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A 50 year study shows grass cover has increased in shrublands of semi-arid South Africa

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ABSTRACT

In many parts of the world the boundaries between grassland and shrubland biomes have changed substantially over the course of the last century. Many are projected to shift further from being grass-dominated to shrub-dominated by 2050 under global climate change and land use change projections. This paper used long-term surveys and repeat photography to assess vegetation change at the shrubland-grassland ecotone in semi-arid, South Africa. Changes in several climate variables as well as in the cover of grasses and dwarf shrubs over three time periods (1962, 1989 and 2009) were investigated at eight localities within a broad 500 km ecotone between the Grassland and Nama-karoo biomes. Results showed that for most sites grass cover has increased and that dwarf shrub cover has decreased over time. This contradicts earlier views which warned against the expansion of dwarf shrublands in response to over-grazing as well as more recent views which suggest that more mesic biomes in the Karoo Midlands will contract in response to climate-induced aridification. The decline in stocking densities and more conservation-friendly land management practices together with an increase in large wet events in the Nama-karoo biome may have contributed to the increase in grass cover.

1. Introduction

Biome boundaries are recognized globally as areas where changes in the distribution of core terrestrial biomes are likely to first become apparent (Churkina and Svirezhev, 1995; Hufkens et al., 2009). Boundaries between grassland and shrubland biomes have already shifted in many parts of the world (Buffington and Herbel, 1965; Heshmati and Squires, 2011) and are predicted to undergo considerable change in the future (Parton et al., 1995). Most projections suggest that C_4 grasslands will be replaced by C_3 shrublands with shrublands becoming increasingly dominant at the boundary between the two (Leadley et al., 2010). There is further concern that the encroachment of shrubs will impact on community stability and species richness (Alvarez et al., 2012; Báez and Collins, 2008) and reduce biodiversity (Rutherford et al., 2012).

While the reason for the expansion of shrubs is complex, most hypothesized drivers are linked to changes in climate and land use (Archer, 2010; Munson et al., 2012; Okin et al., 2009; Peters, 2002; Peters et al., 2011, 2006; Rutherford et al., 2012; Sala et al., 2000; van Auken, 2009). Climatic factors include increases in temperature and drought frequency, decreasing wind and the effects of increasing CO_2 concentration on plant water use (Archer et al., 1995; Bond and Midgley, 2012; Higgins and Scheiter, 2012; Masubelele et al., 2013; Midgley et al., 2008, 2002; Munson et al., 2011a,b; Parton et al., 1995; Peters et al., 2011). Because frost is limiting for many shrubs, an increase in minimum temperature and a reduction in the frequency of frost under future climate change scenarios (D'Odorico et al., 2010) will favour their expansion. Shrubs are also able to outcompete grasses during drought periods where they have access to deeper soil water (Letts et al., 2010). The water use efficiency and growth rate of C_3 shrubs are both positively influenced by the higher concentration of CO_2 in the

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atmosphere (Morgan et al., 2007) while for C_4 grasses both negative and positive increases in growth rate at elevated CO_2 have been documented (Leakey et al., 2009; Morgan et al., 2011).

Land use change is expected to greatly modify climate change effects and may overwhelm the impact of climate change in some areas (De Baan et al., 2012; Parton et al., 1995). For example, the effect of CO_2 enrichment on soil carbon in the grasslands of the Great Plains is relatively small compared to the impact of ploughing and nutrient fertilization of crops (Burke et al., 1990). Land use on its own is also able to cause a switch from grass to shrub dominance in many semi-arid grassland environments especially when stocking rates and carrying capacity are exceeded (Acocks, 1953; Peters et al., 2006). Bestelmeyer et al. (2007), for example, suggested that the consumption of grassland seedlings by native herbivores has played a role in promoting shrub dominance.

An increase in shrub cover is generally thought to be symptomatic of desertification especially when caused by a combination of livestock grazing and drought (Gibbens et al., 2005; Schlesinger et al., 1990; Scholes, 2009). These two factors likely contributed to the degradation of habitat and the switch from grassland to shrubland between the 1870s and 1930s not only in South Africa (Acocks, 1953) but in many drylands of the world (Gibbens et al., 2005). In some areas, however, an altered climatic regime that consisted not of increased drought, but of increased winter precipitation is also thought to have been responsible for this switch from grasses to shrubs. Under these conditions, the availability of moisture in the cool season favours the establishment of C_3 woody shrubs over C_4 grasses which are generally more active during the warmer, summer months (Booth et al., 2003).

