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Analysis

Managing ecosystem services for agriculture: Will landscape-scale management pay?

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ABSTRACT

Agriculture's reliance on ecosystem services creates economic and ecological interdependencies between crop production and biodiversity. Interactions with mobile organisms are particularly complex because they depend on the spatial configuration of habitat at large scales. As such conserving habitat is likely to benefit multiple farmers whereas conservation costs are born individually, creating potential interdependencies among farmers. We explore under what conditions landscape-scale management of ecosystem services is likely to benefit farmers compared to managing them at the farm-scale. To do this we develop an agent-based model (ABM) to predict the landscape configuration emerging from farm-scale management under different conditions: initial landscape, crop and pollinator characteristics. As a benchmark, the landscape configuration from landscape-scale management is derived through a global optimization procedure. Not only do we find that efficiency improves with landscape-scale management, but also that all farmers would benefit from it (given dependence of crop yields on ecosystem services). However, we also find that the individual incentives to avoid maintaining habitat on one's own land are relatively high; therefore creating conditions for a Prisoner's Dilemma-type problem. On the other hand we also demonstrate that an incentive-compatible contract exists that can promote efficient landscape management (by combining side-payments with fines for defection).

1. Introduction

The tremendous increase in global food production in recent decades has been brought about not only by the development of high yielding cultivars and clearing, but also by prodigious increases in inputs of inorganic fertilizers and chemical crop protectants (Matson et al., 1997). Despite this industrialization, agriculture still remains intertwined with ecosystems, most obviously via the soil. Less obvious is the relation with wild organisms present in or eradicated from the resultant landscapes (Bommarco et al., 2013). For instance pollination of crops (Klein et al., 2007) and control of pests by natural enemies (Bianchi et al., 2006) rely on insects that are negatively affected by pesticides or conversion of semi-natural habitat to arable landscapes. Collectively, such supporting and regulating ecosystem services create economic and ecological interdependencies between agriculture and biodiversity. Critical voices claim that extreme industrialization is threatening ecosystem services of value to agriculture, through degradation of habitat (Bennett and Balvanera, 2007).

If ecosystem services have value to farmers for producing crops, then surely they should desire to take better care of them. Managing ecosystem services in agricultural landscapes is, however, complicated by biodiversity and attendant habitat being a common-pool resource, in the sense that it is impossible to exclude neighboring farms from enjoying the ecosystem services stemming from organisms living in habitat which is located on a particular farm. In general, ecosystem services mediated by mobile organisms are affected by management at a larger scale than the individual farm (Kremen et al., 2007). Although habitat is located on individual farms, the associated ecosystem services accrue to all or many farms in the landscape, which encourages free-riders: farmers being able to benefit from ecosystem services provided by their neighbors without the need to maintain habitat themselves. Accordingly, if all farmers pursue narrow self-interest then farm-scale management could lead to a poorer outcome than possible: a lower supply of ecosystem services than if the distribution of habitat was optimized in the whole landscape (Eichner and Pethig, 2006).

Despite growing evidence of an on-going ‘tragedy of ecosystem services’ (Lant et al., 2008), it is proving difficult to eliminate it. At a fundamental level we lack knowledge about the extent of interdependencies between agricultural production and biodiversity in agro-ecosystems (Swift et al., 2004). Not only because species contributing to ecosystem services are poorly identified (Luck et al., 2009), but also because of insufficient information about the effects of different farming practices on biodiversity and associated ecosystem services (Zhang et al., 2007). Landscape composition is also important for ecological processes, but

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our grasp of processes at this scale is in its infancy (Tscharntke et al., 2005). For these reasons farmers might not be fully aware of the benefits provided to them by wild organisms.

At the policy level, current instruments, such as the EU's agri-environment schemes, focus on conserving biodiversity per se where farmers are regarded as suppliers of a public good that needs to be financed by society. These payments target individual fields and habitats at the farm scale, therefore failing to provide farmers with incentives to manage the whole landscape efficiently (Parkhurst and Shogren, 2007). Consequently there is a call for new policy that considers the landscape scale (Goldman et al., 2007). Examples include an agglomeration bonus (Drechsler et al., 2010) or social engineering through trust building among farmers (Pretty, 2003), and between farmers and government (Stenseke, 2009), and even enabling local governance (Sutherland et al., 2012). Choosing among such a disparity of responses to a resource management problem requires better understanding of the character of the problem.

Ecosystem services that benefit agriculture present a fundamentally different problem to solve than that of providing a pure public good, since farmers themselves are the beneficiaries of their collective conservation actions (compare, e.g., Engel et al., 2008). The economics of this problem—by which we mean to begin with, understanding the incentive structures faced by the individual farmers populating a landscape—has received little attention in comparison. Although ecologists are accumulating considerable evidence that farmers are, collectively, mismanaging ecosystem services of great value to them (Carvalheiro et al., 2011), they have only been able to hypothesize about the underlying behavioral causes (e.g., Lant et al., 2008).

