Global Environmental Change 23 (2013) 51–60

Contents lists available at SciVerse ScienceDirect

Global Environmental Change

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

Social–ecological traps and transformations in dryland agro-ecosystems: Using water system innovations to change the trajectory of development

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ARTICLE INFO

Article history:
Received 31 December 2011
Received in revised form 18 September 2012
Accepted 5 October 2012
Available online 10 November 2012

Keywords:
Farming
Water system innovations
Social–ecological dynamics
Ecosystem services
Poverty
Development trajectory
Feedback

ABSTRACT

Recent efforts to achieve a much needed productivity increase in farming systems across semi-arid and dry sub-humid sub-Saharan Africa have highlighted the potential of small-scale water system innovations (SWSIs). This paper takes a social–ecological resilience approach to investigate how this type of water management technology would influence agro-ecosystem dynamics, using a catchment in northeastern Tanzania as an example. The analysis finds that three external drivers (increasing dryspell frequency, population growth, and institutional changes) have interacted with a set of key variables in the studied system to shape a development trajectory over the past half-century where off-farm ecosystem services are being degraded while agricultural yields remain low and people remain poor. The analysis further finds that the evaluated SWSIs have the potential to destabilize feedbacks maintaining this social–ecological trap through several different mechanisms, and thereby open up for new development trajectories. A concluding discussion identifies a number of challenges to this type of transformation in sub-Saharan Africa, and outlines the type of investment approaches that would be needed to go from potential to reality.

1. Introduction

Semi-arid and dry sub-humid sub-Saharan Africa (SSA) present large challenges in terms of eradicating poverty and hunger while at the same time ensuring environmental sustainability (Biggs et al., 2004; Reynolds et al., 2007; Rockström et al., 2007). Alarming poverty levels in combination with a heavy reliance on small-scale rainfed agriculture has made productivity improvements in existing farming systems a top priority over several decades by now (PACD, 1977; Parr et al., 1990; Rockström et al., 2007; McIntyre et al., 2009). However, with increasing understanding of the importance of ecosystem services for human well-being (Costanza et al., 1997; Daily, 1997; Millennium Ecosystem Assessment, 2005; Daily and Matson, 2008), and with ample evidence for the negative environmental consequences that intensified agriculture may have (Pretty et al., 2000; Tilman et al., 2002; Foley et al., 2005; Gordon et al., 2008), also comes an awareness that these farming systems have to be upgraded in ways that safeguards productivity beyond the field. In other words, while improved agricultural production is a primary objective, a parallel goal must be to maintain, or even enhance, multi-functionality in the landscape so that the generation of food as well as other ecosystem services can be sustained over time (Swinton et al., 2007; Bossio et al., 2010; Foley et al., 2011).

Although the continuously low yield levels experienced among smallholder farmers in semi-arid and dry sub-humid SSA are the outcome of a number of complex problems, one fundamental constraining factor in these dryland regions is lack of water. More specifically, the problem is often temporary water shortages in the crop root zone during sensitive development stages (Stroosnijder, 2009). Frequent dry-spells (Barron et al., 2003), and large unproductive flows in the field water balance (Rockström and Falkenmark, 2000) lead to agricultural droughts and crop water deficits more or less every season, even though the cumulative rainfall is enough to produce a crop had it been more evenly distributed. The conventional agronomic solution to crop water deficits has been the development of large-scale irrigation systems, but high investment costs, inefficient water use, and large environmental consequences has led to a general consensus that the era of rapid expansion of large-scale irrigation is over (Falkenmark and Rockström, 2004; Molden, 2007). Recent efforts to improve productivity in small-scale rainfed farming have instead increasingly focused on a number of smaller-scale solutions, ranging from in situ soil and water conservation, to various forms of run-off water harvesting, external catchment water harvesting, and small-scale supplemental irrigation systems. These technologies, which I hereafter will refer to as small-scale water system innovations (SWSIs), aim to bridge agricultural

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http://dx.doi.org/10.1016/j.gloenvcha.2012.10.007

droughts by minimizing runoff, evaporation and drainage, and by increasing infiltration and the soil's capacity to retain moisture. Although relatively little is known about the potential cascading (hydrological, environmental, and social) effects on watershed or basin scales from widespread adoption of these practices (Rockström et al., 2004), they appear to have a large potential to stabilize and increase yields in current farming systems (Li et al., 2000; Fox, 2003; Barron, 2004; Reij et al., 2005; Makurira et al., 2009). It has been suggested that they can do so while at the same time conserving ecosystem services both on and off-farm (Pretty et al., 2006; Vohland and Barry, 2009). Thus, they provide a promising route for transformation of current agro-ecosystems in the drylands of SSA.

