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The relationship between satellite-derived indices and species diversity across African savanna ecosystems

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A B S T R A C T

The ability to use remotely sensed diversity is important for the management of ecosystems at large spatial extents. However, to achieve this, there is still need to develop robust methods and approaches that enable large-scale mapping of species diversity. In this study, we tested the relationship between species diversity measured in situ with the Normalized Difference Vegetation Index (NDVI) and the Coefficient of Variation in the NDVI (CVNDVI) derived from high and medium spatial resolution satellite data at dry, wet and coastal savanna woodlands. We further tested the effect of logging on NDVI along the transects and between transects as disturbance may be a mechanism driving the patterns observed. Overall, the results of this study suggest that high tree species diversity is associated with low and high NDVI and at intermediate levels is associated with low tree species diversity and NDVI. High tree species diversity is associated with high CVNDVI and vice versa and at intermediate levels is associated with high tree species diversity and CVNDVI.

1. Introduction

Savanna ecosystems constitute approximately 20% of the area of world's terrestrial ecosystems (Sankaran and Anderson, 2009; Van Wilgen, 2009). One-fifth of the world's population depends on the savanna ecosystem (Solbrig et al., 1996; Parr et al., 2014). These ecosystems also contain 5–20% of the world's herbivore biomass (Owen-Smith, 1993; Cowling et al., 2004; Sankaran et al., 2005). Thus, the ability to understand patterns of species diversity in savanna ecosystems, especially at large spatial extents is important for their efficient management and conservation. In this regard, the need for methods that can achieve this large scale mapping is critical.

The development of satellite remote sensing has provided an opportunity to map diversity at large spatial extents (Nagendra et al., 2010; Rocchini et al., 2015). In fact, remotely sensed data provide an effective and evident way to address ecological patterns at different multiple scales (Simova et al., 2013). However species distribution patterns are easier to map at a broader scale compared to fine-scale distributions (Kerr and Ostrovsky, 2003; Gillman et al., 2015). To this end, several studies have used remote sensing to map species diversity in ecosystems (Scheiner and Jones, 2002; Rocchini et al., 2010b; Hernandez-Stefanoni et al., 2015). The main drawback with most of these studies has been their focus on one type of ecosystem, thus making generalizations difficult or impossible. Development of general understanding of the relationship between remotely sensed indices and diversity is, therefore imperative for enhancing the understanding of diversity in ecosystems. Savannas particularly exist in different states depending on moisture regimes (Devine et al., 2015). For example, Southern African savannas exist as dry savanna, wet savanna and coastal savannas (Scholes and Archer, 1997; Scholes and Walker, 2004; Devine et al., 2015). There are differences in species composition, structure and ecological processes between dry savannas, wet savannas and coastal savannas (Justice 1994). Thus, developing remote sensing models that can be applied generally across various ecosystems is crucial.

The application of remote sensing in understanding ecological patterns in savanna woodlands principally depends on the suitability of the remotely sensed indices used to relate to ground measurements of biological diversity (Mutowo and Murwira, 2012; Hernandez-Stefanoni et al., 2015) as well as on whether these indices incorporate the range of variation in the savanna ecosystem. Satellite-derived vegetation indices, such as the Normalized Difference Vegetation Index (NDVI) have been shown to be useful estimates of productivity and can also be used to quantify vegetation-related spatial heterogeneity thereby shap-

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Table 1
Description of the seven study sites, the soil data of Zimbabwe (Kutsaga, Shurugwi) was extracted from (Nyamapfene 1991), the soil data of Zambia (Kaoma, Kasenu, Simungoma) were extracted from (Trapnell et al., 2001) and the soil data of Mozambique (Miti, Mofid) were extracted from (Maria and Yost, 2006).

Site	Location	Mean Annual Rainfall (mm)	Mean Annual Temperature	Soils	Vegetation data
Kutsaga	17° 55′S 31° 08′E	850	18.6 °C	Ferallic cambisols	Miombo woodlands dominated by *Julbernadia globiflora*, and *Brachystegia spiciformis*
Shurugwi	19° 58′S 29° 51′E	800	17.6 °C	Lithic leptosols	Miombo woodlands dominated by *Julbernardia globiflora*, Msasa *Brachystegia spiciformis* and *Terminalia*.
Kaoma	15° 70′S 24° 45′E	1100	21.5 °C	Ferrallic arenosols	Miombo woodlands characterized by *Brachystegia, Julbenardia paniculta and Marquesia marcroura Isoberlinia Angolensis,*
Kasenu Simungoma	15° 30′S 25° 30′ E	1000	27.7 °C	Ferrallic/ cambic arenosols	The Kalahari woodland dominated by *Cryptosepalum*
Miti	11° 39′S 39° 33′E	1000	31.7 °C	Ultisols	Miombo woodland dominated by Dry Deciduous Thicket with *Guibourtia schliebenii*
Mofid	11° 43′S 39° 47′E	1400	26 °C	Oxisols	Sclerophyllous species which include *Manilkara sansibarensis*, *Warneckea sansibarica* and *Baphia macrocalyx*

