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Designing neutral landscapes for data scarce regions in West Africa

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ABSTRACT

Despite its popular adoption and use, neutral landscape models have been unexplored in data scarce areas of the Sudanian Savanna region where its application could serve as inputs for spatial ecosystem service assessment. Thus, the need for an easy to use tool to produce landscape patterns similar to real landscapes in this area is imminent. In this article, we aimed at introducing SG4GISCAME as a tool to meet this purpose by exploring it capabilities to generate landscapes similar to real agricultural landscapes of the Vea catchment area in Ghana in three steps. We used Voronoi tessellation polygons to develop the image patterns. The resulting artificial patterns were subsequently evaluated through a visual and landscape structural metric comparison between the simulated and real landscapes. Finally, we used a modified Turing Test to test the credibility of SG4GISCAME model output through expert pattern identification cues. The results show that SG4GISCAME can successfully generate agricultural landscape mosaics similar to real landscape under different parameters and user specifications. We attribute this to the tools' intuitive and interactive user interface. Statistical test outcomes of the modified Turing Test suggested that geographic information systems and remote sensing map experts found marked pattern similarities between real and synthesis maps, resulting in challenges in identifying real maps from synthetic ones. Our approach could be replicated in other landscapes of West Africa to provide a substitute for unavailable or expensive spatial data and to test the hypothetical relationship between patchy landscape structure and ecosystem service provision through modelling.

1. Introduction

The past three decades have seen increasing approaches and proposals by scientist on providing an integrated, predictive, and adaptive approaches to assess, manage, and monitor ecosystems services (ES) such as flood control, food, biomass production, and aesthetics at local, national, and international scales respectively (Ayensu et al., 1999). Both, spatial (Frank et al., 2012a; Frank et al., 2012b) and non-spatial (Cowling et al., 2008) ecosystem services (ES) assessment play key roles in synthesising and communicating complex land resource information to inform and influence policy and decision-making processes (Ash et al., 2010; Wilson et al., 2014). Generally, results from these assessments target policy decisions and governmental initiatives to effect changes for environmental sustainability and human wellbeing. However, the quest to improve the essentials of ecosystem services assessment (ESA) to policy consulting and integration in some part of the Global South has failed due to the absence of land use land cover.

In Africa, significant progress has been made through the Southern African Sub Global Assessment (SAfMA) initiative (van Jaarsveld et al., 2005), considered a part of the larger Millennium Assessment (MA), for Sub-Sahara African countries to develop cross-scaled methods and frameworks for ES assessment. However, growth and opportunities in ES assessment approaches and methods have been sporadic. The incidence of spatial data gaps resulting from persistent cloud cover (Forkuor et al., 2014) in West Africa (WA) is an underlying factor for the subregion's limited contribution towards the development of ES assessment framework to address ES policy and decision making. Solutions to the issue of data gaps emanate from a consideration of where gap exist. In one instance, gaps may arise from empty spot in satellite images, thus requiring algorithms to fill these gaps. In another instance, gaps may arise from the critical absence of data, requiring the need create new landscapes using neutral landscape modelling (NLM) approaches. We focus on the latter in this article.

The challenge further inhibit the potential to explore the relevance of ES assessment and its inherent opportunity in identifying land management options aimed at optimizing human and environmental

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benefits while reducing ES trade-offs. Thus, alternative options for generating spatial landscape patterns for structural ES assessment in WA is worth exploring. In examining existing approaches to alternative landscape generation, Pe'er et al. (2013) compared the outcome of pattern based models and process based landscape generators and found that though the former are simple to implement, their spatial pattern outcomes are usually fragmented. Relatedly, the later produced highly realistic patterns and appeared too complex for generic applications as a replacement for real landscapes. Nonetheless, the authors argued in favour of process based models due to their reproducibility for a wide range of spatial patterns under explorative cases.

Neutral landscape models (NLM), a process based model, have been used to generate landscapes without the influence of underlying ecological processes which naturally act to determine landscape composition and configuration (Gardner et al., 1987; Gaucherel, 2008). NLM adopts a raster based approach to randomly allocate land uses to pixels and utilizes several algorithms to cluster them (Saura and Martínez-Millán, 2000). In principle, key characteristics of patch geometry, neighbourhood rules or typologies, and land use attribute are explicitly factored in NLM. Thus, in comparison to process-explicit models and or geostatistical models, NLM provides random landscape structures as a basis for comparison with real landscape patterns (Gardner et al., 1987; Le Ber et al., 2009). The NLM approach has a wide application area in science. For instance, while fractal models have been widely employed in the past to model forest landscape mosaics (Kurz et al., 2000), polygonal approaches through tessellation modelling have been used to model landscape for application in agronomy and land use planning (Le Ber et al., 2009).