Before remedies are prescribed it seems necessary to improve our understanding of the incentive structures driving farmers' habitat management decisions, and hence landscape evolution, when they benefit from biodiversity via ecosystem services (Goldman et al., 2007). For instance the underlying problem implied by the listed policy responses is quite different in each case: in the first, top-down policy payments are assumed to be needed to encourage landscape-scale management and in the latter it is deemed sufficient to break down social barriers to cooperation such as lack of trust among farmers.

Our overriding aim is to investigate whether landscape-scale management of ecosystem services is better for farmers than managing them individually at the farm scale. We also consider how the benefits are likely to be affected by different initial landscapes, crop dependence on ecosystem services and pollinator characteristics. A number of specific but intricately related questions are also addressed: Basically, is society (i.e., farmers as a group) likely to benefit from landscape-scale management of ecosystem services? If so how are the benefits and costs of such management likely to be distributed among farmers? Will there be winners and losers? Given landscape-scale management is beneficial under some circumstances, are there incentives working against such a solution? If so, is there an efficient policy to support landscape-scale management? The answers to most of these questions are not obvious and will be addressed at a conceptual level to guide empirical research and provide insights into appropriate governance responses in real landscapes.

To do this we link an illustrative ecosystem service generated by mobile organisms (pollination of flowering crops by central place foraging pollinators) with farmers' land-use decisions and profits from agriculture. The model can however be applied to other mobile-organism based ecosystem services with some modifications, e.g. biological control. An agent-based model (ABM) is developed to model the landscape emerging from farm-scale management; each farm-agent's objective is to maximize their own profits while ignoring the impacts on other farms (analogous to the non-cooperative solution in game theory). A benchmark or global optimization model is solved to model landscape-scale management, which is equivalent to assuming that the whole landscape is managed as a single farm (the cooperative solution).

Although we study incentive structures, we limit consideration of the appropriate level of governance for correcting potential efficiency problems (e.g., top-down policy or local governance) to the discussion.

2. Literature Review

In this section we identify gaps in the economics literature on habitat conservation and motivate why we have chosen ABM to achieve the aims of the paper.

2.1. Overview of the Economics of Habitat Conservation

The economics literature on habitat management focuses on the conservation of biological assets ('biodiversity') such as individual species (Murphy and Noon, 1992), groups of species (Lambeck, 1997) and ecosystems (Weitzman, 1992); and how to cost-effectively allocate scarce budgets in the selection of sites for conservation reserves (Naidoo and Iwamura, 2007). Site selection predominantly considers biodiversity per se even though optimizing ecosystem services could influence economic benefits generated by the landscape for farmers (Landis et al., 2000). Similarly, the literature on policies to promote habitat conservation, such as taxes (Panayotou, 1994), subsidies (Ferraro and Simpson, 2002) and tradable permits (Innes et al., 1998), only considers biodiversity and not economic benefits (e.g. Williams and Lathbury (1996)).

Relatively few papers consider the linkages between habitat management, biodiversity conservation, ecosystem services and economic returns, though the need was recognized decades ago (Westman, 1977). This deficiency in the literature has probably been due to the practical difficulties in generating estimates of the value of ecosystem services to farmers given the long chain of biological processes underpinning potential economic returns (Polasky et al., 2005). Considering this complexity, it is not surprising that modeling ecosystem services, currently in its infancy, is being pursued primarily outside of mainstream economics (de Groot et al., 2010).

Modeling ecosystem services in or related to agriculture is leading the field: sustainable food production is naturally of utmost importance and in general there are strong connections between agriculture and ecosystem services. Because connectivity between habitats could be necessary for optimizing biological assets, such as population size and species viability (McDonnell et al., 2002), economists began to study the issue of "cooperation" or landscape-scale management in promoting the optimal spatial allocation of habitat for conservation (Parkhurst et al., 2002). Nevertheless, scant attention has been paid to the question of whether it is in the interests of farmers to manage habitat at the landscape-scale for generating ecosystem services.

2.2. Choice of ABM Approach

Interest in ABM as a tool for economic analysis is growing. Farmer and Foley (2009) argue that ABM is an important alternative to two mainstream economic approaches: econometric and dynamic stochastic general equilibrium modeling. Most applications of ABM in economics concern financial markets (Rashid et al., 2011), but even micro-economic applications exist (Brady et al., 2012). There are also applications of ABM in the ecological and conservation literature (referred to there as individual-based models), where the focus is on simulating interactive behavior among individual animals, and examining the effects of landscape structure and management on their populations and associated physical levels of ecosystem services (DeAngelis and Mooij, 2005). Others model farmers' conservation decisions but only considering how their interactions affect the costs of achieving conservation targets and not considering the value of ecosystem services (Drechsler et al., 2007). Interactions among farm-agents and learning