ing biodiversity patterns (Tucker and Sellers, 1986; Thiollay, 1997; Shimabukuro et al., 1998; Loboda et al., 2013; Girma et al., 2016). In addition, the variance in NDVI has also been used as a useful measure of diversity in ecosystems (Bongers et al., 2009). The variance in NDVI as an index for estimating diversity in ecosystems is well supported by the spectral variation hypothesis. The theory of Spectral Variation proposes that spatial variation on a remotely sensed image is related to spatial variations of the environment which reflects habitat heterogeneity (Rocchini et al., 2010a; Heumanna et al., 2015). Therefore, habitat heterogeneity is linked to the structural complex of habitats which may provide environmental resources leading to an increase in species diversity (Oldeland et al., 2010). Although, variance in NDVI has been used to successfully characterize tree species diversity in the dry savanna woodlands of Mukuvisi, Mutirikwi and Mabalauta in Zimbabwe (Mutowo and Murwira, 2012), this work did not include various types of savanna such as wet savanna sites, as well as, coastal savannas. Thus, the inclusion of different savanna sites in modeling the relationship between species diversity and remotely sensed indices could improve our capacity to map diversity at large spatial extents. Therefore, in this study, we test the hypothesis that tree species diversity and satellite-derived indices of NDVI should be positively correlated, and that tree species diversity will be positively correlated with the Coefficient of Variation of NDVI.

The use of remote sensing in ecology is vital as it has been widely used to identify spatial and temporal patterns in biodiversity in different ecosystems over a period of time (Wiens et al., 2009). Remotely sensed spectral heterogeneity information also offers an inexpensive means to derive spatially complete environmental information for large areas in a consistent and systematic manner (Levin et al., 2007; Rocchini et al., 2010b). Ecologists may gain critical knowledge about the drivers of the spatial and temporal distribution of biodiversity at any given time (Pettorelli et al., 2014). Through the use remote sensed data, we can understand the positive as well as the negative impacts on biodiversity, predictions about the future and action to prevent ecological degradation strategy to mitigate adverse the impacts observed (Dodson et al., 2000; Zellweger et al., 2013). Principled and appropriate forest management can lead to increased biological diversity (Parma and Shataee, 2013).Explaining the mechanisms driving the observed relationships is of fundamental importance to understanding the determinants of biodiversity (Mittelbach et al., 2001).The biodiversity patterns observed may suggest dynamic, nonequilibrium community processes encountered in ecosystems (Graham and Duda, 2011). Remote sensing approaches may provide planners and conservation biologists with an efficient and cost-effective method to study and estimate biodiversity different ecosystems (Levin et al., 2007).

In this study, we tested the relationship between species diversity measured in situ with the NDVI and CVNDVI derived from high and medium spatial resolution satellite data in dry, wet and coastal savanna woodlands. We selected the study sites in the dry savanna of Zimbabwe, wet savanna of Zambia and coastal savanna in Mozambique because they experience different climatic conditions which as a result influence different ecological patterns.

2. Materials and methods

2.1. Study area

The study was carried out at 7 study sites (Fig. 1a): Zimbabwe (Kutsaga and Shurugwi), Zambia (Kaoma, Sesheke Simungoma, and Sesheke Kasenu) and Mozambique (Miti and Mofid) (Table 1). Each of the six study sites covered 100 km^2 in area.

3. Field data

3.1. Tree species data

We randomly selected six transects using ArcView GIS 3.2 (ESRI, 2002) in each study site. The transects had a minimum length of 3 km and a maximum length of 6 km. Transect length was determined on how accessible were the sampling points, transects with a maximum length of 6 km were characterized by rugged terrain which makes the sampling points to be inaccessible (Marshall and Region, 2000). The starting point and the ending point of each transect were navigated using a handheld Global Positioning System (GPS) receiver. The locational accuracy of the field plots was within the 15 m error of the GPS. We defined sample plots of 15 m × 15 m which were north oriented at 500 m distances along each transect and in each sample plot, species names were recorded. Research has shown that sampling plot sizes widely used ranges between 25 and 200 m^2 in tall shrub communities and 200–25000 m^2 for trees in woods and forests (Sutherland and Krebs, 1997) and our plot size of 225 m^2 falls within this range. A sampling distance of 500 m between the sampling plots was used because it is a distance that can capture the spatial variations in forest structure, species composition and vegetation density thereby reducing uniformity