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Rangeland management and fluvial geomorphology in northern Tanzania

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ABSTRACT

Researchers have independently documented the effects of land use on rivers and threats to river management institutions, but the relationship between changes in institutional context and river condition is not well described. This study assesses the connections between resource management institutions, land use, and rivers by integrating social science, geospatial analysis, and geomorphology. In particular, we measured hydraulic geometry, sediment size distributions, and estimated sediment yield for four rivers in northern Tanzania and conducted semistructured interviews that assessed corresponding resource management institutions. Communities managed rivers through both customary (traditional, nonstate) and government institutions, but the differences in the resource management policies and practices of the study rivers themselves were fairly subtle. Clearer differences were found at broader scales; the four watersheds exhibited substantial differences in land-cover change and sediment yield associated with the location of settlements, roadways, and cultivation. Unexpectedly, these recent land-use changes did not initiate a geomorphic response in rivers. The long history of grazing by domestic and wild ungulates may have influenced water and sediment supplies such that river channel dimensions are more resistant to changes in land use than other systems or have already adjusted to predominant changes in boundary conditions. This would suggest that not all rivers will have the anticipated responses to contemporary land-use changes because of antecedent land-use patterns; over long time scales (centuries to millennia), the presence of grazers may actually increase the ability of rivers to withstand changes in land use. Our findings point to a need for further interdisciplinary study of dryland rivers and their shifts between system states, especially in areas with a long history of grazing, relatively recent changes in land use, and a dynamic social and institutional context.

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1. Introduction

Understanding the ways in which humans affect rivers has great practical importance for maintaining ecosystem function and resource availability. However, detecting river degradation and identifying its links to particular activities is challenging, especially because resource-use rules often mediate the relationships between people and the environment. Failure to recognize these institutions and their relationship to resource-use decisions can result in substantial misunderstandings of the processes driving environmental change.

Rivers are especially valued features of arid and semiarid rangelands because of the ecosystem services they provide and the biodiversity they sustain. East African rivers, our focus here, support vegetation communities and wildlife assemblages that are distinct from the surrounding landscape mosaic (Medley and Hughes, 1996). Dry-season water and forage availability make them important habitats for consumers, and the spatial distribution of these resources structures wild ungulate migrations (Western, 1975), as well as livestock movements (Coppolillo, 2000). Yet East African rivers face threats from agriculture, resource extraction, damming, and settlement (Stave et al., 2001, 2003, 2007; Mango et al., 2011).

The effects of human activities on river channel geomorphology are well studied (Gregory, 2006). Channel dimensions and sediment size distributions are common metrics for describing river channels, whether to document natural patterns in undisturbed landscapes or as an indicator of possible adjustment to changing boundary conditions. Width to depth ratios (W:D) for dryland rivers range widely (3.8 to 255, Schumm, 1961; 16 to 340, Shaw and Cooper, 2008). Lower order streams and smaller drainages typically exhibit low W:D (Shaw and Cooper, 2008), and W:D is also inversely related to weighted mean percent silt-clay in the channel perimeter (Schumm, 1961). Channel dimensions can be affected by changes in land use that alter water and sediment supply from the surrounding landscape. The conversion of land to agriculture is associated with increases in flood magnitude (Knox, 1977), and additional loss of forest in the Mara River watershed (Kenya) is projected to decrease low flows and increase peak flows

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(Mango et al., 2011). Increased peak discharge yields more erosive stream flows that cause channel incision, especially in areas with fine, loose soils (Fu, 1989). Channel incision can then initiate a sequence of changes, wherein increased channel depth weakens riparian vegetation and stream banks, and can eventually lead to channel widening (Bull, 1997). Grazing is also a source of geomorphic change and has been associated with channel widening (Platts, 1991); similarly, livestock exclosure has been linked to decreased width, increased depth, and decreased W:D (McDowell and Magilligan, 1997).

In addition to these channel morphology changes are those affecting the sediment load and water load delivered from the watershed into the channel itself. The sediment size distributions of riverbeds provide information on changes in sediment supply and transport capacity. Bedload particle size typically decreases in the downstream direction (Knighton, 1998), but changes in land use affect runoff as well as sediment delivery to channels (Clark and Wilcock, 2000), and in turn also impact in-channel erosion, sediment texture, and sediment transport (e.g., particle size, Pizzuto et al., 2000). Cultivation and rural roadways are significant sources of sediment in East African river catchments (Dunne, 1979).

Land use changes, and their effects on rivers, are mitigated by customary (traditional, nonstate) and by governmental resource management institutions. In East Africa, top-down rangeland management policies have, in many cases, marginalized traditional land tenure arrangements and land use patterns, often to the detriment of rangeland condition and local land users. In particular, government interventions have eroded systems of exchange, access, and mobility that previously governed livestock distributions and range condition (e.g., Sandford, 1983; Fratkin, 1997; Homann et al., 2008; Mwangi and Ostrom, 2009). Customary systems for regulating riparian resource use have also been threatened by national policies that ignore indigenous knowledge and tenure arrangements (Stave et al., 2001, 2007). Recent efforts have recognized group property rights and decentralized land administration, but this too has been met with substantial challenges. In many places there are overlapping claims of tenure and conflicting resource demands across groups, and within groups there are problems related to power sharing, accountability, and equitability (Mwangi, 2009).

