Land Use Policy 70 (2018) 479–484

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Global assessment of the non-equilibrium theory of rangelands: Revisited and refined

John-Oliver Engler*, Henrik von Wehrden

Department of Sustainability Science, Leuphana University of Lüneburg, Germany

ARTICLE INFO

Keywords:
Climatic variability
Commercial farming
Degradation
Drylands
Grazing
Rainfall
Rangeland management
Subsistence farming

ABSTRACT

We re-investigate evidence for the non-equilibrium concept for rangelands using a georeferenced data base of $N = 83$ studies published in peer-reviewed journals. Following up on a previous study by von Wehrden et al. (2012), we use their global map of rainfall variability and their method to distinguish between three different types of degradation depending on the presence or absence of water sources or key resources in the studied areas. Addressing recent discussions in the rangeland science community, we include the distinction between commercial or subsistence use as parameter in our data base. We find that zonal degradation, i.e. degradation with no presence of water or key resources, is predominantly reported for locations with a precipitation coefficient of variation below the threshold of 33%, as proposed by the non-equilibrium concept. We do not find any statistical evidence for a systematic difference between commercial and subsistence farming in terms of degradation incidence.

1. Introduction

Estimates of the extent of global rangelands range from 30 to 56 per cent, or 41 and 74 million square kilometers, of Earth's ice-free terrestrial surface (Sayre et al., 2017). Today, rangelands directly provide for 0.7–2 billion people, depending on sources (Reynolds, 2007; Thornton 2010). Thus, rangelands play an important role for future global food security, given it is very likely that the number of humans on Earth will increase to 11 billion by the end of this century (United Nations, 2015). While rangeland ecology generates an ever increasing understanding of ecological processes and dynamics in rangelands (Vetter, 2005; Fox et al., 2009; Briske et al., 2011; von Wehrden et al., 2015), the link and interaction between ecological knowledge and socio-economic dynamics is still under-researched, despite a growing body of social-ecological and ecological-economic research that focuses on these aspects (Fernándéz-Giménez, 2002; McCabe, 2004; Galvin et al., 2006; Baker and Hoffman, 2006; Quaas et al., 2007; Olbrich et al., 2014). Thus, further improvement and integration of our understanding of the complex social-ecological system of rangelands is needed.

Currently, two strands of discussion are especially prominent in the rangeland science community. On the one hand, much discussion has evolved around the non-equilibrium concept for rangelands, particularly in the context of grazing-induced change of vegetation cover[1] (Illius and O'Connor, 1999; Briske et al., 2003; Vetter, 2005). The non-equilibrium concept for rangelands (Ellis and Swift 1988) states that precipitation variability, measured by the coefficient of variation (*Cv*), is the main driver of rangeland dynamics, while the influence of the overall sum of precipitation for rangeland health indicators is overall negligible. The concept proposes a *Cv* value of 33% annual precipitation sum as threshold value, which separates equilibrium conditions below and non-equilibrium conditions above. A central prediction is that equilibrium conditions ($Cv < 33\%$) favor worse biophysical rangeland conditions, because of less frequent droughts, which, by causing animal die-offs, would allow the system to recover from the constantly high grazing pressure. On the other hand, there is a strand of debate that focuses on the impact of land tenure and associated land use practices on rangeland health (Sandford 1983; Ellis and Swift 1988; Behnke and Abel 1996; Sullivan and Rohde 2002; Vetter and Bond 2012; Berger et al., 2013; von Wehrden et al., 2015). Some contributions postulate a tendency to overgrazing in communal farming systems (e.g., Lamprey 1983; Wolters, 1994; Parsons et al., 1997), often strongly based on the idea of the Tragedy of the Commons (Lloyd, 1980 [1833]; Hardin, 1968). Today, the impact of grazing on communal land, the majority of which serves the subsistence of smallholder farmers, is a contentious issue (Shackleton, 1993; Ward et al., 1998; Rowntree et al., 2004; Vetter and Bond 2012; Sayre et al., 2017). Closely related is the discussion about potential differences of grazing impacts in commercial

* Corresponding author at: Quantitative Methods of Sustainability Science Group, Leuphana University of Lüneburg, Scharnhorststr. 1, D – 21335, Lüneburg, Germany.
E-mail address: engler@leuphana.de (J.-O. Engler).

[1] Grazing-induced change of vegetation cover is often synonymously referred to by the judgmental term of ‚degradation' in the literature.

https://doi.org/10.1016/j.landusepol.2017.11.026
Received 22 March 2017; Received in revised form 28 July 2017; Accepted 12 November 2017
0264-8377/

and subsistence rangelands (Darling, 1956; Smet and Ward, 2005; Kgosikoma et al., 2013; Behnke and Mortimore, 2016; Sayre et al., 2017).

The question if there is an empirical difference between small-scale subsistence and large-scale commercial use of rangelands in terms of grazing impact has not been addressed in a quantitative meta-study so far. Economic theory would suggest that a privately-run company with exclusive local access rights would foster long-term rangeland health (e.g., Hanley et al., 2007). Yet, there are little studies that explicitly address this question. Available evidence for the example of commercial cattle farming in Namibia is split (Quaas et al., 2007; Ingenillem et al., 2014), and Vanderpost et al. (2011) find no clear differences in land quality between commercial and subsistence farm land in Botswana, based on long-term satellite data. For the example of grazed savannah ecosystems, Kgosikoma et al. (2013) report no differences between commercial and subsistence farming approaches, based on a qualitative assessment of the literature.

