial structure of land cover patterns within a defined geographic area. The term ‘landscape metrics’ has historically referred exclusively to metrics for quantifying patterns in categorical maps (McGarigal et al. 2012). These conventional landscape metrics are computed using the "patch-mosaic model" (PMM; Forman 1995), which represents landscapes as mosaics of discrete patches (Figure 1). More recently, the term "landscape metrics" has been used to include other data types as well, such as graphs and continuous rasters, the latter of which are also called gradients. The computation of traditional landscape metrics using categorical maps is highlighted first, followed by a discussion of other data models below.

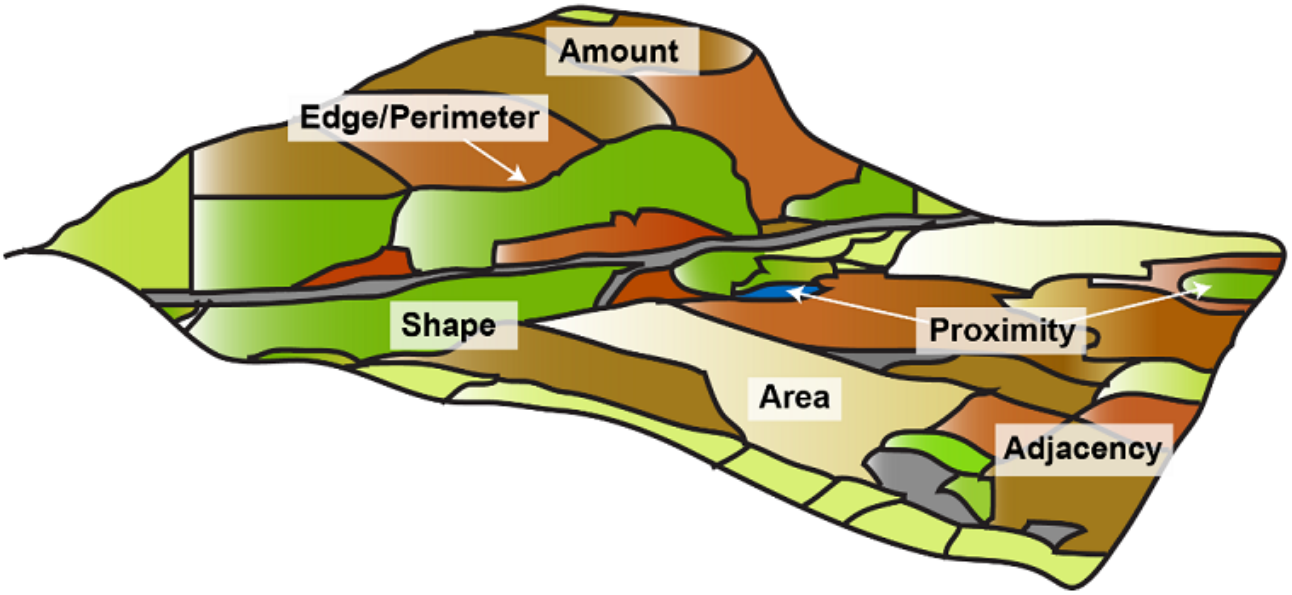


Figure 1. Conceptualization of a landscape mosaic of discrete patches. Source: author.

Landscape metrics quantify the two fundamental elements of landscape pattern: composition and configuration. **Composition** refers to the number and amount of each patch type without considering the spatial characteristics of the individual patches or their placement and location in the landscape. Examples of composition include the proportion or area of each land cover type and the number of different land cover types present in a geographic area. **Configuration** refers to the spatial arrangement and distribution of the different land cover classes. Examples of configuration include the shape of individual patches (e.g., compact or sinuous) as well as their distribution across the landscape such as whether they are aggregated or dispersed. Hundreds of metrics have been developed to quantify composition and configuration of land covers, but most rely on five basic components (Table 1).

Table 1. General Landscape Metric Components

Component	Measures
Amount	Composition: abundance and variety
Area	Composition: proportion
Perimeter	Configuration
Adjacency	Configuration
Distance	Configuration

2.2 Levels of Analysis: Cell, Patch, Class, Landscape

Patches are the fundamental building blocks for computing landscape metrics (McGarigal et al. 2012). Patches represent relatively homogenous areas of the landscape that differ from their surroundings. They can be represented with either vectors or contiguous raster cells. However, many software programs support raster inputs only, where cells are the fundamental mapping unit. In raster models, each cell in a raster contains a location (x,y for the cell center) and an attribute (e.g., land cover type). Contiguous cells with the same attributes comprise patches (Figure 2a). Certain metrics operate directly on the cells themselves (e.g., perimeter, adjacency) while others operate on the patches defined by sets of cells (e.g., number of patches). In vector models, discrete patches are delineated by vector geometries with land cover (or habitat variables) contained as attributes (Figure 2a).

