Journal of Environmental Management 177 (2016) 9–19

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Biodiversity and agriculture in dynamic landscapes: Integrating ground and remotely-sensed baseline surveys☆

Andrew N. Gillison [a,*], Gregory P. Asner [b], Erick C.M. Fernandes [c], Jacinto Mafalacusser [e], Aurélio Banze [d], Samira Izidine [d], Ambrósio R. da Fonseca [e], Hermenegildo Pacate [f]

[a] Center for Biodiversity Management, P.O. Box 120 Yungaburra, Queensland 4884, Australia
[b] Department of Global Ecology, Carnegie Institution for Science, 260 Panama Street, Stanford, CA 94305, USA
[c] Agriculture and Rural Development (LCSAR), The World Bank, 1818 H Street, NW Mail Stop 16-603, Washington, DC 20433, USA
[d] National Institute for Agricultural Research (IIAM), No. 2698, Avenida das FPLM, Maputo, Mozambique
[e] Gabinete do Plano do Zambeze (GPZ), Tete, Mozambique
[f] DPCA Provincial Directorate of Coordination of Environmental Action (DCPA), Tete, Mozambique

ARTICLE INFO

Article history:
Received 6 March 2012
Received in revised form
22 March 2016
Accepted 23 March 2016

Keywords:
Integrated survey
Rapid biodiversity assessment
Remote sensing
Gradsects
VegClass
Soil fertility index
Plant functional types
Biodiversity value
Biodiversity surrogates
Adaptive management

ABSTRACT

Sustainable biodiversity and land management require a cost-effective means of forecasting landscape response to environmental change. Conventional species-based, regional biodiversity assessments are rarely adequate for policy planning and decision making. We show how new ground and remotely-sensed survey methods can be coordinated to help elucidate and predict relationships between biodiversity, land use and soil properties along complex biophysical gradients that typify many similar landscapes worldwide. In the lower Zambezi valley, Mozambique we used environmental, gradient-directed transects (gradsects) to sample vascular plant species, plant functional types, vegetation structure, soil properties and land-use characteristics. Soil fertility indices were derived using novel multidimensional scaling of soil properties. To facilitate spatial analysis, we applied a probabilistic remote sensing approach, analyzing Landsat 7 satellite imagery to map photosynthetically active and inactive vegetation and bare soil along each gradsect. Despite the relatively low sample number, we found highly significant correlations between single and combined sets of specific plant, soil and remotely sensed variables that permitted testable spatial projections of biodiversity and soil fertility across the regional land-use mosaic. This integrative and rapid approach provides a low-cost, high-return and readily transferable methodology that permits the ready identification of testable biodiversity indicators for adaptive management of biodiversity and potential agricultural productivity.

1. Introduction

1.1. The need for improved technologies

Largely negative ecological consequences of rapidly expanding human population and agriculture for food, fibre, and fuel highlight the need for more efficient and sustainable resource management practices (Tilman, 1999). The Convention on Biological Diversity (CBD) has yet to identify cost-effective ways of acquiring baseline data that can be readily accessed by landholders and policy-makers at differing environmental and spatial scales (cf. Green et al., 2005). Improved quantitative approaches are needed to identify synergies and tradeoffs between biodiversity conservation and agricultural development, and to broaden the use of environmental assessments as a tool to value and integrate biodiversity into land use and agricultural policy, planning and decision-making (Pagiola et al., 1998; Bräuer, 2003). For planning purposes, upscaling of survey data acquired from different sources is restricted by the lack of conformity among recording protocols. In this paper we demonstrate how this limitation can be largely overcome by the use of a new rapid survey technology and standardized recording protocols.

1.2. Biodiversity as a value-added ecosystem component

Biodiversity is an important driver of ecosystem services such as

☆ **Institute of origin**: Center for Biodiversity Management, P.O. Box 120 Yungaburra, Queensland 4884, Australia www.cbmglobe.org.

* Corresponding author.
E-mail address: andygillison@gmail.com (A.N. Gillison).

http://dx.doi.org/10.1016/j.jenvman.2016.03.037
0301-4797/

soil fertility, pest control, pollination, hydrological flows and water quality (McNeely and Scherr, 2001; Lavorel et al., 2013, 2015). Nonetheless, the linkages between biodiversity and associated ecosystem services are not obvious and often difficult to quantify (Grime, 1997; Wardle and Zackrisson, 2005; Dias et al., 2013; Grigulis et al., 2013; Lavorel et al., 2013, 2015; Allan et al., 2015). Partly for this reason a much-needed framework for assessing the value of biodiversity and related ecosystem services requires a more integrated approach (cf. Chee, 2004; Mattison and Norris, 2005).

1.3. Biodiversity quantified through species and functional types

Effective land management requires ready access to baseline data that are sufficiently comprehensive to enable the identification of the primary environmental determinants of biological diversity and related agricultural productivity. The most common types of biodiversity baseline data such as species lists are rarely used by decision-makers as they carry very limited information about the response of biota to environmental change. In species-rich environments, problematic identification and low frequency of individual species can also limit the selection of indicators for adaptive management purposes. On the other hand, identifying complementary functional characteristics of biodiversity with respect to key ecosystem processes related to land and water productivity shows promise in deriving economic and policy-relevant indicators (Gillison, 2013; Allan et al., 2015).

