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A social-ecological typology of rangelands based on rainfall variability and farming type

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ABSTRACT

We present a social-ecological typlogy for the world's rangelands that integrates the much debated non-equilibrium concept from ecology with socio-economic characteristics of rangeland systems. We propose that, as a first approximation, the socio-economic properties can be adequately captured and differentiated by the distinction between the two main types of rangeland farming systems worldwide: subsistence and commercial farming. The resulting typology has four categories, which are 'commercial equilibrium', 'commercial non-equilibrium', 'subsistence equilibrium' and 'subsistence non-equilibrium'. We provide and discuss examples for each category. Moreover, we point out how this typology might help to understand and address some of the problems related to unsustainable rangeland management. Finally, we provide and discuss a global map of rangelands that illustrates the geographic distribution of all four rangeland types.

1. Introduction

A substantial part of Earth's habitable land mass is covered by rangelands, i.e. land that is not covered by ice, rocks or water. As of 2009, roughly 52% of global meat production took place in grassland-based systems of South and Central America as well as Africa. The commercial livestock sector was recently estimated to employ at least 1.3 billion people globally (Thornton, 2010), estimates of the number of livelihoods directly depending on rangelands vary from 600 million (Thornton et al., 2006) to 2 billion (Reynolds et al., 2007). Rangelands thus support, directly and indirectly, millions of people. Moreover, rangeland ecosystems provide a multitude of ecosystem services with considerable economic value (Goldstein et al., 2011, Havstad et al., 2007; MEA 2005; Tanaka et al., 2011), are home to numerous species of herbivores and plants (Olff et al., 2002), and are thought to have considerable potential in climate change mitigation (Lal, 2003, 2004; FAO, 2009). Many of these rangeland areas feature arid or semi-arid climates with high inter-annual variability of rainfall (Olbrich, 2012). The main – and often the only economically viable (Quaas et al., 2007) – land use is livestock farming. Even though exact numbers are hard to come by, it is safe to say that a very substantial part of the world's livestock is supported by such dryland rangelands[1] (e.g. FAO, 2009; Thornton, 2010).

Unsustainable management of rangelands, particularly overgrazing, is a major problem in many parts of the globe, especially those that classify as dryland rangelands (Safriel et al., 2005; SADC, 2009; von Wehrden et al., 2012). Many rangelands are vulnerable to interdependent biophysical (e.g. soil degradation, invasive species) and socio-economic (e.g. demographic shifts, market price fluctuations) changes, which unchecked, have potentially negative influence on both human livelihoods and the ecology of these systems. While there is an increasing awareness that rangelands are complex social-ecological systems (Vetter, 2005; Fox et al., 2009; Briske et al., 2011), much of the discussions around rangeland classification have evolved from disciplinary debates focusing on a single aspect of rangelands as illustrated by the non-equilibrium–equilibrium debate in ecology (Illius and O'Connor, 1999; Briske et al., 2003; Vetter, 2005).

While there are some conceptual frameworks that can be used to classify rangelands based on both the ecological and socio-economic properties of these systems, they tend to be difficult to

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[1] According to the 1994 U.N. Convention to Combat Desertification, 'dryland rangelands' are rangelands where annual precipitation is less than two thirds of potential evapotranspiration.

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apply over large spatial extents. For example, the Integrated Social, Economic, and Ecologic Conceptual Sustainable Rangelands Framework (Fox et al., 2009) or Ostrom (2009) General Framework for Analyzing Sustainability of Social-Ecological Systems dissect socio-ecological systems into constituting layers or 'tiers' describing states and interactions within the system. Fox et al. (2009) successfully demonstrated how these tiers and their constituents interact with each other in rangelands. However, their approach requires considerable data input, and we assume that this might be one of the reasons why it has not been widely used so far. Ostrom (2009) approach is less quantitative in nature and has been applied to analyze Tibetan pastoral systems (Wang et al., 2014). Yet, neither approach provides a general typology of rangelands, nor have they been used so far to construct one. However, such a rangeland typology has been advocated by some researchers recently for orientation in the general debate about rangeland health and sustainability (e.g. Vetter, 2005; Briske et al., 2011).

We think that a general typology of global rangelands might indeed be a useful tool to inform sustainable rangeland use. Different system characteristics lead to different outcomes, and what might be a successful policy in one system may be less effective, or even counterproductive in another. A negative externality can, for example, be tackled by a Pigouvian tax in a commercial farming system, but usually not in a subsistence system, because farmers' access to and use of markets is fundamentally different in the two systems. Moreover, the tight coupling of ecological and economic factors in rangelands suggests further policy differentiation is required in terms of both social and ecological system properties.

