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Mapping changes in land use/land cover and prediction of future extension of *bowé* in Benin, West Africa

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ABSTRACT

Desertification and land degradation are worldwide problems affecting soil, vegetation and the livelihoods of rural populations. *Bowal* (plural *bowé*) is a particular form of degraded land that occurs in tropical regions and leads to the exposure of ferricretes, which are unsuitable for farming. *Bowé* are more common on farmland and degraded savanna. Changes in land use/land cover were used to map a region of 6.7 million ha in northern Benin, West Africa in 1975, 1990 and 2010. The changes observed during these periods (1975–1990, 1990–2010 and 1975–2010) were used to predict the occurrence of *bowé* in the period up to 2050 using Markovian chain analysis. The results showed a considerable change in land use/land cover during the three periods. The types of land on which *bowé* occur (farmland and degraded savanna) increased in northern Benin by 5.4% per year during the period 1975–1990 and 9.5% per year during the periods 1990–2010, while the natural vegetation (forest, woodland and tree savanna) decreased by the same amount. The future scenarios also predicted the same trend. In the period 1975–1990, 1.28 million ha (26%) of natural vegetation was converted to degraded savanna and farmland while 2.23 million ha (53%) of natural vegetation was converted to degraded savanna and farmland in the period 1990–2010. Based on the dynamics recorded during the period 1975–1990 and 1990–2010 respectively, a total of 1.28 million ha (26% of the natural vegetation that was present in 1975) and 1.29 million ha (31% of the natural vegetation that was present in 1990) will be converted to farmland and degraded savanna in the study area by 2050.Thus *bowalization* will persist and increase in the period up to 2050. The natural vegetation could disappear if protection and restoration measures are not taken. It is thus important to take measures to stop the degradation and to implement programs to restore soils on *bowé* based on the soil and water conservation techniques used on highly degraded West African soils, such as *zaï* pit and stone rows with grass strips. Some native plants species adapted to *bowalization* and resistant to climate change in northern Benin (e.g. *Asparagus africanus*, *Andropogon pseudapricus* and *Combretum nigricans*) should be used in association with soil and water conservation techniques on *bowé*.

1. Introduction

Desertification and land degradation are worldwide problems affecting soils, vegetation and the livelihoods of rural populations (D'Odorico et al., 2013; Gao and Liu, 2010). Desertification and land degradation lead to increasing levels of poverty, starvation, land abandonment and migration out of the affected regions (Verstraete et al., 2009). Combating desertification and land degradation is crucial for reducing global poverty, biodiversity loss and human-induced global climate change (MEA, 2005).

The adoption of control measures for desertification and land degradation requires the identification and monitoring of early warning signs. Among the commonly used biophysical indicators are changes in land use/land cover (Vogt et al., 2011). Changes in land use/land cover are affected by the ways in which the biophysical attributes of the land are manipulated and by the intentions underlying these manipulations (Qingqing et al., 2012). By 2100, the impact of changes in land use/land cover on biodiversity is likely to be more significant than the impact of global climate change, nitrogen deposition, species introductions and changing atmospheric concentrations of carbon dioxide

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(Sala et al., 2000). The analysis of the dynamics of changes in land use land/land cover is therefore a fundamental tool in the adoption of strategies for the conservation of biodiversity (Verburg et al., 2009) and in planning appropriate management techniques for degraded land.

The analysis of changes in land use/land cover has become a fundamental tool in assessing the environmental consequences of human activity (Kanianska et al., 2014; Verburg et al., 2011). Changes in land use/land cover have consequences for biodiversity (Brink et al., 2014), geochemical cycles (Powers, 2004) and water quality (Schippers et al., 2004). The dynamics of changes in land use/land cover are influenced by the type of land cover, ecological mechanisms of succession and regeneration, the physical components of the environment, socioeconomic activities and their cultural context, meteorological phenomena and natural disasters (Yu and Lu, 2011).

Bowal (plural *bowé*) is a particular type of degraded land that forms on hardened ferruginous soils (ferricretes) in tropical regions with a unimodal pattern of precipitation. It is a very distinctive landscape. The name originates from the *fulfulde* language in Guinea (Aubréville, 1947). *Bowalization* occurs when ferricretes are exposed as a result of the erosion of the soil surface by a combination of a dry climate and deforestation (Padonou et al., 2014, 2015b). *Bowé* retain very little water, so any vegetation quickly desiccates and burns early in the dry season. Root growth is impeded and the trees are dwarfed, gnarled and widely scattered. As the soils rapidly absorb and re-radiate solar energy, *bowé* become extremely hot and barren in the dry season. The land cover on *bowé* is mainly grassland and savanna (Padonou et al., 2013; Zwarg et al., 2012). Thus, it may be possible to predict the occurrence of *bowé* in tropical regions with a unimodal pattern of precipitation and hardened ferruginous soils by analyzing changes in land use/land cover.