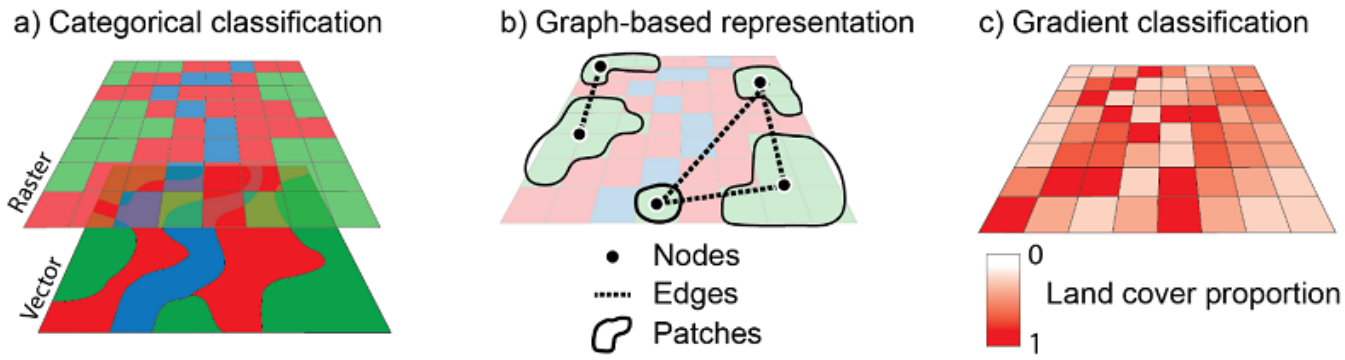


Figure 2. Different data models and landscape conceptualizations for computing landscape metrics: (a) categorical classifications in either raster or vector format, (b) graph-based representations, and (c) gradient, or continuous, classifications where cells represent land cover proportion. Source: author.

There are three conceptual levels of analysis at which metric computations can occur. Patch-level metrics are performed for each individual patch. These metrics can then be aggregated at the class-level for all patches belonging to the same land cover class type using a variety of summary and distributional statistics. Similarly, metrics for all patches in the landscape can be aggregated to provide landscape-level measures. For instance, each patch of forest in a landscape can be assessed individually for area. Then, the area of all forest patches can be averaged to provide a class-level statistic for mean patch area. Lastly, the area of all patches in the landscape, regardless of land cover type (e.g., forest, wetlands, grasslands, etc.), can be averaged to provide a landscape-level mean value for

patch area.

2.3 Spatial Explicitness

It is important to recognize that the computation of most landscape metrics is not spatially explicit, meaning the precise spatial location (x,y) of each patch is not considered in the analysis. Computations consider compositional and configurational characteristics of individual patches such as the area and perimeter. Some metrics also consider the relationships between cells or patches (e.g., class of patch or cell adjacent to the patch/cell of interest or the distance from one patch to its nearest neighbor), but these associations are not necessarily spatially explicit. Spatially explicit autocorrelation measures such as Moran's I are not suitable for analyzing landscapes represented by categorical land cover maps.

Outputs are also not spatially explicit but instead consist of a tabular list of values, with each row representing the result for a single patch, class, or the entire landscape depending on the level of analysis. While spatially explicit results can be produced by implementing a moving window or other local neighborhood technique and computing a separate metric value within each neighborhood, in these cases it is the filter producing the spatial output and not the metrics themselves.

2.4 Redundancy, Correlation, and Scale-Dependency

Since most metrics rely on the same basic measures (i.e., amount, area, perimeter, adjacency, distance), many are correlated or redundant. Metrics that measure or represent the same basic information are considered to be conceptually redundant because they inherently measure the same thing and thus provide the same information about the landscape. Metrics that include similar measures or equations for the basic components of composition and configuration are often empirically redundant because they are statistically correlated. Researchers have dedicated considerable efforts to identifying the fundamental components of landscape pattern and investigating methods to select a small set of parsimonious metrics (Gustafson 2019). It is incumbent upon the researcher to select a set of non-redundant metrics that are appropriate for analyzing the problem at hand.