Here, we take up this demand for a general typology of rangelands and propose a relatively simple approach towards a social-ecological classification that might be used to inform rangeland management in a way that accounts for their ecological and socio-economic properties. Our proposed rangeland typology is based on two key system properties; the ecologically driven and empirically well-supported non-equilibrium concept for rangelands (Ellis and Swift, 1988; von Wehrden et al., 2012) and a socio-economic categorization based on whether farming is subsistence or commercial (cf. Hardin, 2004). We show how these two system properties can be combined to construct an easily applicable rangeland typology, with four categories, that can inform sustainable rangeland management. We illustrate and discuss our framework with examples of rangeland systems from around the world, and provide a global map of rangelands according to our typology, which can be seen as a complement to the "anthropogenic biomes" approach by Ellis and Ramankutty (2008), with a focus on sustainable rangeland use.

2. A social-ecological classification of rangelands

Beginning with key concepts, we set up, explain and discuss our social-ecological classification for rangelands in the following. Subsequently, we provide examples for each resulting category. Finally, we provide a global map using our classification, and discuss our findings.

2.1. Key concepts

High *inter-annual precipitation variability* is the central climatic characteristic of (semi-) arid rangelands world-wide (Olbrich, 2012). Ecologically, there is a correlation between the absolute sum of precipitation *and* its inter-annual coefficient of variation (*Cv*) with net primary productivity of above-ground biomass (ANPP). In fact, precipitation variability may be more important for ANPP than absolute sum of precipitation (Knapp et al., 2002). High inter-annual variability in precipitation leads to highly variable grass production creating, in turn, income uncertainty for farmers, since what a farmer can produce in any given year depends directly on what the land can support (Quaas et al., 2007). This close relationship of ecology and economics has made (semi-) arid rangelands a prime object of study for ecological economics (e.g. Olbrich, 2012; Jacoby et al., 2014).

Biophysical degradation commonly refers to the worsening of one or several biological or physical parameters with respect to several consecutive data collections at different points in time. A unified or commonly accepted rule when an author refers to a rangeland as being in a "degraded" state seems to be lacking, so there is a certain degree of subjectivity involved.

The *non-equilibrium theory* of rangelands (Ellis and Swift, 1988) links precipitation variability with ecological dynamics. The key tenet of non-equilibrium theory is that precipitation variability is the main driver of rangeland dynamics in arid and semi-arid rangelands.[2] With its emphasis on abiotic rather than biotic factors as primary drivers of vegetation and livestock dynamics, the non-equilibrium concept constitutes a controversial shift of paradigm in ecology (Vetter, 2005). Particularly, the non-equilibrium concept proposes a *Cv* value of 33% as threshold value, above which non-equilibrium conditions hold (Ellis and Swift, 1988). The theory predicts that equilibrium conditions (*Cv* ;< ;33%) generally favor biophysical degradation, because of less frequent droughts, which, by causing animal die-offs, allow the system to recover from grazing pressure. A recent global meta-analysis of rangelands studies found widespread use of the non-equilibrium concept and strong support for the validity of the 33% *Cv* threshold (von Wehrden et al., 2012). We therefore adopt this threshold to clearly distinguish between rangelands with equilibrium dynamics and rangelands with non-equilibrium dynamics.

Rangeland systems can be further differentiated by two socio-economic system types that occur in both equilibrium and non-equilibrium rangelands: commercial and subsistence farming.

Commercial livestock farming refers to the rearing of animals on private land for production of, among others, meat, eggs, dairy products and skins for the exclusive purpose of selling them at markets to make a profit (Cambridge Dictionaries Online, 2014). Commercial farmers generally have good access to well-developed markets for selling their produce, but also for the acquisition of farming infrastructure such as irrigation systems, extra fodder, chemical fertilizer, land, and financial capital or insurance (e.g. Ingenillem et al., 2014). Commercial farming mostly takes place in higher income countries, with China, India, Pakistan and Namibia being notable exceptions, and accounts for 53% of the world's agricultural GDP (World Bank, 2009). In high income countries, particularly in the United States, there has been a trend in recent decades towards shifting production capacities from extensive rangeland farming to more intensive production systems (Food and Water Watch, 2010). Nevertheless, globally there remains a continuum of commercial farming practices from extensive to intensive grazing, often determined by the biophysical constraints of the particular rangeland in which the grazing occurs.

Subsistence livestock farming or *communal livestock farming* refers to the rearing of animals such as goats, sheep, cattle, yaks or camels mainly for the personal use of their milk, eggs, meat or other animal products. Typically, subsistence farmers try to sell or exchange some of their produce at local markets to supplement their livelihoods when possible, but most or all of the produce is regularly consumed by the farmer and their family (Waters, 2007).

[2] In humid rangelands, selectivity by herbivores is another important driver of plant composition and rangeland dynamics.

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