Journal of Environmental Management 209 (2018) 393–408

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

A framework to assess landscape structural capacity to provide regulating ecosystem services in West Africa

Justice Nana Inkoom [a, c, d, *], Susanne Frank [b], Klaus Greve [c], Christine Fürst [d]

[a] Center for Development Research (ZEF), Department of Ecology and Natural Resources Management, University of Bonn, Walter-Flex Strasse 3, 53113, Bonn, Germany

[b] GICON Großmann Ingenieur Consult GmbH, Tiergartenstraße 48, 01219, Dresden, Germany

[c] Geographisches Institut der Universitaet Bonn, Postfach 1147, D-53001, Bonn, Germany

[d] Institute for Geosciences and Geography, Department Sustainable Landscape Development, Martin Luther University Halle-Wittenberg, Von-Seckendorff-Platz 4, 06120, Halle, Germany

A R T I C L E I N F O

Article history:
Received 7 September 2017
Received in revised form
7 November 2017
Accepted 10 December 2017

Keywords:
Regulating ecosystem services
Landscape configuration
Expert weighting
Analytical hierarchical process
Landscape metrics
GISCAME

A B S T R A C T

The Sudanian savanna landscapes of West Africa are amongst the world's most vulnerable areas to climate change impacts. Inappropriate land use and agriculture management practices continuously impede the capacity of agricultural landscapes to provide ecosystem services (ES). Given the absence of practical assessment techniques to evaluate the landscape's capacity to provide regulating ES in this region, the goal of this paper is to propose an integrative assessment framework which combines remote sensing, geographic information systems, expert weighting and landscape metrics-based assessment. We utilized Analytical Hierarchical Process and Likert scale for the expert weighting of landscape capacity. In total, 56 experts from several land use and landscape management related departments participated in the assessment. Further, we adapted the hemeroby concept to define areas of naturalness while landscape metrics including Patch Density, Shannon's Diversity, and Shape Index were utilized for structural assessment. Lastly, we tested the reliability of expert weighting using certainty measurement rated by experts themselves. Our study focused on four regulating ES including flood control, pest and disease control, climate control, and wind erosion control. Our assessment framework was tested on four selected sites in the Vea catchment area of Ghana. The outcome of our study revealed that highly heterogeneous landscapes have a higher capacity to provide pest and disease control, while less heterogeneous landscapes have a higher potential to provide climate control. Further, we could show that the potential capacities to provide ecosystem services are underestimated by 15% if landscape structural aspects assessed through landscape metrics are not considered. We conclude that the combination of adapted land use and an optimized land use pattern could contribute considerably to lower climate change impacts in West African agricultural landscapes.

1. Introduction

Growing international research efforts have focused on the protection of biodiversity and ecosystem services (ES) in response to decreasing resilience of land systems towards climate change (CC). After releasing the Millennium Ecosystem Assessment (MEA) report in 2005, several countries across Europe and America institutionalized policy frameworks to identify, map, monitor, and evaluate the changing pattern of ES and biodiversity degradation across different scales (see Maes et al., 2016; IPBES/4/8). The assessment frameworks and standards defined by MEA[1] or TEEB[2] and Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES) provide guidelines for how the value of nature and different ecosystems from different landscapes

* Corresponding author. Center for Development Research (ZEF), Department of Ecology and Natural Resources Management, University of Bonn, Walter-Flex Strasse 3, 53113, Bonn, Germany.
E-mail address: j.inkoom@uni-bonn.de (J.N. Inkoom).

[1] Millennium Ecosystem Assessment (MEA) (Source: http://www.millenniumassessment.org/en/index.html).

[2] The Economics of Ecosystems and Biodiversity (TEEB) (Source: http://www.teebweb.org/).

https://doi.org/10.1016/j.jenvman.2017.12.027
0301-4797/

can be assessed (Fürst et al., 2012). Intergovernmental mapping and assessment through IPBES helps to standardize and further develop methods, frameworks, and assessment tools for an efficient mapping and assessment of ES for developed and developing countries.

Specific attention has been paid to studies with focus on forest ES, urban and rural ES, as well as river and watershed ecosystems with limited focus on ES provided by agricultural landscapes (Leh et al., 2013; Boafo et al., 2015; Sinare et al., 2016). Studies on agroecosystem services have focused on provisioning services (Huang et al., 2015), while regulating services have been narrowly studied within the past decade (Burkhard et al., 2015). Focusing on agricultural landscapes, Dale and Polasky (2007) and Reyers et al. (2010) found multiple interrelationships between agricultural management practices and ES provision. They found that the attraction of pollinators across agricultural lands increases crop yields thus serving as a provisioning service. Relatedly, crop diversification as a farm management approach in developing countries resulted in a mean increase in crop yield by about 79 percent (Pretty et al., 2006). Nonetheless, no study exists to explore the potential trade-offs of this management practice on the provision of other related agroecosystem services such as flood control. Most scientific studies frequently estimated ES provisioning capacities by scaling up the results from single ecosystems or land uses, while the question of how to optimally structure land uses in agricultural landscapes is only rarely studied (Frank et al., 2014). The argument that regulating ES such as flood mitigation and water erosion control are determined by landscape structural characteristics such as configuration, size, and the form of the land use classes is not new (Goldman et al., 2007; Fürst et al., 2016). However, research on the dependence of regulating services related to CC and how the resilience of land systems can be improved through "optimal" restructuring of land uses and other landscape elements is missing (Bennett et al., 2009; Fürst et al., 2012).