In this study, we considered land cover to be the biophysical state of the Earth's land surface and immediate subsurface, including the biota, soil, topography and groundwater. We analyzed changes in land use/land cover using a previously published set of categories (Lambin et al., 2003). Changes in land cover include changes in the biodiversity, the actual and potential primary productivity and soil quality.

2. Materials and methods

2.1. Study area

Data were collected in the municipality of Banikoara (11° 18′ N and 2° 25′ E) in northern Benin (Fig. 1). This area is considered to be the breadbasket of the country (Kokoye et al., 2013) and agriculture plays a major part in the livelihoods of local people. Decisions about the allocation of land among farms in this region are made by farmers on socioeconomic and demographic grounds, taking into account production factors, such as labor and capital (Kokoye et al., 2013). A household's capital is an important influence on decision-making about the amount of land allocated to cereals, legumes and cash crops. The allocation of land to cash crops is also determined by the farmers' access to credit.

The natural vegetation of this region is characterized by a mosaic of woodland, dry forest, tree and shrub savanna and gallery forest (Adomou et al., 2006). This zone was selected for study because it is dominated by the ferruginous soils (Fig. 1) on which *bowé* occur (Padonou et al., 2014, 2015a). *Bowé* could occur anywhere within the study area.

2.2. Land cover maps

Three sub-scenes of Landsat imagery for the years 1975 (Landsat Multi-Spectral Scanner), 1990 (Landsat Thematic Mapper) and 2010 (Landsat Enhanced Thematic Mapper plus) were interpreted (Fig. 2). The images were all taken during the dry season to minimize any variation in phenology of the vegetation (Clerici et al., 2007). An on-screen visual interpretation was carried out by a method similar to that proposed for the Tropical Ecosystem Environment Observations by Satellites Project (TREES) phase II (Achard et al., 2002). The three land cover maps were digitized and then the different land cover types were delineated using ENVI 4.1 software. Color composition (RGB 4, 7, 5) was used to improve the differentiation of the land cover types on the screen. Bands RGB 4 (0.750–0.900 μm), 7 (2.090–2.350 μm) and 5 (1.550–1.750 μm) made it possible to emphasize the differences between the stages of succession in the forested areas in addition to the savanna and farmland areas. The interpretation was aided by three additional data sources: 1:200,000 land cover maps edited in 1975 and 1987 by CENATEL Benin (the National Center of Remote Sensing) and the 2007 National Forest Inventory database, from which the land cover classes of forest, woodland, tree savanna, degraded savanna and farmland were adopted.

Bowé occurred most often on farmland and degraded savanna (Fig. 3); by contrast, there was no *bowal* in either forest or woodland. The polygons of the land cover classes in the sub-scene acquired in 1975 were labeled according to their cover class as shown in the land cover maps from CENATEL. Once the digital map of the coverage had been finalized, the polygons were copied and overlaid with the 1990 image. The segments that required modification were changed by adding, deleting or modifying the polygon boundaries to reflect the changes in land cover between 1975 and 1990. The same process was used to visualize the changes between 1990 and 2010. This methodology was used because it avoids the generation of false changes that may occur if the databases contain a spatial mismatch (Mas et al., 2004). Areas without any recognizable vegetation in the images (water bodies, clouds and infrastructure) were excluded to reduce bias.

The classification accuracy was assessed by an error matrix (Congalton, 1991). Three hundred reference points (50–60 per class) were used and these were distributed across the study area using a stratified sampling scheme (Achard et al., 2002). The error matrix was normalized with an iterative proportional fitting procedure that forced each row and column to sum to unity using the program MARGFIT (Congalton, 1991). A kappa analysis was then performed with the Kappa program to determine the accuracy of the classification (Congalton and Green, 1999).

2.3. Changes in land use and land cover

The elaborated maps were incorporated into a geographical information system using Arcmap 10 (ESRI) software. An overlay analysis was performed to assess the pathways of change observed over the three periods. A mask was generated to eliminate areas without vegetation (water bodies and infrastructure) to allow a comparative analysis of the same area at different times (Hall et al., 1995). After subtraction of the masked areas, the resulting area was 6,735,489 ha. Categories of change were classified into three stages: cover loss; cover regeneration; and unchanged cover. Cover loss refers to land cover that was subjected to a change with a concomitant loss in a regressive manner (for example, from forest to savanna or from woodland to farmland). Pathways of change that flowed in the opposite direction indicated regeneration.

2.4. Land use/land cover transition probability matrices

Transition probability matrices were elaborated for the periods 1975–1990 (15.5 years), 1990–2010 (20.5 years) and 1975–2010 (35.5 years) to describe the changes in each land cover class. Each matrix represents either the probability of the persistence of each land cover category, or the probability of a transition to another land cover category from the first to the last year in the period. The matrix values were standardized using the procedure proposed by Rovainen (1996) to obtain annualized changes and to make comparisons. To annualize the matrix values, each probability matrix was used separately to compute the matrix's eigenvectors and eigenvalues using the diagonalization