In the present paper, we propose to link these two strands of research and investigate the current literature on health in grazed commercially and subsistently managed (non-) equilibrium rangelands. Concretely, we take up the meta-analytic statistical approach of Wehrden et al. (2012) that has provided strong support for the non-equilibrium concept and refine their analysis by researching and analyzing a larger literature data base ($N = 83$). In additon, we specifically look into literature concerned with commercial or subsistence farming in the context of rangelands to provide a first analysis of whether there is a difference between commercial farms and subsistence farms in terms of degradation incidence and central precipitation characteristics.

2. Material and methods

2.1. Data base of case studies

We refined the database of von Wehrden et al. (2012) that investigated the incidence of ecological degradation in rangelands. To obtain a larger set of relevant studies, we searched the ISI Web of Science and the Scopus data base using the following set of keywords: “rangelands”; or “grassland”; or “pastur*”; or “meadow” and “grazing*”; or “livestock”; or “stocking”; or “cattle” and “degrad*”; or “*diversity”; or “biomass”; or “disturb*”; or “*productivity” and “non-equilibrium”; or “*equilibrium”; or “commercial”; or “subsistence” and “precipitation”; or “rainfall”; or “clima*”. We treated the terms ‘non-equilibrium’ and ‘disequilibrium’ as synonymous; and excluded those studies that were not specifically dealing with rangeland degradation.

For the reported types of ecological degradation in a study, we used the same approach as von Wehrden et al. (2012: 394): we focussed on studies assessing biophysical degradation, i.e. degradation with respect to bioproductivity, biodiversity and soil parameters, such as vegetation and species composition, biomass productivity, plant functional traits, vegetation cover and chemical soil analyses to capture a complete, yet conservative approach. Moreover, we used an approach to classifying degradation according to three types, which is based on ecological functions of resource types to livestock in an area (cf. von Wehrden et al., 2012). ‘Zonal degradation’refers to degradation in a system where forage availability largely reflects the local microclimate, and is unrelated to other influences, such as additional water sources or key resources. Degradation occurring at sites which have a stable and high level of forage provision due to the presence of key resources essential for plant growth is called ‘key resource degradation’. Key resources in this sense may be brought about by geographical conditions such as mountains or salt marshes, but provision of additional forage by herders or farmers also falls into this category. ‘Water-related degradation’ are all those instances of degradation that are caused by the repeated use of an area by livestock as a drinking spot, such as the immediate vicinity of water sources (Leggett et al., 2003). For simplicity and consistency, we will use the short labels ‘Zonal’, ‘Key’, ‘Water’ and ‘None’ for these degradation types hereafter. In addition, we also recorded whether a study site was situated in a commercial or subsistence farming system. Where available, we followed the indication of the authors of a study or used the definitions of farming types from the Cambridge Dictionaries Online (2014) and Waters (2007) together with the description in the respective paper to decide whether a system was classified as commercial or as subsistence farming, where we treated the terms ‘subsistence’ and ‘communal’ as synonyms.

We geo-referenced each case study. For studies that spanned larger areas instead of just one single location, we used the center point of the area as a first approximation for further analysis. Hence, we geo-referenced these studies as one single point. If the study site’s name was given, but geo-coordinates were only given for a municipality or city ‘close-by’ (in one case, there was a 60 kilometer discrepancy, which led to a large difference), we extracted the exact coordinates from Google Maps to prevent erroneous *Cv* values. Finally, we obtained precipitation data from the ‘Worldclim’ global climate data base, which includes data from over 26′000 locations from all over the world (Hijmans et al., 2005). We extracted the inter-annual variation coefficient from the data base obtained in von Wehrden et al. (2012).

2.2. Data analysis

We used analysis of variance (ANOVA) to test for statistically significant differences between the four degradation classes ‘Zonal’, ‘Key’, ‘Water’ and ‘None’. We also employed pairwise *t*-tests for comparisons between the degradation classes and between the groups according to the reported farming system (commercial and subsistence). All statistical analyses were performed within the R environment (R Development Core Team, 2009).

3. Results

Following the method described in Section 2, we identified $N = 83$ suitable studies that explicitly reported on the incidence of degradation in the presence of livestock grazing. Of these 83 studies, 44 were identified as investigating a commercial farming system and 36 were identified as subsistence farming system (Table 1). In three cases, it was impossible to make a reliable classification. The results of the geo-referencing process can be seen in Fig. 1, where we show the locations of the studies contained in our database. The spatial pattern reflects the global distribution of rangelands, so Europe is largely absent, except for one study in Greece and one in Spain. The majority of studies is based in Sub-Saharan Africa, most notably in South Africa ($N = 14$), Kenya and Senegal ($N = 4$). Several studies were also conducted in the United States ($N = 13$) and Argentina ($N = 4$) in the Americas and Mongolia ($N = 7$) and Australia ($N = 11$) in Asia and Oceania.

In summary, 13 (or 15.7% of) the studies included in our data base report ‘Key’ degradation, 51 (61.4%) studies report ‘Zonal’ degradation, 10 (12.0%) studies find degradation of the ‘Water’ type and 9 (10.8%) studies do not find any evidence of degradation, implying that 89.2% of the sampled studies report some form of degradation. Degradation assessment was either done by some form of vegetation cover and biodiversity assessment (plant and species sampling, pictures) or chemical soil analysis. Table 1 shows the incidence of different degradation types depending on reported farming system.

First, we tested whether there is a significant difference in *Cv* and annual mean precipitation values between these degradation types

Table 1
Frequencies of degradation types when controlling for farming type.

	Total	Water	Zonal	Key	No
Commercial	44	5	27	10	2
Subsistence	36	5	22	2	7