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Woody vegetation dynamics in the rangelands of lower Omo region, southwestern Ethiopia

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A B S T R A C T

Woody encroachment is one of the several factors aggravating rangeland degradation in arid and semiarid areas. The goal of this study is to improve our understanding about the relationship between woody encroachment and its potential drivers by analyzing the temporal and spatial pattern of land-cover changes in the lower Omo region of southern Ethiopia. We used a combination of multi-temporal images, as well as climatic and demographic data for the analysis. Between 1985 and 2010 woody vegetation cover increased by 30.6% in the pastoral landuse type, while declining by 4.4% in the semi-pastoral areas. The increment was negatively associated with altitude and browser livestock density. However, contrary to the traditional presumption, it was not associated with grazer livestock density. Moreover, woody encroachment was higher in remote sites, farther from rivers and towns, where there is relatively lower human activities and livestock disturbance. The finding suggests the ecological significance of landuse type and livestock browsing to regulate the dynamics of woody vegetation in disturbance-adapted rangelands. Thus, a careful introduction of native larger browsers into woody encroached pastoral areas may help to facilitate rapid ecosystem recovery.

1. Introduction

Rangelands cover approximately 50% of the earth's land surface (Asner et al., 2004) and support more than 50% of the world's livestock population, in addition to a large number of wild animals (WRI, 1992). Besides supplying forage and habitat for domestic and wild animals, rangelands provide various ecosystem goods and services, including biodiversity conservation and carbon sequestration (Solomon et al., 1993). Nevertheless, there is an increasing global concern over rapid socio-economic and environmental changes and their implication on the sustainability of the ecosystem (Archer, 1995). According to some estimates (e.g., Dregne and Choun, 1992), more than 70% of rangelands are already suffering from moderate to very severe degradation due to landuse and land-cover changes.

The rapid invasion of woody plants into open grazing areas, referred to as woody encroachment, bush encroachment or shrub encroachment, has been widely considered as one of the several factors accelerating rangeland degradation in both arid and semi-arid areas (Hudak et al., 2003; Maestre et al., 2009). Depending on the scale of encroachment and the characteristics of invading tree or shrub species, woody encroachment may alter the physico-chemical and biological properties of the soil (Biederman and Boutton, 2009), the hydrology (Petersen and Stringham, 2008) and local biodiversity (Biederman and Boutton, 2009; Sirami et al., 2009) of rangeland ecosystems. One of the well documented adverse effects of woody encroachment is the suppression of herbaceous cover, which limits animal production (Dalle et al., 2006). This phenomenon has been reported in many African countries (Moleele et al., 2002; Ward, 2005), North America (Archer, 1995), South America (Cabral et al., 2003), Australia (Lunt et al., 2010) and some parts of Europe (Kunstler et al., 2007).

Woody encroachment drivers are many and complex (Archer, 2010; Ward, 2005). On a global and regional scale, atmospheric warming, elevated CO_2 concentration, nitrogen deposition and high rainfall variability could be the possible drivers (Archer, 1995; Wigley et al., 2010). Moreover, it could be facilitated on a local scale by a range of factors such as the suppression of fire (Ward, 2005; Wigley et al., 2009), the exclusion of large browsing herbivores (Scholes and Archer, 1997) or overgrazing (Walker and Noy-Meir, 1982; Walter, 1971), depending on the dynamics of the particular rangeland system. Three different types of rangeland dynamics are frequently discussed in the literature (Sankaran et al., 2004): In equilibrium rangeland systems, which have relatively stable rainfall patterns and

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a fixed tree–grass ratio for a given average climate, overgrazing could drive woody encroachment by altering the competitive balance between trees and grasses (Jeltsch et al., 2000; Scholes and Archer, 1997). In disequilibrium rangelands, where the long-term persistence of the tree-grass balance is maintained by fire and herbivory, the suppression of those disturbances may lead to the aggravation of woody encroachment as it pertains to a good rainfall regime (Sankaran et al., 2004). By contrast, in a non-equilibrium rangeland system, woody encroachment could be facilitated by a rainfall variability that switches the tree-grass balance by disrupting the overall vegetation and herbivores structure (Briske et al., 2003; Vetter, 2005). Nevertheless, there is no conclusive understanding on the mechanisms of how those driving factors operate at various scales in different rangelands (Ward, 2005). A detailed review about the three rangeland systems is given by Sankaran et al. (2004).

The goal of this study is to improve our understanding of the relationship between woody encroachment and its main drivers by assessing the land-cover/landuse dynamics from the analysis of remotely-sensed multi-temporal imageries. Remote sensing has recently been used as a tool for detecting and comparing land-cover/landuse changes at a relatively cheaper cost, as opposed to the use of traditional field survey techniques (Lu et al., 2004). Even though several similar works have been carried out in other rangeland areas in the past, we have not yet achieved a proper understanding of how land-cover changes in general, and the expansion of woody encroachment in particular, are influenced by the complex interactions of environmental, demographic and socio-cultural changes taking place in various rangelands (Ward, 2005; Wigley et al., 2009).