While the majority of studies suggest that shrublands have expanded over time, there are a few studies of grassland/shrubland boundary dynamics which suggest that grasses can recover and dominate shrublands under conditions of high rainfall and low grazing pressure (Peters, 2002). For example, in an earlier study of the Grassland/Nama-karoo shrubland interface in South Africa, Hoffman and Cowling (1990) used repeat photography and a resurvey of existing vegetation data and showed that grass cover had increased significantly at most sites that were previously dominated by shrubs. However, future climate change projections for this and many other semi-arid grassland environments suggested that they will become drier and therefore shrubbier in response to an increase in temperature and drought frequency (Beaumont et al., 2011; Midgley and Thuiller, 2011; Midgley et al., 2002).

Here we report on a study of changes along a semi-arid shrubland/grassland ecotone over the last half century. Nama-karoo shrublands grade into semi-arid grasslands in the Karoo Midlands region of South Africa. We documented the nature and extent of long-term rainfall and vegetation change along the ecotone. Firstly, changes in rainfall and drought incidence were assessed to determine if there was evidence in the historical record for the predicted drying trend which has been projected by global climate change models (Midgley et al., 2002). Secondly, by building on the data sets of Hoffman and Cowling (1990), the nature and extent of vegetation change within grassland and shrubland communities over the last 20 years was considered in terms of future biome-level projections for the region (Midgley et al., 2008). We wished to determine whether shrublands had expanded at the expense of grasslands as suggested by future biome-level projections or whether the trend of an increase in grass cover, reported 20 years ago by Hoffman and Cowling (1990), still holds. Our analysis also explored the relative influence of land use (particularly stocking rate) and rainfall on shrub/grass dynamics with a view to suggesting which key drivers best explain the changes in vegetation cover and composition along this biome boundary. Finally, we considered the implications of these findings for key policy and land management debates in the region.

2. Study area

The study took place along a 500 km transect in the central interior of South Africa from Richmond in the Nama-karoo biome (a semi-arid shrubland dominated by shrubby members of the Asteraceae) in the south west to Dewetsdorp in the Grassland biome in the north east. Eight sites, which were previously surveyed by Roux (1968) and Hoffman and Cowling (1990) were resurveyed in January 2009. All sites were located on colluvial slopes of wide valleys in the region (Roux, 1968). The location and description of each site is summarized in Table 1.

3. Methods

A combination of approaches including analyses of historical rainfall and land use data, repeat photography and long-term ecological monitoring was used to assess changes in the vegetation along a 500 km transect from the shrub-dominated Nama-karoo biome in the southwest to the Grassland biome in the northeast.

3.1. Rainfall

Long-term change in rainfall at representative sites along the transect was assessed. Data were obtained from the South African Weather Service (www.weathersa.co.za). All the time-series data were visually inspected for discontinuities and missing values. Empty cells were replaced with average values for a specific month. Data sets which appeared unreliable with many missing values and discontinuities, such as Wepener, were replaced with the nearest adjacent site for which reliable data were available (e.g. Hobhouse). Annual rainfall was recorded as the sum of values from October the previous year to September in the current year. In addition, the historical incidence of drought along the transect was assessed for a 24 month time scale using the Standardized Precipitation Index (SPI) (McKee et al., 1993). A detailed explanation of the SPI (see Appendix A.2) is provided in Edwards and McKee (1997), Lloyd-Hughes and Saunders (2002) and World Meteorological Organization (2012). A copy of the programme used to calculate the SPI value may be downloaded from: http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx. Statistically significant changes in rainfall and drought incidence over time were assessed using a non-parametric Mann Kendall test for trend (Modarres & da Silva, 2007).

3.2. Land use

The number of domestic livestock (cattle, sheep and goats) censused over the period 1911–1996 within magisterial districts (Table 1) along the Nama-karoo shrubland/Grassland biome ecotone was obtained from the Agricultural Census Database of the Department of Agriculture. The total number of cattle, sheep and goats recorded each year in a magisterial district was converted to a Large Stock Unit (LSU) value by using the conversion tables in Meissner et al. (1983). LSU values were summed for a magisterial district and stocking rates were calculated by dividing the LSU value by the total area of each magisterial district. The results for the four magisterial districts in the study area which occurred predominantly in the Nama-karoo shrublands were grouped and compared with the grouped results for the four magisterial districts which occurred predominantly in the Grassland biome.