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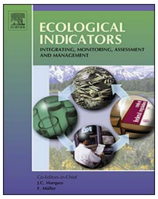

Original Articles

Suitability of different landscape metrics for the assessments of patchy landscapes in West Africa

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ABSTRACT

The study aimed at identifying a core set of landscape metrics for assessing potential ecosystem services provision and for application in spatial planning in the highly anthropogenically dominated landscapes of the Sudanian Savannah region. Twenty-two metrics for ES services assessment and spatial planning selected from literature were calculated. We employed Spearman's rank correlation and multivariate principal component analysis factor analysis to identify redundancies between the assessed metrics and select the most promising ones. In our conclusion, we suggest the use of effective mesh size (MESH), mean patch size (AREA_MN), landscape patch index (LPI), COHESION, and aggregation index (AI). While MESH, AREA_MN, and LPI could be appropriate for assessing ecosystem services in our African landscapes, COHESION and AI could represent the most plausible utility metrics for application in spatial planning because they were less redundant. However, application of these metrics in these areas of study is possible if initial preconditions such as spatio-temporal data quality, scale of application, and objectives for their adoption are satisfied.

1. Introduction

Globally, landscapes have been considered as a system composed of functionally interacting land units whose composition and configuration influence the landscape's ability to trap and retain resources such as rain water, soil particles, organic matter, and to provide needed habitats for flora and fauna (Bastin et al., 2002). Human activities such as agriculture and urban development (specifically settlement expansion as well as road and dam construction), as well as various abiotic and biotic processes shapes the landscape structure and patterns (Van Eetvelde and Antrop, 2004; Turner, 2005; Plexida et al., 2014). Landscape structure has not only been used to evaluate the ecological value of landscapes, but also to measure ecological aspects of the sustainability of land use patterns (Odum and Turner, 1989; Wrbka et al., 2004). Other related studies have focused on how increasing human influence on landscape structure shapes the landscape's ability to produce required functions and services for the resilience of the landscape (Wu and Hobbs, 2002). Hence, for relevant landscape management planning and decision making, several authors have shown that quantifying the spatial character of vegetative patches of landscapes presents a useful proxy for assessing the landscape's ability to perform functions such as water and nutrient retention. Among other things, quantifying the landscape's spatial structure provides an understanding of the underlying impact on ecological processes (Braimoh, 2006), and more importantly helps to monitor the effect that changing patterns has on ecosystem services (ES) provision. Some authors have studied the strong interlinkages between landscape structural properties, ecological processes and functions (Turner, 2005). However, for a broader understanding of landscape functions, landscape metrics (LM) have been used as indicators for landscape assessment. As a widely used technique, LM are predominantly used in combination with other traditional landscape pattern analytical approaches to analyze and evaluate landscape mosaics and the spatial arrangement of the landscape structure (McGarigal et al., 2002; Haines-Young and Chopping, 1996;

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Walz, 2011; Uuemaa et al., 2012; Walz et al., 2016). While Blaschke (2006) applied LM to provide valuable information **to** the design of sustainable strategies for planning purposes, Billeter et al. (2008) used LM to monitor biodiversity on agricultural landscapes. Similarly, Fu et al. (2006) applied LM to investigate how the changes in the agricultural landscapes of the Ansai County, China, affect ecological sustainability of that landscape. In 2001, the European Environment Agency used LM as indicators to monitor changes in the agricultural landscape gradient.

Similarly, Syrbe and Walz (2012) argued that the spatial arrangement of landscapes must be considered, because they play a significant role in their influence on ecosystem service generation and benefit to humanity. Feld et al. (2007) explored the option of using LM to assess spatial pattern induced by the landscape structure and their impact on structurally related ES. Nonetheless, the adoption of LM to assess landscape services in the context of spatial planning assumes a slightly different approach. The initial process requires quantitative assessment of landscape heterogeneity and structure. This is followed by a selection of landscape based metrics of biotope, surface, and land use structure required to efficiently capture and analyze the ecological system. Beyond exploring geobiophysical properties to assess soil erosion on large territories, LM in general have been useful in assisting landscape managers in understanding how landscapes function in order to retain vital resources in the aftermath of soil erosion (Ludwig et al., 2002). Another practical approach in the use of LM for improved assessment of ecological functioning and aesthetic value of a region is provided in Frank et al. (2012) and Dramstad et al. (2006), respectively. Additionally, Uuemaa et al. (2007) used LM to assess ground water quality. Likewise, the Mid-Atlantic Landscape indicators project conducted by the United States Environmental Protection Agency (EPA) used landscape indicators to identify trends and monitor landscape changes and to determine ecosystem health (EPA, 1995).

