Ecological Economics 131 (2017) 129–138

Contents lists available at ScienceDirect

Ecological Economics

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

Analysis

Multi-scale resilience of a communal rangeland system in South Africa

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ARTICLE INFO

Article history:
Received 10 September 2015
Received in revised form 9 August 2016
Accepted 10 August 2016
Available online 1 September 2016

Keywords:
Socio-ecological system
Resilience
Agent based model
Rangeland systems
South Africa
Development

ABSTRACT

Resilience has either been assessed on system or individual scale so far. Ignoring the other scale may potentially change the interpretation of resilience in socio-ecological systems (SES). Thus, this paper argues that the co-evolution of both resiliencies must be studied to capture multi-scale complexity. We attempt to close this gap by assessing resilience at both scales of a village community in Thaba Nchu, South Africa. Villagers use a commonly managed rangeland for beef cattle production. An agent based model of household interaction coupled with a biophysical model of the rangeland measures the resiliencies of the SES towards a shock, a stress and a policy intervention. Currently, the SES remains in a stable attractor in terms of SES resilience. Household resilience, however, degrades in a process of structural change. A drought scenario shows improved SES resilience but structural change at household level accelerated. An increase in the number absentee herders increases the likelihood for SES collapse by eroding social embededdness. Finally, an introduced basic income grant demonstrates that the SES is able to cope with an increased number of appropriators. However, interaction of the policy intervention with an exogenous stress translates into an increased probability of SES decoupling.

1. Introduction

Benefits from communal rangelands are substantially contributing to rural livelihoods in Southern Africa (Cousins, 1996; Berzborn, 2007). Livestock serves as a source of cash income, savings, drought power, manure provider, is of cultural importance or signals status (Shackleton et al., 2005; Shackleton et al., 2001; Dovie et al., 2006). In the former homelands of South Africa, livestock constitutes the most important agricultural asset (Vetter, 2013). At the same time those crowded areas are subject to the dual threat of poverty and rangeland degradation (Dougill et al., 2010). Thus, agencies are concerned with the development of the South African commons (Department of Agriculture, 2007). However, many developments attempts fail due to the narrow assessment of community-rangeland systems prior to intervention (Vetter, 2013). If quantifiable, resilience is a measure which offers a deeper level of insight with respect to rangelands being coupled socio-ecological systems (SES) and their dynamic properties (Gross et al., 2006; Horan et al., 2011; Rammel et al., 2007; Janssen et al., 2000; Plummer and Armitage, 2007; Perrings, 2006; Schlüter et al., 2014; Biggs et al., 2009).

Resilience definitions in the context of SES are diverse. These range from highly abstract concepts on system level to social- or ecosystem specific indicators (e.g. Seixas and Berkes, 2003; Hawes and Reed, 2006; Holling, 2001; Schlüter and Pahl-Wostl, 2007). The growth of theoretical approaches to explain the resilience increases fuzziness (Pendall et al., 2010) and contradictions. This shortcoming may originate from the fact that resilience is not directly observable (Carpenter et al., 2005). Carpenter et al. (2005) advice us to infer resilience indirectly which led them to use the term 'surrogates' instead of indicators for resilience. According to Miller et al. (2010), resilience measures should capture dynamic processes instead of being static indicators. Such processes are thought to be created over multiple scales simultaneously. The multi-faceted view on resilience measures was also noted by Carpenter et al. (2005). In addition of being multi-scale, dynamic and measurable by means of surrogates, SES resilience is stated to be an emergent phenomenon (Berkes et al., 2003). If we adopt Walker et al.'s (2006b) definition of SES resilience as the

"[...] capacity of a system to experience shocks while retaining essentially the same function, structure, feedbacks, and therefore its identity",

we must understand system identity on SES level as exactly that: the identity of emergent phenomena and stylized facts of the coupled system measured by means of dynamic resilience surrogates emerging over different SES scales. Thus, SES resilience is non-normative.

However, from a development standpoint the above definition is not satisfactory in its own right as it ignores the resilience of the individual and is only concerned with the continuity of system identity (Barrett and Constas, 2014; Walker et al., 2006b). Barrett and Constas (2014), created the notion of development resilience as a *complementary*

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http://dx.doi.org/10.1016/j.ecolecon.2016.08.012
0921-8009/

measure to SES resilience. Development resilience is strictly normative, lends from theories of poverty traps and is concerned with the individual (e.g. person or household) representing a lower scale of the SES. Surrogates for development resilience would capture poverty measures or the well being of individuals. It has similarities to the vulnerability concept but is distinct from it as it is concerned with poverty dynamics contrary to current resistance levels.

Both resilience measures might converge or diverge if the system is subject to one of three exogenous changes. System changes are shocks, stresses or interventions with the aim to build resilience. Shocks are sudden changes, stress is a constant pressure and resilience building tries to change those system characteristics which constitute resilience (Barrett and Constas, 2014; Walker et al., 2002).

Past work on the adaptive cycle investigating SES level resilience (Holling, 1986; Walker et al., 2006a), ignores the existential importance of the survival/well-being of the individual for that individual. Moreover, the interaction of SES resilience with lower-scale resilience on household level might be an explanation for the deviations from the adaptive cycle found in some case studies (Anderies et al., 2006). Likewise, a sole focus on development resilience as in e.g. Keil et al. (2008) emphasises the positive effect of the possession of assets on household resilience without considering a potential non-linear feedback effect on system level. That is, an increase of assets on the household level, increasing household resilience, might jeopardize SES resilience as it supports increased appropriation from the resource in the future. To our knowledge, no study has investigated the co-evolution of SES and development resilience for a SES so far. A reason for the lack of such an integrated approach might be the complexity in the assessment. Traditional methods used in case study research (e.g. participant observation, econometrics, narratives) are lacking the ability to account for such complexity. The aim of this paper is to quantitatively measure the co-evolution of both resiliencies for an exemplary community-rangeland SES case in South Africa with a SES modelling approach. We choose generic resilience indicators and measurement scales which are applicable beyond the specific case presented thereafter.

