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The climate-population nexus in the East African Horn: Emerging degradation trends in rangeland and pastoral livelihood zones

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ABSTRACT

Increasing climate variability and extreme weather conditions along with declining trends in both rainfall and temperature represent major risk factors affecting agricultural production and food security in many regions of the world. The rangelands of Ethiopia, Kenya, and Somalia in the East African Horn remain one of the world's most food insecure regions, yet have substantially increasing human populations predominantly dependent on pastoralist and agro-pastoralist livelihoods. We identify regions where substantial rainfall decrease between two periods interrupted by the 1998 El Nino event (1981–2012) in the East African Horn is coupled with human population density increases. Vegetation in this region is characterized by a variable mosaic of land covers, generally dominated by grasslands necessary for agro-pastoralism, interspersed by woody vegetation. Recent assessments indicate that vegetation degradation is occurring, adversely impacting fragile ecosystems and human livelihoods. Using AVHRR and MODIS vegetation products from 1981 to 2012, we observe changes in vegetation patterns and productivity over the last decade across the East African Horn. We observe vegetation browning trends in areas experiencing reduced main-growing season precipitation; these areas are also concurrently experiencing increasing population pressures. We also found that the drying precipitation patterns only partially statistically explain the vegetation browning trends, indicating that other factors such as population pressures and land use changes might be responsible for the observed declining vegetation condition. Furthermore, we show that the general vegetation browning trends persist even during years with normal rainfall conditions such as 2012, pointing to potential long-term degradation of rangelands on which approximately 10 million people depend. These findings may have implications for current and future regional food security monitoring and forecasting as well as for mitigation and adaptation strategies in a region where population is expected to continue increasing against a backdrop of drying climate trends and increased climatic variability.

1. Introduction

The African continent is identified in most climate-change predictions as potentially the world's most vulnerable populated region, exacerbating recurring droughts and crop failures, water scarcity, and disease burden. Increasing climate variability and extreme weather conditions, especially in the context of declining and more irregular precipitation in some regions (Cooper et al., 2008; Verdin et al., 2005; Durack et al., 2012), are considered major risk factors affecting agricultural production and food security in many African countries in the coming decades (Haile, 2005; Christensen et al., 2007). The largest potential impacts are likely to be felt in smallholder systems with reduced adaptive capacity, which are primarily dependent on rainfall, are largely ineffective yield-wise, and apply low levels of agricultural inputs (Muller et al., 2011). Boko et al. (2007) estimate that by 2050, yields from Africa's rainfed farm production could decrease by 50 percent as a result of changes in climatic conditions. Moreover, many semi-arid regions throughout Africa, primarily rangelands, pastoral and agro-pastoral, on which millions of people depend for their livelihoods, are changing at a rapidly increasing rate.

The Millennium Ecosystem Assessment (Assessment, 2005) predicts that by 2050 land use and land cover changes (LULCC) will be a more significant driver of ecosystem change and biodiversity loss than climate change by a factor of 4 in Africa. Furthermore, the IPCC's most recent report emphasizes that adaptability to climatic

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change, especially among rural, subsistence-based communities, will be determined by the health of the ecosystem; which in turn is closely related to the policies and cultural practices governing resource use. Many studies in Africa point to increasing environmental and vegetation degradation due to human activities and climate change (Kassahun et al., 2008a; Roba and Oba, 2009b; Brink and Eva, 2011; Solomon et al., 2007a; Gemedo-Dalle et al., 2006). Even though people have adapted to changes and the harshness of these highly variable environmental conditions through the generations (Fratkin, 2001), in light ongoing rates of environmental changes and continued population increases, their ability to adapt may become threatened (Collier et al., 2008; Holmgren and Öberg, 2006; Samson et al., 2011). Understanding the extent and effects of climatic and LULC changes on livelihoods and, indirectly, adaptive capacity at regional and local scales has never been more important given that almost 50% of the Earth's natural ecosystems have already undergone some type of alteration (Barnosky et al., 2012).

The East African Horn region, comprised primarily of Ethiopia, Kenya, and Somalia, as well as parts of Southern Sudan, Sudan, and northern Tanzania and Uganda, is one of the world's most food insecure regions with increasing human populations that are highly dependent on the natural resource base for their livelihoods. Pastoralism constitutes the major land use in the drylands of the East African Horn (EAH) region (Ericksen and Herrero, 2011). It is a diverse and dynamic livelihood system well adapted to dryland environments, typically are characterized by unstable and scarce resources and particularly vulnerable to food insecurity (Ced Hesse, 2006; Thornton et al., 2003). Drylands, defined as areas receiving less than 600 mm rainfall a year, are already regions of high human vulnerability to perturbation and environmental variability. They are systems of low biological productivity covering approximately 40 percent of the Earth's surface and providing home to over 2 billion people, more than 90 percent of whom live in developing countries and 1.1 billion of whom live in Africa. About half of the drylands population in East Africa lives below or close to the poverty line and recent regional assessments indicate that poverty is continuously increasing (Kassahun et al., 2008b; Ericksen and Herrero, 2011). Population growth in this region is also unusually high, paired with some of the highest infant mortality rates in the world, ranging from ~150 to 180 per 1000 live births (CIESIN, 2005).

