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Research article

Managing adaptively for multifunctionality in agricultural systems

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ABSTRACT

The critical importance of agricultural systems for food security and as a dominant global landcover requires management that considers the full dimensions of system functions at appropriate scales, i.e. multifunctionality. We propose that adaptive management is the most suitable management approach for such goals, given its ability to reduce uncertainty over time and support multiple objectives within a system, for multiple actors. As such, adaptive management may be the most appropriate method for sustainably intensifying production whilst increasing the quantity and quality of ecosystem services. However, the current assessment of performance of agricultural systems doesn't reward ecosystem service provision. Therefore, we present an overview of the ecosystem functions agricultural systems should and could provide, coupled with a revised definition for assessing the performance of agricultural systems from a multifunctional perspective that, when all satisfied, would create adaptive agricultural systems that can increase production whilst ensuring food security and the quantity and quality of ecosystem services. The outcome of this high level of performance is the capacity to respond to multiple shocks without collapse, equity and triple bottom line sustainability. Through the assessment of case studies, we find that alternatives to industrialized agricultural systems incorporate more functional goals, but that there are mixed findings as to whether these goals translate into positive measurable outcomes. We suggest that an adaptive management perspective would support the implementation of a systematic analysis of the social, ecological and economic trade-offs occurring within such systems, particularly between ecosystem services and functions, in order to provide suitable and comparable assessments. We also identify indicators to monitor performance at multiple scales in agricultural systems which can be used within an adaptive management framework to increase resilience at multiple scales.

1. Introduction and key concepts

Given the current and future challenges faced by agricultural systems, including the need to feed an additional 3 billion people while increasing sustainability and decreasing water use (Alexandratos and Bruinsma, 2012; Rockström et al., 2009), there is an increasing need for both design and management that improves their triple bottom line - social, environmental and economic - sustainability (Elkington, 1997). Doing so may increase the number of beneficial outcomes agricultural systems provide, ensure food and livelihood security, and increase the quantity and quality of ecosystem services. For agricultural systems to achieve such goals they could be managed for multiple functions – not just production and profit. Here we present adaptive management as an approach for achieving sustainability and managing tradeoffs in agricultural systems. In order for the multifunctional outcomes of agricultural systems to be recognized and valued, we re-address the definition of agricultural performance to evaluate the economic, environmental and social functions in a more global and multidimensional manner, as opposed to a one-dimensional optimization approach with economic productivity at the core. We present an overview of

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the functions sustainable agricultural systems can provide, redefine performance of agricultural systems and introduce a new framework for assessing the performance of agricultural systems from a multifunctional perspective. We apply this framework to two cases of agricultural systems: one pastoral and one arable. Each case study uses literature comparing adaptively and conventionally managed agricultural systems in order to identify the functions achieved in each and their distribution across the social, economic and environmental pillars, their performance according to the new definition, multiscalar trade-offs and outcomes for sustainability.

Agricultural systems are managed social-ecological systems (SES) - integrated systems in which humans are part of nature and therefore cultural, political, social, economic, ecological and technological components interact (Berkes and Folke, 1998) around the production of commodities, whether food or non-food. This definition encompasses a great diversity of systems, typically delineated by spatial scale – i.e. from the field level, to farming landscapes, to examining the sector as a whole. Before continuing, we first need to differentiate between a food and an agricultural system. In the most basic sense, food systems entail all the inputs, activities and outcomes associated with food production, processing, distribution, consumption and waste disposal (Ericksen, 2008). Whatever the scale, as a managed system, food systems are a human creation for a fundamental human objective: human biological sustenance. As such, food systems are coupled social-ecological systems as they *“incorporate multiple and complex environmental, social, political and economic determinants encompassing availability, access and utilization”* and involve varying spatial, temporal, and institutional scales (Ericksen, 2008:234). An agricultural system has environmental, social, political and economic boundaries encompassing agricultural production, with less focus on the phases of processing, distribution, consumption and waste disposal other than that which occurs on-farm. Here, we focus on the farm level as key for transitioning towards sustainability, including both individual farmers as managers and farmers collaborating within a landscape. These systems can be framed as SESs because of their integrated nature and influence on desired outcomes such as food security and provision of ecosystem services.