The lower Omo region of southwestern Ethiopia is an ideal place to demonstrate how natural processes and human activities shape the land-cover pattern from temporal and spatial dimension. Like many other arid and semiarid rangelands, the area has experienced rapid land-cover/landuse changes over the past few decades. The recent rapid invasion of woody plants into previously open grazing sites is a major challenge for local livestock herders and rangeland managers (Gil-Romera et al., 2010), and no tangible attempt was made in the past to evaluate the magnitude of the phenomenon and its driving factors in this region. In order to promote a better decision making for sustainable rangeland resource management, a better understanding of the factors that influence land-cover change in the area is needed. Therefore, this study is aimed at: (1) assessing the magnitude and pattern of land-cover/landuse changes in the study area over the past 25 years; (2) understanding the effect of climate, human- and livestock-population densities, type of landuse systems and physiographic factors on the temporal- and spatial-patterns of woody encroachment.

2. Materials and methods

2.1. Study area

Our study area, the Hamer district, lies between 4.43°–5.50°N, and 36.09°–36.99°E in the lower Omo region of southwestern Ethiopia. It covers an area of 5742 km^2 and shares borders with the Borana rangeland to the east, the Mago National Park to the north and Kenya to the south (Fig. 1). The Omo River, which flows from the highlands of central Ethiopia to Lake Turkana, also comprises the western boundary of the district. Approximately 95% of the area has a semiarid climate, whereas the rest is arid and sub-humid. The rainfall has a bimodal pattern, with a primary rainy season between March and May, and occasional rain between October and December. The average annual rainfall varies from 581 mm in the lowlands to 796 mm in the highland regions, with the altitude ranging from roughly 400 to 2000 m above sea level. The high-

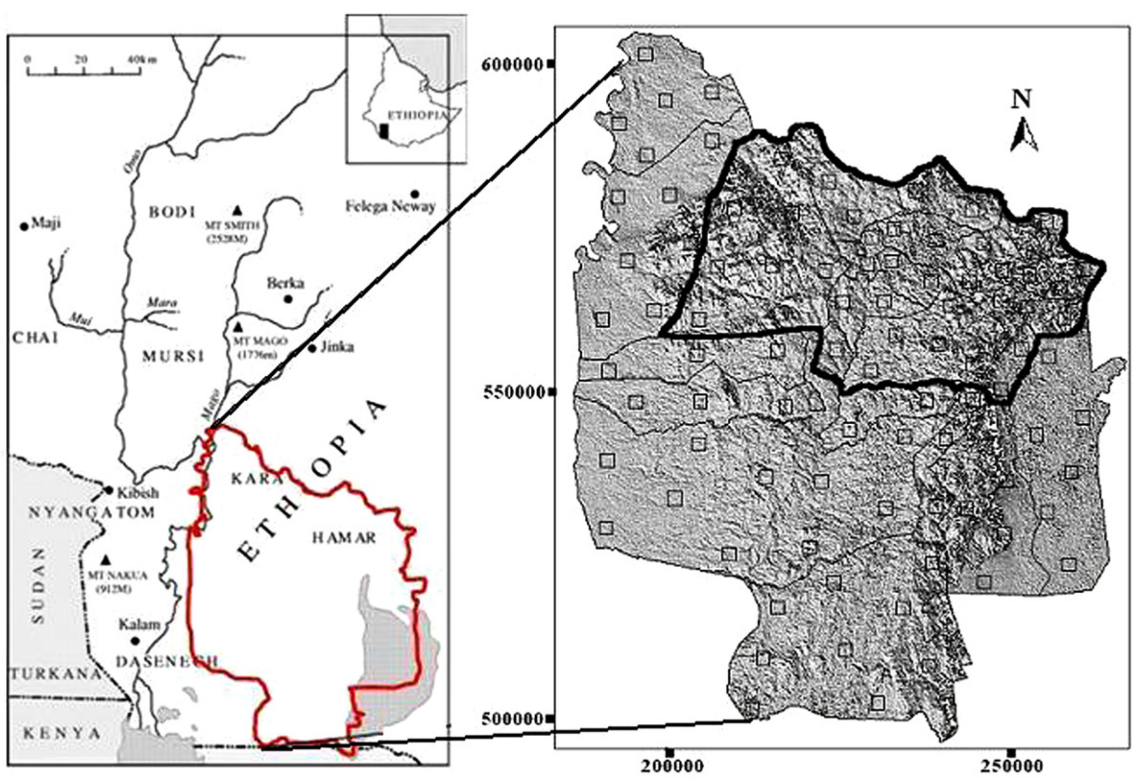

Fig. 1. Left: Location of the lower Omo region in southwestern Ethiopia. Right: Location of the two landuse systems and the sampling grid cells in Hamer district. The district is divided into peasant associations. The location of semipastoral areas (in the north) is demarcated with bold lines, whereas the remaining lowland area in the south and southwest is pastoral. Square polygons inside the map represent the locations of the grid cells (sites).