Plant Functional Types (PFTs) and their component elements (PFEs) or traits can help elucidate ecosystem and species behaviour along environmental gradients. In this way, compared to species, PFTs have the capacity provide more readily interpretable outcomes. As much of the biota can be described both in terms of species and their functional types, we regard both as complementary elements of biodiversity. In addition to species information, the use of plant functional traits and their syndromes (PFTs, plant functional types or groups), in biodiversity assessments provides a useful means of quantifying plant community and ecosystem responses to environmental change that, in turn, can be used directly in planning for adaptive management (Chapin, 2003; Schmidt, 2006; Liira et al., 2008; Gillison, 2013). Through established linkages with relative growth rate, water use efficiency, carbon accumulation and primary productivity (Díaz and Cabido, 1997; Wright et al., 2004; Lavorel et al., 2011; Díaz et al., 2016), PFTs are known to change predictably along biophysical and environmental gradients including soil fertility (Jager et al., 2015; Maire et al., 2015). While the use of PFTs offers a means of assessing ecosystem performance along quantifiable gradients of environmental change, their use is constrained by limitations in trait characteristics. When used in conjunction with species and vegetation structural features, however, (e.g. mean canopy height and basal area of all woody plants), testable dynamic linkages can be demonstrated between key faunal groups, soil condition and potential agricultural productivity (Gillison et al., 2003).

Previous studies (Gillison, 2002, 2013) showed that PFTs can be used to establish a reference baseline for estimating plant community response to environmental change along land-use intensity gradients. Recent studies at the landscape level provide empirical evidence for the detection and spatial modeling of PFTs using conventional satellite imagery (Alvarez-Añorve et al., 2008; Ustin and Gamon, 2010). This new-found capacity to couple remote-sensing platforms with ground-based PFT and species-based biodiversity inventories along with land-use types and soil fertility information provides a novel and potentially powerful analytical framework for assessing impacts of resource management interventions from field to watershed and landscape scales; and this new methodology is the focus of our paper.

1.4. Potential links between PFTs, species and remotely-sensed imagery

Advances in remote sensing technology show considerable promise in detecting combinations of vegetation structure, biochemistry and physiology and phenology that, in turn, are indicated by specific plant functional trait syndromes or PFTs (Ustin and Gamon, 2010; Ollinger, 2011). Variation in vegetation cover is a function of plant physiological response to available light, water and nutrients that is also reflected in certain PFT combinations some of which can be readily detected by remote sensing (Field et al., 1992; Bonan et al., 2002; Asner and Martin, 2011). We therefore hypothesize, that if ground-based observations can be successfully linked with spaceborne imagery, then this might offer a greatly improved tool for tracking (and thus predicting) vegetation response along measureable gradients of land use intensity and other key environmental features such as land cover, drainage and soil type. However, with the exception of light detection and ranging (LIDAR) and radio detection and ranging (RADAR) systems, most remote sensing measurements extract information primarily about vegetation canopy, thus excluding understorey species and associated plant functional traits (Alvarez-Añorve et al., 2008; Ustin and Gamon, 2010).

We therefore address the questions:

1. Can rapid, low-cost, gradient-based surveys using standard recording protocols acquire sufficient ecological and other baseline information for management purposes?
2. Can such methodology be effectively complemented by remotely-sensed applications?
3. Can these procedures be integrated to generate on-demand spatially-explicit landscape models for management decision-making in dynamic landscapes?

To answer these questions, and in order to establish a spatially explicit reference baseline for management and policy decision-making processes, we explore potentially predictive linkages between plant biodiversity, soil fertility and remotely-sensed variables recorded along land-use intensity gradients in dynamic landscapes. In so doing we apply newly developed, multidisciplinary techniques to acquire readily interpretable, biophysical and socioeconomic baseline information from local to regional scales. We present the results of a rapid survey of a complex, biophysical environmental regional gradient in a changing landscape that typifies many of the world's developing tropical and subtropical regions subject to rapid anthropogenic and climate-driven change.

2. Materials and methods

2.1. Study area

We surveyed an environmentally representative area of the lower Zambezi river basin of Mozambique (approximately 17.647° S, 36.677° E/18.091° S, 36.926° E) (Fig. 1) that occupies a biodiversity 'corridor' from the uplands (500 m a.s.l.) in Tete Province to the Zambezi delta at sea level and stretching across 12,000 km^2 in Sofala Province. The Zambezi river basin is the largest within the Southern African Development Community region and drains almost 1.4 million km^2 of which wetlands cover almost 66,000 km^2 with total water storage estimated at 100,000 million m^3. The study area is highly biodiverse (Timberlake, 2000) and contains six terrestrial ecoregions (Olson and Dinerstein, 2002) covering