Many metrics are also scale-dependent, meaning their values change as the scale (both resolution and extent) of the input data changes. For some metrics, these changes are predictable (Wu 2004) whereas in other cases, the changes are erratic. Since the resolution of the data model determines the scale of analysis, it is important to ensure that the resolution is appropriate both from an observational and analytical perspective.

3. Emerging Directions

Conventional landscape metrics for categorical, land cover maps have dominated landscape analyses, but they do have limitations. Representing the landscape as a mosaic of discrete patches with the PMM is not always ecologically appropriate, and some landscape metrics have been found to lack relevancy for landscape investigations (Kupfer 2012). New conceptual models, data streams, and software packages are moving landscape metric research into new frontiers. Three of these are highlighted below including (1) graph-based approaches, (2) surface metrics, and (3) 3D metrics.

3.1 Graph-based Approaches

Graph-based metrics are an alternative to traditional landscape metrics. In graphs, **nodes** are used to represent land cover patches, and **edges** represent connections between the nodes (Figure 2b). The landscape is thus modeled as a network instead of a patch-mosaic, allowing more complex analyses of fragmentation and connectivity. Furthermore, nodes can incorporate both qualitative and quantitative information, while edges can incorporate weights or directions (Dale and Fortin 2010), which are possible with patches in the PMM. While edge weights are typically defined according to geographic distances, they can also be defined based on non-conventional conceptualizations of distance as well, such as ‘organizational’ or ‘social’ distances, allowing graph-based metrics to capture both functional and structural aspects of landscapes.

While some graph-based metrics mimic their patch-based counterparts (e.g., area of the nodes vs. area of the patches), many provide a more functional way to assess landscapes. A popular graph-based metric is the Probability of Connectivity (Saura and Torné 2009), which measures the likelihood two nodes (patches) are "connected" functionally in a landscape. As an example, the PC index was used to prioritize vacant urban lots for connecting open spaces by assessing the probability that people would walk from an existing open space to each new patch (Frazier and Bagchi-Sen 2015).

3.2 Surface Metrics

Both patch-based and graph-based approaches represent landscapes categorically, but in the real world, land covers often gradually transition across ecotones. **Gradient surface models (GSM)** represent landscape elements using numerical (ratio) instead of categorical values (Figure 2c), thereby allowing more of the heterogeneity present in the real-world to be captured by the data model (Frazier and Kedron 2017). However, gradient surface models lack the discrete boundaries and edges on which conventional landscape and graph-based metrics rely. As a result, GSMs cannot be analyzed using the same metrics.

Surface metrics are an alternative set of algorithms for quantifying the spatial structure of land cover patterns in GSMs. Surface metrics were originally developed for mechanical engineering and manufacturing but have recently been adopted by geographers and landscape ecologists to quantify patterns in gradient landscapes (McGarigal et al. 2009; Kedron et al. 2018). They operate at the **cell-level**, and can be either spatial or aspatial. Aspatial surface metrics are based on value distributions such as a histogram or Abbott curve. Spatial metrics consider the spatial arrangement of the cell values. For instance, the surface metric "roughness average" computed for a landscape of NDVI values would provide the average NDVI of the landscape; the metric "surface skewness" would characterize any skew in the distribution of NDVI values, and the metric "texture direction" could provide information about the directionality of crop rows (if data are at a high enough resolution).

A critical difference between the PMM and GSM is that PMMs can represent multiple different land cover types in a geographic area while GSMs represent only the proportion/intensity of a single land cover variable. Additionally, the patch-, class-, and landscape-level conceptualizations that define computations of landscape metrics in the patch-mosaic paradigm do not translate into the gradient paradigm. The application of surface metrics to land cover maps is maturing, but much work is still needed to determine

meaningful interpretations of many existing surface metrics (Kedron et al. 2018).

3.3 3-D Metrics

With the proliferation of three dimensional (3D) data captured from LiDAR and other sources such as radar (Mathews et al. 2019), landscape metric development is extending into three dimensions. While raw LiDAR data consists of 3D point clouds, more often the data are processed into raster format in the form of digital elevation or terrain models (DEM/DTM) of the 'bare earth' or digital surface models (DSM) of the natural and built features. These rasters present an interesting challenge since the data are continuous, gradient surfaces of heights but objects being represented are discrete (e.g., buildings, trees, etc.). Recently, studies have been experimenting with thresholding techniques to discretize the continuous data back into categorical format.

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