Since real data are unavailable and too expensive to acquire in high resolution standards in WA, we propose the use of NLM to develop landscapes to investigate prospect for best landscape configurations for ES assessment and to influence landscape management policy consideration. To our best of knowledge, there exist no neutral landscape generators or models to simulate landscape under different management types in this subregion.

Thus, we propose to use SG4GISCAME to simulate agricultural landscapes of the Vea catchment area of the Upper East region of Ghana and test their configurational and compositional characteristics to real landscapes. Based on this objective, an appropriate algorithm which generates landscapes with close similarities to a real landscape on the basis of tessellation polygons should be investigated.

The objectives of this study are to: 1) explore different algorithms to create artificial landscapes as basis for ES assessment; 2) assess simulated results of these algorithms using land cover data from model regions with the aid of landscape pattern indices to test the reliability of the algorithms and recommend solutions for particular data situations; 3) test the credibility of the outcome of the SG4GISCAME using a modified version of the Turing Test (Hargrove et al., 2002); and 4) discuss the potential transferability of SG4GISCAME to other project areas in order to support ES assessment in West Africa. To critically appraise the third objective, we hypothesized that an expert's ability to make a correct selection is based on the experts experience and not on randomness.

To achieve our objectives, we simulate agricultural landscapes using tessellation methods implemented in SG4GISCAME[1]. Our model, SG4GISCAME (see Section 2.3), is developed on the basis of the polygon decomposition algorithm for generating arbitrary polygons. The study was carried out in the Vea Catchment area, Upper East, Ghana. This area is one out of the three research areas under the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) project. The overarching goal of WASCAL, which directly interfaces with the aims of this research, is to explore alternative modelling approaches to provide model data and technical suggestions to the incidence of data unavailability for ES assessment within the project countries.

2. Methods

2.1. Creating artificial landscapes

Tessellation in GISCAME can be based on midpoint or random midpoint displacement (Saupe, 1988; Feder, 1988; Palmer, 1992) to create artificial landscapes as basis for exploring which landscape pattern are optimal for providing ecosystem services (see Inkoom et al., 2017). Though both methods have been well researched and documented elsewhere (see Saupe, 1988; Feder, 1988; Keitt, 2000; Etherington et al., 2015; Cambui et al., 2015; van Strien et al., 2016), we sought to employ the complexity of their underlying fractal outcomes to create landscapes as a basis for implementing a set of landscape metrics in support of the ES assessment (Frank et al., 2012b). In a related case, the task to assess current Sudanian Savanna landscapes and their future development regarding a transition from the current highly patchy landscape pattern to potentially more homogenous and less patchy landscape pattern resulting from merging agricultural parcels.

To realize this, we performed the following procedures (see Fig. 1) to create new landscapes:

- Step 1. Triangulation: here, the area of the region is separated into an infinite number of triangles for which a regular midpoint was determined as a first step.
- Step 2. Merging: here we modified the midpoint of triangulated polygons from Step 1 to obtain irregular triangles which – after merging them – provide more realistic polygons over which potential land use types will be distributed in Step 3. To determine the next central position for polygon decomposition, a tolerance area is defined so that user-designed irregular triangles are generated. Alternatively, a random process to define where the mid-point should be located can be activated. The decomposition continues until the final triangle under the specified maximum cell area size is created. The resulting initial triangles are merged into polygons in accordance with defined max/min tolerance levels and areas. Considered a model calibration requirement, we define tolerance levels as a range of values in measurable unit, used to specify the extent of acceptable deviation of a model parameter in order to eliminate unintended outputs while optimizing model performance and influencing realistic outcomes. Further, tolerable, or intolerable neighbouring land use types can be defined as basis for the land use distribution. Where similar landscape types are within a close proximity neighbourhood, they merge into a unique polygon class. In our case, we used statistical information representing the typical average plot sizes and shape forms in the case study area to obtain initial pattern and make assumptions regarding how average sizes and forms could change in future.
- Step 3. Statistical distribution of land use types: Here, land use types are allocated based on existing land management practices specified in Step 2. Of specific interests are the tolerable or intolerable neighborhood land use types specified to: 1) maintain polygonal forms; and 2) serve as transition probabilities for land use type distribution. This is controlled using statistical information on the average area of each land use type, and minimum or maximum values for the polygon sizes. For future landscapes, users could make hypothetical assumptions regarding how land use type allocations could look like.

Finally, the resulting vector data are transformed into raster data. In it virtual state, users can alter or refine the shapes of the initial output using either a manual distribution option, or through the use of the

[1] The structure generator, SG4GISCAME, is a module within the GISCAME Software Suite.