Ecological Indicators 64 (2016) 158–170

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

A weighted aggregation and closeness approach to measuring the compactness of landscape with multiple parts'

Jinhao Zhou[a], Ningchuan Xiao[b], Lin Liu[a,c,*], Qiuping Li[a]

[a] School of Geography and Planning, Center of Integrated Geographic Information Analysis, Sun Yat-sen University, Guangzhou, PR China
[b] Department of Geography, The Ohio State University, Columbus, OH 43210, USA
[c] Department of Geography, University of Cincinnati, Cincinnati, OH 45221-0131, USA

ARTICLE INFO

Article history:
Received 30 June 2015
Received in revised form 4 November 2015
Accepted 11 December 2015
Available online 12 January 2016

Keywords:
Compactness
Disconnected landscape pattern
Fragmentation
Landscape ecology metrics

ABSTRACT

Existing landscape ecology measures may not effectively capture the compactness of patterns that have multiple, disconnected parts. We develop a new way of measuring the compactness of such disconnected landscape patterns. Our method uses a map generalization approach to aggregating the multiple parts into a connected polygon while preserving the overall shape of the original pattern. We then measure the compactness by considering the weighted area-perimeter ratio of the aggregated shape and the closeness between the parts. Our measure, called weighted aggregation and closeness (*WAC*), is compared with 15 other landscape ecology metrics and the results suggest that *WAC* outperforms the other metrics by providing a more reasonable description of the compactness for patterns with multiple parts.

1. Introduction

The compactness of landscape patterns is an important measure that can be used to indicate social, economic, and ecological functions of the land (Diamond and Wright, 1988; Fischer and Church, 2003). A compact shape of the landscape is often desired in various applications such as land acquisition (Shirabe, 2005; Ligmann-Zielinska et al., 2008), landscape ecology (Hargis et al., 1998; O'Neill et al., 1999; Alagador et al., 2012), nature reserve site selection and design (Fischer and Church, 2003), urban planning (McDonnell et al., 2002; Nalle et al., 2002; Li et al., 2008), and districting (Janelle et al., 2004; Grubesic, 2008). For example, compact sites often exhibit agglomeration effects with high utility and low land acquisition cost (Williams et al., 2005). Furthermore, compact landscapes may mitigate influences from the surrounding environment and cover maximal scope, which are often preferred by land acquirers, planners, and decision-makers (Xiao et al., 2002; Malczewski, 2004).

Compactness is a shape characteristic and, in a broad sense, the compactness of a landscape pattern indicates how the components of the pattern are closed or proximate to each other (Aerts et al., 2003). It is generally accepted that a landscape pattern is compact if it exhibits a circular or square shape (Tong and Murray, 2012). On class-level, compactness describes the shape of all the patches of the same type. For example, in a landscape of two types, habitat and non-habitat, we can use compactness to indicate the shape of all the habitats in the landscape. Over the past few decades, researchers who study the compactness in landscape have focused on geometric parameters of land parcels such as perimeter (Wright et al., 1983), edge or border (Onal and Briers, 2003), perimeter and area ratio (Minor and Jacobs, 1994), and total core area (Williams and Re Velle, 1996; Ohman, 2000). While these measures are effective in some applications, there often exist different spatial configurations with the same geometric parameters. To address this issue, researchers developed other measures that can be used to directly or indirectly (as a proxy) indicate the compactness. These measures include fractal dimension (Lovejoy, 1982; Milne, 1988), proximity value (Gustafson and Parker, 1992), cohesion index (Schumaker, 1996), buffer zone (Williams and ReVelle, 1998), spanning tree (Bunn et al., 2000; Kim and Xiao, 2011), shared edges (Nalle et al., 2002), and neighborhood accounts (Moilanen, 2005). It should be noted that the aforementioned methods have been applied in different studies and no particular measure has consistently performed better than others (Young, 1988; Hargis et al., 1998; Li et al., 2008; Wang et al., 2014).

Many landscape patterns consist of multiple parts that are often disconnected. For example, the forests in a study area may have several disconnected patches, and a construction project may include sites that are not geographically adjacent to each other. Existing compactness measures described above, however, are

* Corresponding author at: Department of Geography, University of Cincinnati, Cincinnati, OH 45221-0131, USA. Tel.: +1 5135563429.
E-mail addresses: HenryZhou541@163.com (J. Zhou), xiao.37@osu.edu (N. Xiao), liulin2@mail.sysu.edu.cn (L. Liu), liqp3@mail.sysu.edu.cn (Q. Li).

http://dx.doi.org/10.1016/j.ecolind.2015.12.022
1470-160X/

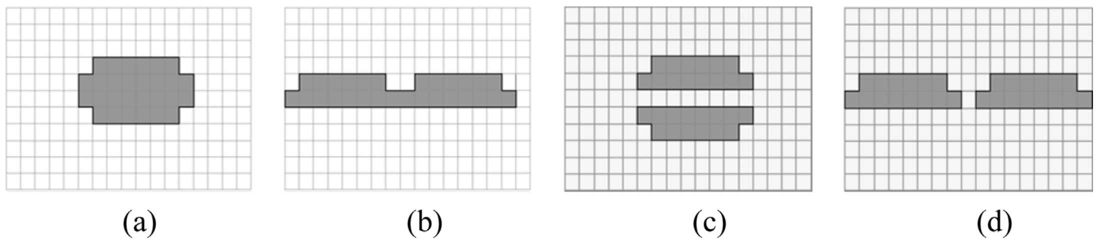

Fig. 1. Four landscape patterns consisting of two parts.