Using the example of the Makanya catchment in northeastern Tanzania, this paper takes a social–ecological resilience approach to investigate how SWSIs influence current agro-ecosystem dynamics. The analysis has two main parts. In the first part I interpret the present situation in Makanya as the outcome of interactions between a set of external drivers and key system variables. Over the past half-century these interactions have shaped a trajectory of development where off-farm ecosystem services are being degraded while crop yields remain low and people remain poor, a situation that can be understood as a social–ecological trap. In the second part of the analysis I show how the introduction of SWSIs would destabilize current system feedbacks in Makanya and thereby open up for transformation towards a development trajectory with higher agro-ecological productivity. Finally, I identify a number of challenges to this type of transformation in SSA, and outline the type of efforts are needed to overcome them. The paper builds on data collected during four years of fieldwork in Makanya, within the framework of the SSI program (Rockström et al., 2004; Bossio et al., 2011), an international research initiative studying existing and introduced water system innovations in semi-arid and dry sub-humid SSA. Using conceptual systems modeling, the paper synthesizes some major findings of this research.

2. Theory

2.1. Smallholder farming systems in semi-arid and dry sub-humid SSA

The semi-arid and dry sub-humid regions of SSA are home to more than 300 million people. With more than 40% of the population living on less than 1 USD per day, these are among the poorest regions in the world. The majority of the population (60–90%, depending on country) lives in rural areas and bases their livelihoods on small-scale rainfed crop farming.

While islands of intensive agriculture with substantially higher yield levels exist (Tiffen et al., 1994; Mortimore, 2005), especially in densely populated areas with good market connections, the typical smallholder-farming enterprise in SSA is non-mechanized and use few external inputs. Large efforts have been made to intensify these systems, but unlike in, e.g. South Asia these attempts have mostly been short-lived and a similar green revolution has not been sustained. Maize yields in dryland SSA, for example, still average around 1.5 ton/ha, and sorghum just below 1 ton/ha. A large part of the increase seen in cereal production over the past half century has been achieved through expansion of farmland rather than through intensification of production (Molden, 2007).

Due to the seasonal nature of agriculture and as a way to spread risks, smallholder farmers in these regions have traditionally also had a range of other livelihood sources (Scoones, 1996). The use of local off-farm ecosystem services for additional food, medicines, and construction materials is common (Millennium Ecosystem Assessment, 2005; WRI, 2005), and incomes from small-scale businesses, wage labor, and remittances are becoming increasingly important. Not neglecting the substantial contribution of the latter income sources to contemporary smallholder livelihoods, or the broader processes of social, economic, and political change that are underway in Africa, farming and livestock keeping still provide the base for rural livelihoods in much of semi-arid and dry sub-humid SSA. And this will likely remain the case in the foreseeable future (Rosegrant et al., 2002; Diao et al., 2007; Hazell et al., 2007).

2.2. Towards a better understanding of dryland dynamics

A conclusion of the discussion above is that it is more urgent than ever to find sustainable ways to improve productivity in rainfed smallholder systems in semi-arid and dry sub-humid SSA. Given the unsatisfying outcome of investments during the past few decades in African agriculture, new models are needed to improve our understanding of dynamics and complexity in these agro-ecosystems. Attempting a step in that direction, this paper takes a social–ecological resilience approach, with a focus on ecosystem services, to interpret dryland dynamics and analyze the role that SWSIs may play in shaping these dynamics.

The most fundamental assumption of this approach is perhaps that social and ecological systems are inextricably linked (Berkes and Folke, 1998; Folke, 2006), and that any attempt to study one without the other will only generate partial understanding. Many changes in ecosystems are directly caused by human activities, such as land-use. These changes alter the flow of ecosystem services on which humans depend, which in turn triggers societal responses (Carpenter and Folke, 2006). For any social–ecological system these dynamics could play out in many different ways, although some configurations are more probable than others, due to key system variables, dominant feedback processes and existing external drivers, as schematically illustrated in Fig. 1 (Carpenter et al., 2001; Walker et al., 2009). This means that the possible development of a SES often can be thought of in terms of a set of alternative trajectories, whose social and ecological outcomes differ (Folke et al., 2010). For a given system, each trajectory is characterized by a specific set of and/or qualities of ecosystem services, and maintained by specific social–ecological feedback processes. Depending on how strong these feedbacks are, the system can show more or less path dependency, when faced with changing conditions. If the level of change is important enough to alter the main feedbacks, the system will change its trajectory of development. While a shift from one trajectory to another can be a slow process (in a human time perspective), some systems have key variables that respond in a nonlinear way to changing conditions (Scheffer et al., 2001). This can lead to a sudden change in system feedbacks, and consequently an abrupt shift between trajectories (Folke et al., 2004; Scheffer, 2009). Regardless of transition time, however, a shift will eventually be detectable through the change in quantity and/or quality of the ecosystem services produced, with subsequent effects on human wellbeing.

In line with this reasoning, the dryland challenge outlined above can thus be reformulated to: How do we maintain these agro-ecosystems on development trajectories that provide us with the ecosystem services that we need (including food), or alternatively, if the current pathway is considered undesirable (e.g. if too little food and other ES is being produced), how can we destabilize existing feedbacks so as to open up for transformation, and then navigate towards a more desirable trajectory? This constitutes an essentially new way of thinking about the agro-ecosystems in semi-arid and dry sub-humid SSA (parallels to which have recently been expressed in Walker et al., 2009 and Van Apeldoorn et al., 2011); starting with the recognition of a genuine coupling of these systems' social and the ecological components, emphasizing their continuous interaction in an ever changing