Although researchers have independently documented threats to customary resource management institutions and river systems in East Africa, there is a lack of research on the relationships between them. This gap in our understanding of the proximate and more distal drivers of river change limits our ability to effectively manage watersheds. As a result, this study asked: how do communities in northern Tanzania manage water resources, and what are the implications for river systems?

The goal of our study was to identify and describe the institutional governance of natural resources, and how those institutions affected fluvial geomorphic forms and processes. We thus used an integration of social science methodology, geospatial mapping, and standard fluvial geomorphic field work and analysis. The goal was not to develop novel methodology within any particular subfield but, rather, to understand how these subfields contribute to understanding the landscape that has been shaped by humans, their institutions, and ongoing natural processes.

2. Regional setting

East African rangelands support remarkable populations of wildlife, a network of world-renowned protected areas, and human communities. About 79% of the East African land surface is rangeland (Kenya 87%, Tanzania 74%, Uganda 79%) (Pratt and Gwynne, 1977). The rangelands of northern Tanzania and southern Kenya receive a mean annual rainfall of about 300 to 1200 mm (Gichohi et al., 1996). Annually, the climate regime is characterized by one long dry season from June to October and one rainy season from November to May, which is subdivided into the short rains (November to January) and the long rains (February to May) (Prins and Loth, 1988).

The Simanjiro Plains, located in northern Tanzania, are semiarid with an average annual rainfall of about 600 mm. The vegetation consists of short grassland and smaller areas of woodland, bushland, and bushed grassland that is seasonally water-logged (Kahurananga, 1979). These savanna communities intergrade with riparian zones, which support remnants of tropical rainforest that became isolated and fragmentary because of climatic drying around 4000 YBP (Medley and Hughes, 1996). The soils of the Simanjiro Plains range from dark red sandy clay loam in the grasslands to black clay in the depressions (Kahurananga, 1981).

At the beginning of the wet season, wildlife – especially zebra (*Equus burchelli*) and wildebeest (*Connochaetus taurinus*) – migrate from Tarangire National Park (TNP) to the Simanjiro Plains (Kahurananga, 1981; Kahurananga and Silkiluwasha, 1997). As the dry season progresses, much of the wildlife migrates from Simanjiro back into TNP. Wildlife distributions are partly structured by water quality (particularly salinity; Gereta, 2004) and habitat and food preferences (Lamprey, 1963), but they are also attracted to TNP by surface water in the Tarangire River and the Silalo Swamp.

Water is a primary concern for Maasai pastoralists living in Simanjiro during drought and nondrought years. Streams and rivers are widely used water sources, particularly during times of water scarcity when boreholes break or become crowded, and dams dry up. When surface water is no longer available in rivers, hand-dug wells are used to access water for livestock, households, and even schools. Rivers and riparian zones are used for a variety of other purposes including washing, bathing, grazing, honey production, charcoal production, and as a source of building materials (timber and bricks). This study focuses on four rivers in Simanjiro: the Kikoti, Kiti Engare, Loiborsiret, and Terrat rivers (Fig. 1).

Livelihoods and land use in the study area have changed substantially in recent decades. This area is predominantly inhabited by Maasai pastoralists, who, in recent decades, have been diversifying their livelihoods through increased participation in agriculture and wage labor (Little et al., 2001; Thompson and Homewood, 2002; McCabe, 2003; Homewood et al., 2009; McCabe et al., 2010; Baird and Leslie, 2013). At the same time, there has been an influx of cultivators and commercial agriculture interests from other parts of Tanzania (Igoe, 2004). These changes have led to the expansion of cultivated land area and concern over the maintenance of wildlife migration routes between TNP and the Simanjiro Plains (Msoffe et al., 2011a,b).

Before assessing differences in land use and fluvial geomorphology across these rivers, it is necessary to account for the possibility that underlying biophysical variation could amplify or attenuate anthropogenic impacts on channel form. For instance, a confined bedrock river reach would likely have a lower channel width than an unconfined alluvial reach with the same level of human disturbance because bedrock reaches have less capacity for adjustment and are more resistant to change (Brierley and Fryirs, 2005). To ascertain the biophysical similarity of the study rivers and their capacity for channel adjustment, we borrowed methods from stages 1 and 2 of the river styles framework (Brierley and Fryirs, 2005), classifying the rivers based on their levels of confinement, landscape units, and elevation profiles.[1]

Preliminary fieldwork in 2009 and 2010 and initial geospatial analysis indicated that the four study rivers vary in terms of land use change but are comparable in other respects (Table 1). All rivers exhibit low slope angles and have a single active channel with predominantly sand/gravel bed material. Surprisingly, the drainage areas (calculated for the most downstream sampling points in each river) vary more widely; Kikoti River's drainage area is much smaller than the other

[1] We derived elevation profiles, slope estimates, and drainage areas from a 30-m digital elevation model (ASTER Global DEM) using the *TauDEM* extension for *ArcGIS 10.0*. This was the highest resolution, freely available DEM available for this remote region.

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