Many studies have introduced several assessment methods which utilizes land use types as clues for ES provision due to their proximity to human settlements (Chan et al., 2006; Ruhl, 2016). Troy and Wilson (2006) used land cover classes to account for the connectivity of settlement clusters to other land use classes. In South Africa, Egoh et al. (2008) combined maps of soil erosion potential and vegetation cover to create a map of soil retention as a proxy for assessing regulating services. Burkhard et al., 2009, 2015 utilized an assessment matrix to link land cover information obtained from remote sensing and GIS with expert interviews. Busch et al. (2012) argued that though these approaches provide an understanding of the nature of ES provisioning from different land cover types, they have been criticized for not being reliable due to the limited knowledge and objectivity of the expert involved. In recent publications, Baral et al. (2013) and Jacobs et al. (2015) employed quantitative and qualitative approaches to assess uncertainties aimed at minimizing experts subjectivity of the assessments. The use of landscape metrics (LM) as a proxy for assessing ES provisioning capacities at the landscape scale has only recently experienced attention (Fürst et al., 2010a,b; Frank et al., 2012a,b; Syrbe and Walz, 2012). To assess the impact of the landscape structure on the provision of landscape aesthetics as a cultural service, Frank et al. (2012a,b) found that without including landscape metrics in the assessment process, the actual potential of the poorly structured agricultural landscapes of the Region of Saxony, Germany, would be over-estimated in a practical landscape planning context. In Jordan, Albalawneh et al. (2015) combined the LM approach with Analytic Hierarchy Process (AHP) to prioritize and assess potential agricultural landscape sites suitable for water harvesting.

In West Africa (WA), increasing population, urbanization, extensive instead of intensive agricultural practices, poor land use planning, and land management strategies continuously jeopardizes sustainable ES provision. The reliance on primary agricultural production for consumption and livelihood sustenance combined with extreme CC impacts requires a pragmatic approach for spatial explicit mapping. The focus reflects the status and potential loss of ES provisioning capacities in this region and suggests alternative landscape and farm level management options to support decision-making in agricultural systems (Swinton et al., 2007; Crossman et al., 2012; Frank et al., 2012a,b; Callo-Concha et al., 2013; Singh, 2013; Schulp et al., 2014; Burkhard et al., 2015; Inkoom et al., 2017a). Nonetheless, the stifling scientific progress which challenges mapping and assessment of ES in WA is caused by lack of appropriate data resulting in uncertainty and qualitatively poor assessment results (Eigenbrod et al., 2010; Forkuor et al., 2014; Inkoom et al., 2017b).

This paper introduces a semi-quantitative ES assessment framework that combines expert knowledge on land use and land management with landscape metrics assessment adapted to the specific case of West African agricultural landscapes. Due to the extremely small patches and very heterogeneously mixed cropping systems, the usability of metrics developed for European or North-American agricultural landscape to these landscapes are usually questionable. The underlying assumption of our case study was that the more heterogeneous an agricultural land use pattern is, the higher the landscape's capacity level to provide regulating ecosystem services and to enhance the land systems resilience towards CC. Further, we tested our assessment of landscapes' capacity to provide regulating ES with and without the influence of landscape structure under two landscape resilient scenarios. Our assessment was based on the GISCAME,[3] a framework that facilitates the development of land use/land cover change scenarios together with experts or based on transition probabilities (Fürst et al., 2010a,b; Frank et al., 2013). GISCAME includes a set of landscape metrics to assess fragmentation, connectivity and landscape diversity as criteria that might affect landscape capacities to provide ES (Frank et al., 2010, 2012a,b; 2013; Koschke et al., 2012, 2013). We adapted the inherent evaluation bases for ES assessments by local expert knowledge including an appraisal of the uncertainties of this information. **We implemented this framework within the context West African Science Service Center on Climate Change and Adaptation Land Use (WASCAL) project with the aim of providing technical and practical recommendations to farmers and planners amidst continues climate change impact.** Finally, we discuss lessons drawn from our case study as a pioneering research in WA.

2. Methods

2.1. Conceptual framework

By this framework, we seek to express essential methodologies applicable for ES assessment in our case study location as a means to improve the reliability, validity, and replicability of our methods and results to other domains of assessment. Our proposed assessment framework combines independent methodologies in a systematic order to arrive at the overall goal assessing the landscapes capacity to provide ES. The framework is in three main components: identification, quantification, and appraisal. Though the components presented here are separate, a key feature in the main framework is the interrelationships and interdependencies. While

[3] Geographic Information System Cellular Automaton Multi-criteria Evaluation (GISCAME) formerly known as "Pimp Your Landscape" – (Source: http://www.giscame.com/giscame/english.html).