ENVIRONMENTAL SCIENCE & POLICY 23 (2012) 85–94

Available online at www.sciencedirect.com

SciVerse ScienceDirect

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

Biodiversity and agriculture: Production frontiers as a framework for exploring trade-offs and evaluating policy

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ARTICLE INFO

Published on line 19 August 2012

Keywords:
Production possibility frontier
Biodiversity conservation
Agricultural production
Agro-environmental policy

ABSTRACT

Increasing global demand for agricultural products will continue to affect biodiversity. Various strategies to address this tension, such as payments for ecosystem services, wildlife-friendly farming, and conservation-reserve planning, emphasize different aspects of the system and different policy approaches. We argue that the strategic approach must be matched to the region. That is, land-use policy and research agendas focusing on improving agronomic and ecological functioning need to be coordinated, and informed by integrated knowledge about the ecological, agronomic and socio-economic characteristics of a region. We trial the use of agricultural-production and biodiversity-conservation possibility sets as an integrating framework. We find two benefits. First, the process of developing production possibility frontiers enables researchers from different disciplines to jointly identify and debate the critical types and scales of interactions among production and biodiversity where there exist opportunities for improving the system. Second, we demonstrate how the shape of the biodiversity-production trade-off frontier, and where existing landscapes sit in relation to it, can determine the effectiveness of a policy in achieving production and conservation goals. Production possibility frontiers therefore provide a simple, flexible tool for a critical trans-disciplinary appraisal of policy, and can guide the choice of more sophisticated approaches to managing agricultural landscapes.

1. Introduction

Landscapes worldwide are under increasing pressure to provide food, fibre and fuel for a burgeoning human population. Global demand for food alone is expected to double by 2050 due to increases in both total population and wealth-driven per capita consumption (Thompson, 2007). This could increase the need for agricultural land by as much as 200–400 Mha (Fischer et al., 2001). In addition, shifting climatic, technological and socio-economic conditions are continually driving change in the use of agricultural land (e.g. Mattison and Norris, 2005). Agricultural development and intensification therefore pose significant threats to biodiversity globally. As a result, meeting food production needs and protecting biodiversity are increasingly part of the same agenda (Godfray, 2011). Research and policy initiatives therefore need to consider both ecological and agronomic perspectives.

A natural framework for analysing the complex relationship between agricultural production and biodiversity conservation is the simple production possibility frontier (PPF) derived from introductory economics (Samuelson, 1983). This framework is

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1462-9011/$ – see front matter.
http://dx.doi.org/10.1016/j.envsci.2012.07.013

increasingly being used to describe the possible combinations of production and conservation that can be achieved in a given area (e.g. DeFries et al., 2004; Polasky et al., 2008) and to describe how various interactions among production and conservation affect this relationship (Phalan et al., 2011). The purpose of this paper is to examine the value of PPFs as a framework for developing trans-disciplinary research and policy strategies for agricultural landscapes. Using three examples we illustrate that PPFs can play two important roles. First, the PPF framework can assist researchers from different disciplines to jointly identify, describe and debate the critical types and scales of interactions among production and biodiversity that determine opportunities for improving system function. That is PPFs may enable trans-disciplinary research by providing an effective boundary object (Star and Griesemer, 1989), since the PPF framework is commonly used by researchers from production and conservation disciplines to describe how their work contributes to conservation in agricultural regions. Second, PPFs enable analysis of how research strategies and land-use policies need to be matched to each other and to the characteristics of the natural system in order to achieve both production and conservation goals.