Table 1
Metrics values for four patterns shown in Fig. 1. These values were calculated using a software package called Fragstats (McGarigal and Marks, 1995).

Metrics	(a)	(b)	Metrics	(c)	(d)
Perimeter and area ratio	0.86	1.36	Mean perimeter and area ratio	1.43	
Shape index	1.09	1.73	Mean shape index	1.82	
Fractal dimension	1.08	1.35	Mean patch fractal dimension	1.22	
Related cirumscribing circle	0.48	0.86	Mean related cirumscribing circle	0.73	
Contiguity	0.75	0.58	Mean contiguity	0.57	
			Core area	0	
			Patch number	2	
			Total shared edges	36	
			Mean proximity	3.5	
			Cohesion index	90.35	
			Aggregation index	80	
			Contagion index	100	

generally designed to capture the geometric properties of landscape with interconnected parts. When the parts are disconnected, these measures may not be effective. Let us consider 4 hypothetical landscapes patterns with the same 2 parts that are arranged differently (Fig. 1). It is clear that the pattern in Fig. 1a has a more circular shape than that in Fig. 1b, and therefore we deem that the pattern in Fig. 1a exhibits a higher level of compactness than that in Fig. 1b. Commonly used landscape ecology metrics have supported this (Table 1). However, interconnected parts are often separated by roads, rivers or administrative boundaries in applications. When we apply each of the landscape metrics (i.e. mean perimeter and area ratio, mean shape index, mean patch fractal dimension, mean related circumscribing circle, mean contiguity, core area, patch number, total shared edges, mean proximity, cohesion index) to test the compactness of the two patterns where two parts are separated only one unit length (Fig. 1c and d), all return the same value for both configurations (Table 1) failing to capture any difference between them. Therefore, an improvement upon the existing metrics is much needed.

The purpose of this paper is to develop a new class-level compactness measure that extends the capability of existing metrics so that it can be applied to landscape with disconnected parts. In the remainder of this paper, the next section details the steps and formulas for computing the compactness measure. Then the new measure is tested using a variety of spatial cases and compare the results with other landscape ecology metrics. The advantages and limitations of the new measure are discussed prior to conclusions.

2. Methods

2.1. Aggregation of multiple parts

To measure the compactness of a disconnected landscape pattern, we first aggregate the multiple parts in the pattern into a connected geometric feature (Fig. 2). The aggregation should not introduce excessive additional areas to the original pattern so that the shape of the landscape can be maintained. With the connected geometry, we can then measure the compactness by comparing the original shape with the aggregated one.

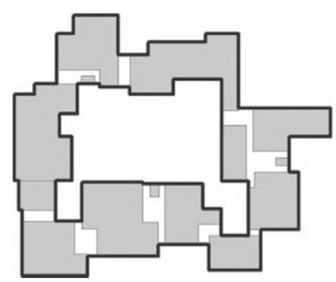

Fig. 2. Aggregation of landscape parts. The gray areas represent the original parts and the area outlined using thick lines shows the connected polygon after aggregation.

We utilize a map generalization method to aggregate the landscape parts. Map generalization as a cartographic process is often used to simplify the features on a given map in order to accommodate the change of map scale. Various techniques can be used to generalize a map, including elimination, simplification, aggregation, collapse, typification, exaggeration, and classification (McMaster and Shea, 1992). A number of methods have been developed to aggregate polygons (Jones et al., 1995; ESRI, 1996; Stoter et al., 2010). The algorithm developed in this research takes advantage of a polygon aggregation tool of ArcGIS. Given an input of the multiple parts (each being a polygon), this tool requires an aggregation distance to proceed and only the polygons that are within the specified the distance will be aggregated. To ensure that the final aggregated polygon maintains the original shape, we start from a minimal distance and then incrementally increase the distance until all the parts are aggregated. The entire algorithm is detailed as follows:

1. If the number of polygons is greater than 1, repeat:
2.   Find the nearest pair of polygon *a* and *b*
3.   Let *d* be the nearest edge-to-edge distance between *a* and *b*
4.   If *a* and *b* are disconnected, repeat:
5.   Aggregate *a* and *b* using distance *d*
6.   Increase *d* by 10%

The above algorithm merges the nearest pair of polygons in each time (lines 4–6) until all the polygons are merged (line 1). The polygon aggregation tool in ArcGIS is called in line 5. To aggregate each pair, we start from the smallest edge-to-edge distance (d) between