1.1. Ecosystem functions and services

The characteristic exchanges and processes within an ecosystem are its functions, and these include energy and nutrient exchanges, regulation of climate and hydrological cycles, and decomposition and production of biomass (Sodhi and Ehrlich, 2010). In contrast, ecosystem services are “*the set of ecosystem functions that are useful to humans*” (Kremen, 2005:468), i.e., have an anthropocentric benefit. For example, pollination as an ecosystem function is necessary for ecosystems to sustain over time. In contrast, pollination as an ecosystem service refers to the pollination of food or fuel crops – i.e. those of use to humans. In order to ensure sustainability, agricultural systems should be managed to achieve a diversity of functions, whether directly beneficial to humans or not. A sustainable agricultural system will provide the functions humans desire (i.e. ecosystem services) as a co-benefit to the necessary ecosystem functions that will ensure the long-term survival and sustainability of working agricultural landscapes. This multifunctional perspective on management supports a different notion of resources in an agricultural system and therefore a different relationship with nature, the result of which is a profound revision of the performance of agricultural systems, as discussed below. In order to achieve a more multifunctional measure of performance, new management regimes based on adaptive modes (rather than prescriptive ones) are required.

1.2. Adaptive management

Adaptive management (AM) is a systematic process that integrates management and learning in an iterative process (Holling, 1978). Management actions are viewed as hypotheses, and uncertainty is reduced over time. As such, AM uses management intervention as a tool to strategically learn about the functioning of the system of interest (Allen and Garmestani, 2015; Allen et al., 2011). AM is not an ‘informed trial-and-error’ strategy but an explicitly structured process including a careful description of fundamental and means objectives, hypotheses of system response to management, alternative management practices and hypotheses, predicted consequences of implementing management alternatives, procedures for collection and analysis of monitoring data and a mechanism for updating management as learning occurs (Allen and Garmestani, 2015). Therefore, we hypothesize an AM strategy can support multiple objectives within a system, for multiple actors, across temporal and spatial scales, and can help design management systems capable of accomplishing of multiple functions, as long as they are clearly defined. In doing so, AM may be the most appropriate tool for sustainably intensifying production whilst increasing the quantity and quality of ecosystem services.

Adaptive management may be particularly suited for application to agricultural systems given their complex and multidimensional nature. Traditionally this complexity has been perceived negatively, and as the origin of uncertainty within agricultural systems, especially given the multiple interacting functions and processes that affect these systems but which are seen as beyond the control of farmers (e.g., fuel prices, market conditions, and climate). In order to increase yields and traditional measures of productivity, conventional agriculture, managed in a prescriptive manner, has tried to reduce the complexity and variability inherent in complex systems, but in doing so has increased vulnerabilities. AM can therefore be used to assess tradeoffs between ecosystem functions and also explicitly define the desired ecosystem services from a diverse set of functions. In doing so, AM can be used to identify functional interactions, highlighting those beneficial for sustainability of agricultural systems by exploring the impacts on ecosystem services. In this paper we therefore test AM’s role in the multifunctionality of agricultural systems, in order to learn how to manage for sustainability at larger scales.

1.3. Resilience of agricultural systems

Agricultural systems have evolved to share a common goal – that of maximizing production output, and often, economic profit. Although agricultural systems are clearly coupled SESs, in agricultural systems there is often a disproportionate influence and control by social and economic drivers over the ecological elements. When an agricultural system is geographically, socially and institutionally bounded with production as the main output, the aim is often to avoid disturbance and enhance stability to achieve the central goal of food security (Hodbod and Eakin, 2015). Modern (industrialized) agriculture seeks this stability and control through the use of inputs (chemicals, fertilizers, energy, water), inducing ‘hard’ tradeoffs with other functions. Managing for stability in this way can make the agricultural system more rigid and less adaptable whilst impeding experimentation and innovation, the lack of which reinforces existing system dynamics, with the potential of pushing the agricultural system into an increasingly rigid state - a rigidity trap. Poverty traps are an example of such a rigidity trap and exist in systems with low connectedness and low potential (Holling et al., 2002). Intensive agricultural systems can be an example of an ‘ecosystem poverty trap’, i.e. a less biodiverse ecosystem with minimal interaction capacities. Although such an SES may be in a

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