DeFries et al. (2004) argue that an important step in managing agricultural landscapes is to identify changes which result in gains that are greater than the losses. For many agricultural regions this is a non-trivial task due to the existence of multiple interactions among production and conservation occurring at a range of scales (Romero and Agrawal, 2011). Different research traditions emphasize different aspects of the problem and different management strategies (Fischer et al., 2008). PPFs may provide a simple framework for comparing these approaches. For example conservation planning (e.g. Margules and Pressey, 2000) focuses on selecting areas where conservation should occur. Polasky et al. (2008) demonstrate how PPFs can be used to frame this problem as selecting conservation areas that efficiently achieve both conservation and production goals at a state level. The debate about when conservation can be most efficiently achieved by either land- sharing or land-sparing (Green et al., 2005) acknowledges the contribution of agricultural land to conservation, and interactions between conservation and production, and therefore also considers the management of the configuration of landscapes. Phalan et al. (2011) use the PPF approach to frame information about how agriculture affects species diversity to inform the land-sharing vs. land-sparing debate. Production-focused perspectives on biodiversity in agricultural landscapes emphasize other strategies and aspects of the system including developing biodiverse agricultural systems (Batáry et al., 2011; Kontoleon et al., 2009) and conservation-friendly systems, e.g. integrated pest, nutrient, and water management systems (Pretty, 2008).

The ecosystem services approach (e.g. Daily, 1997) focuses on understanding and maintaining the range of natural processes that provide benefits to humans. The complexity involved in analysis of multiple ecosystem services can make identifying land-use strategies that optimize this range of values difficult. Egoh et al. (2007) argue that there is a need for frameworks that integrate ecosystem services and conservation planning, reflecting the problem of reconciling spatially focused conservation approaches with the function focused ecosystem services approach. We suggest that a critical question that links these two approaches is the extent to which strategies that aim to maintain the production values from ecosystems also maintain the existence values for biodiversity. We argue that addressing this question in complex landscapes and identifying beneficial change strategies requires simple analytical frameworks that enable communication across relevant production- and conservation-orientated disciplines. The first aim of this paper is therefore to evaluate the use of PPFs as a framework for considering different perspectives for improving agricultural landscapes.

However, identifying desirable changes in agricultural landscapes is only part of the overall challenge of achieving both production and conservation goals. The fundamental economic problem is well understood. Standard economic analysis suggests that market institutions that have evolved for trading agricultural commodities are unlikely to provide private landholders with sufficient incentives to take account of the benefits that biodiversity on their land provides for others (e.g. Perrings et al., 1992). In our analysis we emphasize that a key market failure stems from the fact that the values which people hold purely for the existence of biodiversity constitute a global public good (Swanson, 1992). In addition, the ecosystem service literature argues that multiple other benefits of biodiversity that accrue to various individuals and groups are also not accounted for in market signals or decision making. Collective policy action is therefore likely to be required to influence farmers' decisions about biodiversity provision. If landholders have private knowledge about the costs and benefits of conservation actions on their land, this may limit the ability to design efficient landscapes, and create perverse responses to regulation (Polasky and Doremus, 1998).

This logic motivates policy approaches such as payments for ecosystem services (e.g. Stoneham et al., 2003). Designing effective policies requires consideration of a range of social factors such as the match of policies to existing institutions, the effects of monitoring, enforcement and transaction costs. The difficulty of developing policy mechanisms that will lead to desirable management of agricultural systems is well recognized within the social science literature (e.g. Barrett et al., 2011; Ostrom et al., 2007) and is an active area of economic research. However, until recently, the importance and complexity of policy design problems has been under-appreciated within the ecological literature (Cowling et al., 2008; Daily et al., 2009; O'Farrell and Anderson, 2010). This is an important disconnect because for policy to be effective it must be matched to both the social and biophysical characteristics of a region (Ostrom et al., 2007; Vira and Adams, 2009). For example, biodiversity conservation in Australian agricultural landscapes has previously relied significantly on a policy framework of voluntary activity (Sobels et al., 2001) underpinned by the implicit assumption that maintenance of production values (e.g. productive capacity) will also maintain native biodiversity. Evidence of ongoing biodiversity decline in many Australian agricultural landscapes (e.g. Prober and Smith, 2009) raises concerns about the effectiveness of this approach and the validity of the underpinning assumption that there are win–win