Communal rangeland systems are a suitable SES type to investigate multi-scale resilience as individual households are interacting within the social domain and appropriate from a common resource. Livestock is the principal coupling mechanism between the domains. That is, communal rangelands are coupled systems within which a social realm of interaction is embedded. This set-up creates cascading effects as postulated by complex adaptive system theory (Hawes and Reed, 2006).

SES modelling has been identified as a way to test the system for tipping points without putting the actual SES at risk (Carpenter and Brock, 2004). SES models capture the complexity of both subsystems and, even more importantly, the endogenous feedback between them (Schlüter et al., 2014). Some SES models are explicitly focusing on resilience aspects.

Janssen and Carpenter (1999) presented one of the first SES models with a resilience focus concerned with the management of lakes. Horan et al. (2011) developed a bio-economic model to investigate the impact of institutional constraints on tipping points in a fishery SES. Analysis of a similar model by Carpenter and Brock (2004) suggests that a multiplicity of management regimes increases resilience. A generic, mathematical SES model of landscape exploitation by Fletcher and Hilbert (2007) finds that resilience decreases by approaching maximum profits. Examples of rangeland SES which touch resilience are (Dougill et al., 2010; Ludwig et al., 2001; Janssen et al., 2002; Janssen et al., 2004; Anderies et al., 2002; Gross et al., 2006; Rasch et al., 2016a).

Among the methodological tool set available for SES modelling, agent based models (ABM) are the prominent choice when human behaviour is integral to the research object (Heckbert et al., 2010; Schlüter et al., 2012). ABMs are dynamic in an adaptive sense, allow for any level of agent heterogeneity and enable us to relax rationality assumptions dominant in traditional bio-economic modelling (Rasch et al., 2016b). The object oriented programming paradigm of ABMs fosters the necessary full integration of social and ecological models (Baumgärtner et al., 2008). At the same time ABMs allow to visualize any change in resilience under different scenario settings (Miller et al., 2010).

In the following sections we present our results of an empirical agent based model coupled with a biophysical model adapted from Rasch et al. (2016a). For this study we measured the resiliencies of a communal rangeland SES on the individual HH (development resilience) and on the coupled system level (SES resilience). The model itself is calibrated and parameterized with biophysical and survey data from the Thaba Nchu region in the Free State, South Africa. Against the outlined background, the model is used to answer three main research questions: What are the effects of

1. a drought *shock*,
2. a fundamental change in livestock ownership constituting *stress* to the SES and,
3. a policy *intervention* with the aim of poverty reduction

on the resiliencies of the SES? We furthermore investigate the effect of the policy intervention on the probability of SES decoupling under the current system configuration, under the drought shock and the external stress induced by absentee owners.

We adapt the model in Rasch et al. (2016a) by introducing additional empirical heterogeneity derived from survey data. Here, the authors find that heterogeneity can have a significant impact on model outcomes and should be included if data availability allows. Thus, we present a sensitivity analysis with respect to the impact of our model refinements on resilience surrogates.

Before presenting the analysis itself, we outline the resilience surrogates in the next section (Section 2) and a case description (Section 3).

2. Resilience Surrogates for a Communal Rangeland SES

As outlined in the introduction, we measure resilience on the individual HH and the SES scale. The latter constitutes a higher scale compared to the former. With respect to the higher scale, we follow Walker et al.'s (2002) proposal for measuring SES resilience.

Irrespective of the specific SES, a variable being able to assess the resilience of a *coupled* system should be focused on the intertwined dynamics of emergent phenomena on the social and ecological scale. Walker et al. (2002) propose the mapping of ecological with social variables in a two-dimensional graph to tackle the operationalization of SES resilience.

They focus on the dynamic patterns of such a combined measure. In their example of a rangeland SES, the authors use debt-income ratio and woody vegetation as social and ecological variables, respectively. The system can be characterized by the type of its dynamic patterns which is a function of the size of the basin of attraction as well as of the position of the basin in the configuration space. We follow their approach and use the ecological and social resilience surrogates of basal cover and inequality of herd sizes to map the dynamic patterns on the coupled scale. Both surrogates are present in, and of fundamental importance for, any commonly managed rangeland community.

Basal cover is the area covered by plants at ground level and is directly related to the amount of photosynthetic biomass responsible for future growth and recovery. Basal cover is commonly used as an indicator for rangeland qualities of semi-arid grassland ecosystems of South Africa (Wiegand et al., 2004; Snyman, 2005). Those qualities resemble different grazing histories in terms of grazing pressure. Snyman (2005) found 8.3%, 6.4% and 2.9% basal cover for good, moderate and poor rangeland respectively. Basal cover as a dynamic surrogate can be used to measure the change of rangeland condition and degradation over time.

As a surrogate for social resilience, we apply the Gini coefficient to the herd sizes of HH in our communal livestock production system. The Gini coefficient is a common measure for inequality (Pyatt, 1976). We use inequality as a surrogate for social resilience as it constitutes an emergent attribute of the community which cannot be measured