Despite the increasing adoption of LM to understand and monitor trends in landscape structural changes and their influence on ES, we have limited knowledge and scope of the application of these indicators for ecological and or planning research in the West African Sudanian Savanna landscapes. However, the application of LM in this region could be relevant for several reasons. First, a greater share of the Sudanian Savanna landscape and its related ecosystems have been shaped by anthropogenic activities with natural flora areas converted into other land uses. For instance, agricultural production and mining activities northwards of Upper East region, Ghana, leads to high fragmentation of the landscapes structure. Gastellu (1978) predicted an increasing trend in land fragmentation resulting from the extreme homogenization and unequal patterns of the land tenure systems practiced. However, to date, land fragmentation resulting from ownership of small sizes of 0.04 ha to large sizes of about 16.2 ha plots in different locations with multiple uses within a year poses greater challenges to landscape and land use planning, management and monitoring (Amanor-Boadu et al., 2015).

Secondly, consistent mixed cropping with shares of trees and grasses in different arrangements has resulted in few small forest patches with limited original biodiversity conserved (Laube, 2007). According to Zougmoré (2003), over 40% of agricultural lands in this region suffers under human-induced degradation with over 80% of the area under extensive rather than intensive cultivation (Ouattara, 2007). Insufficient moisture due to high rainfall variability, high temperatures and frequent droughts (Challinor et al., 2007; Yilma, 2006) together with poor soil fertility and nutrient availability resulting from annual burning of vegetation and crop residues (Sanchez, 2002) poses greater ecological constraints. According to the World Bank report (2009), lack of farmers' technical knowledge of agricultural landscape management with respect to proper structural arrangement of multiple land uses results in loss of requisite ES and landscape functions necessary to ensure landscape resilience in the phase of changing climate. Continuous advocacy by scientists against the ongoing shift in ecological zones, specifically the savannization of limited forest patches in the savanna (Aihou, 2003), calls for scientifically verifiable methods to monitor the decreasing trends of landscape functions from savanna landscapes to inform landscape management decisions. Finally, government's failure to enact policies to favor agriculture intensification instead of extensification could further destroy the biodiversity and ecosystems functions in this region.

There is an essential need for the development of sustainable indicators for the assessment of dynamic landscapes such as those of the Ghanaian Sudanian Savanna agricultural landscapes. Nonetheless, two key questions that remain unanswered in the Sudanian Savanna region point at which appropriate LM could be useful for: 1) recording ecosystems services (Dale and Polasky, 2007), and 2) applying spatial planning practices.

Previous authors have developed and assessed landscape structural variables at the landscape and class levels (McGarigal and Marks, 1995; Riitters et al., 1995) and **a**rgued that although several metrics could be used to characterize a particular landscape due to the difference in spatial patterns, the use of highly correlated indices could lead to false results and interpretations (Li and Wu, 2004; Schindler et al., 2008). Relatively uncorrelated metrics must be selected and evaluated to enable analysts make reliable and unbiased contributions to the objective under assessment (Turner et al., 2001). Independent but reliable studies across American and European landscapes have identified core set of metrics for the assessment of landscape heterogeneity and the relationship of human activities that shapes the landscape properties (Botequilha et al., 2002; Schindler et al., 2008). The most common methods for deriving a non-redundant set of metrics have been based on statistical and analytical approaches including Principal Component Analysis, Hierarchical Cluster Analysis, and Factor Analysis suggested in Wu et al. (2002), Riitters et al. (1995), Schindler et al. (2008), and McGarigal et al. (2009). Building on the techniques suggested above, Plexida et al. (2014) identified 10 key landscape metrics to describe landscape patterns irrespective of scale and cautioned, however, that a single metric cannot succinctly capture the pattern in the study of a particular landscape.

Yet, what is consistently missing in West Africa is limited approaches to identify a core set of metrics to assess the influence of landscape structure on **ES** and land use planning. In the initial phase, it is relevant to characterize the Sudanian Savanna landscape to understand its measurability. The main aim of this study is to explore the transferability of existing landscape metrics to an assessment of patchy landscapes in West Africa. Our specific objective was to explore and test a core set of indices that capture important aspects of patchy landscape patterns using the Vea catchment of the Upper East region as a model region. Prior to the assessment, we included landscape metrics popularly used for assessing ES and spatial planning on the basis of literature reviews. To test the replicability of our approach across our study location, we adopted the cellular automaton approach to generate realistic landscapes in GISCAME (Geographic Information System Cellular Automaton Multi-criteria Evaluation) for this purpose.

2. Methods

2.1. Study area

Our study was undertaken in two districts; Bolgatanga Municipal (latitude 10° 46′N and Longitude 0° 51′W) and Bongo district (lies on longitude 0°.45′W and between latitudes 10° 50′N and 11° 09′N), both located within the Vea Catchment area (located between latitudes 10° 30′ to 11° 8′ North and longitudes 1° 15′ West and 0° 5′ East) of the Upper East region of Ghana (Fig. 1). Whereas the actual catchment covers an area of about 300 km^2, the riparian region within which our study is focused covers an area of about 1200 km^2. Hydrologically, the area falls within the White Volta sub-basin system. The main climate is the Sudan-Savannah climate zone with high mean monthly