Despite a lack of recent and inclusive global assessment of the state of drylands and the pastoral livelihoods they support, various regional studies in Africa indicate they are changing fast and facing increased degradation, primarily due to fragmentation, overexploitation, climate change, and climate variability (Galvin, 2009; Munyati and Makgale, 2009; Brink and Eva, 2011). Degradation is defined differently depending on the specific context and location of occurrence but typically refers to a system shifting from a biologically productive state to an unproductive state (Huber-Sannwald et al., 2006). Despite some controversy on driving mechanisms of vegetation degradation in arid and semi-arid areas with typically unpredictable rainfall patterns (Herrmann et al., 2005; Herrmann and Hutchinson, 2005), climate variation and human activities are usually identified as the main underlying causes (Geist and Lambin, 2004; Reynolds et al., 2007). Extensive work in East Africa indicates an overall reduction in rainfall during the main and secondary rainy seasons, accompanied by an increase in the spatial and temporal variability of precipitation that is associated with changes in sea-surface temperature in both the Indian and Pacific Oceans (Williams and Funk, 2011; Lyon and Dewitt, 2012). Increasing spatio-temporal variability of precipitation (expressed in unreliable onset, duration, and intensity of rains and more frequent occurrence of dry spells during the growing periods; Speranza et al., 2008) is the most important factor driving and maintaining chronic food insecurity in the East Africa Horn region. Even during non-drought conditions, a very high proportion of EAH households face various forms of food insecurity (Misselhorn, 2005).

The climatic feedback loop in the dryland pastoralist regions of the East Africa Horn, despite being still relatively poorly understood, is complex, with implications far beyond the region. Decreasing trends in precipitation and increasing climatic variability can have direct impacts on vegetation productivity. This in turn leads to the creation of a positive feedback mechanism between decreasing vegetation cover and a further decrease in precipitation due to increasing albedo, corresponding radiative cooling of the overlying air, and a subsequent enhancement of large-scale atmospheric subsidence (Oyama and Nobre, 2003). Furthermore, ongoing vegetation clearing and degradation might contribute to increases in temperatures and wind speeds and decreases in precipitation and relative humidity, thus creating warmer and drier climates; which, in turn, might contribute to tree cover loss, vegetation degradation, increasing population vulnerability, and food insecurity, particularly in pastoral dryland regions (Hoffmann et al., 2002). For instance, recurring drought (combined with population growth and land tenure/policy changes) has been linked to land use/land cover changes in the central Rift Valley, Ethiopia as farmers have shifted from predominantly pastoral livelihoods to a crop-livestock mixed farming system as a better strategy to reduce vulnerability to drought (Biazin and Sterk, 2013); similar patterns were observed in the northeastern Afar Rangelands of Ethiopia (Tsegaye et al., 2010).

The identification of emerging at-risk populations is increasingly important in the arena of climate change impacts, mitigation, and adaptation, especially for our region of focus. This issue is particularly important in the context of food security crises that can be virtually avoided if we develop a better understanding of potential predictive factors, effective monitoring, and early warning products and systems (Thornton et al., 2011). In this paper, we address the spatial interplay between climate, vegetation change and degradation, and population density changes to create a regional assessment of the state and trends of the East Africa Horn's pastoral and agro-pastoral livelihoods zones. While there is a number of disparate, small-scale studies addressing some of these components in the region (Brink and Eva, 2011; Reid et al., 2000; Serneels et al., 2001; Vanacker et al., 2005; Kiage et al., 2007), the majority of work is either anachronistic or remains based on fairly location-specific survey data (Abule et al., 2005; Desta and Coppock, 2004; Luseno et al., 2003). This paper represents the first attempt to provide a regional-scale, cross-country assessment of recent population, climate, and vegetation degradation dynamics at a multi-national scale. We focus on identifying regions where changes in the spatial distribution of main growing season rainfall (May–June) have occurred over the last 33 years using a high resolution climate dataset (5 km^2) created by the Climate Hazards Group at University of California Santa Barbara and which has already proved to be a key component for early warning systems and climate vulnerability analyses (Funk et al., 2012; Hoell et al., 2013). In places like Eastern Africa, where complex topography produces extremely steep rainfall gradients on ten-kilometer scales, high resolution rainfall mapping is a critical component of effective risk management. We also determine the relative human population density increases that have occurred in this region from the 1990s to 2010 using a combination of gridded population products. We propose that locations where negative changes in precipitation observed during the main growing season occur coincidentally with increasing human population densities represent potential hotspots of population vulnerability to climate changes and inherent food security, thus warranting further investigation.