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Impact of multiple interacting financial incentives on land use change and the supply of ecosystem services

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ABSTRACT

Multiple financial incentives are increasingly common for managing agro-ecosystems. We explored the impact of incentive interactions across multiple ecosystem services through their influence on land use change potential. Taking a spatial approach, we quantified the economic potential for land use change from agriculture to carbon monocultures and environmental plantings. We assessed 1875 scenarios—exhaustive combinations of five incentive price levels for four services (food and fiber, fresh water, carbon sequestration and habitat), and three cost settings. Incentive interactions had complex effects—characterized by synergies and tensions, non-linearity, dependencies, and thresholds. Tensions occurred between commodity price and carbon price in supplying food and fiber, carbon sequestration, fresh water, and indirectly, habitat services. Water price displayed synergies with commodity price, and tensions with carbon price in supplying fresh water services. For the supply of habitat services, a biodiversity price depended on either high carbon prices or low commodity prices. Interaction effects may reduce policy efficiency wherever multiple incentives encourage the supply of services from agro-ecosystems.

1. Introduction

In agro-ecosystems, financial incentives commonly occur which affect the supply of ecosystem services through their influence on land use and management (Antle and Stoorvogel, 2006; Bryan, 2013; Lubowski et al., 2008; Metzger et al., 2006). Broadly, financial incentives for ecosystem services may be generated by institutions ranging from global commodity trade in marketed goods and services (e.g. cereals), to regionally- or locally-implemented market-based schemes designed to encourage the production of non-marketed ecosystem services (e.g. habitat). The latter include a range of policy instruments such as direct payments/rewards, tax incentives, cap and trade markets, voluntary markets, auctions, and certification programs (Farley and Costanza, 2010; Tallis et al., 2008). However, little is known of the potential for interaction between financial incentives and the resulting impacts on policy efficiency and ecosystem services (Zhang and Pagiola, 2011). Exploring these incentive interaction effects is the focus of this paper.

Policy interventions such as financial incentives often have unanticipated consequences which may be positive (co-benefits), negative (trade-offs), or even perverse (the opposite of what was intended) (Merton, 1936). In agro-ecosystems, commodity markets are a prime example which have increased agricultural production of marketed services like food and bioenergy, but at the expense of non-marketed services like habitat and water quality (Power, 2010). The potential for achieving co-benefits has been demonstrated, particularly through the spatial targeting of payments which prioritize cost-effectiveness across multiple services and recognize spatial heterogeneity in service provision (Crossman and Bryan, 2009; Crossman et al., 2010). Recent studies have sought to harness these co-benefits through the bundling of multiple ecosystem services (Connor et al., 2008; Deal et al., 2012; Wainger et al., 2010; Wendland et al., 2010). However, the predominance of trade-offs between ecosystem services over space and time (Raudsepp-Hearne et al., 2010; Rodriguez et al., 2006; Tallis et al., 2008) means that the failure to consider the broader impacts of financial incentives across multiple ecosystem services often leads to negative outcomes (Bateman, 2009).

In many agro-ecosystems, multiple financial incentives co-exist for the supply of ecosystem services. These incentives may interact, with consequences for land use and ecosystem services (Bryan, 2013). The interaction of financial incentives occurs as landholders change land use and management in response to the totality of economic opportunities and risks (Just and Antle, 1990). Some financial incentives act synergistically, working together toward achieving a policy objective. Other incentives may be

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divergent or antagonistic, creating tensions. Zhang and Pagiola (2011) found potential for synergies between a watershed conservation payment scheme and a forest conservation payment scheme for achieving watershed, biodiversity, and development objectives in Costa Rica. In South Australia, Crossman et al. (2011b) found that a biodiversity payment could be used to augment a carbon price to enhance biodiversity conservation. Examples of tensions between financial incentives were evident in the US as the federal Conservation Reserve Program paid people to retire environmentally-sensitive land from agriculture whilst other federal farm subsidies encouraged continued agricultural production (Lubowski et al., 2008). Similarly, accounting for the costs of the water used by reforested areas was found to reduce the effectiveness of a carbon price incentive in motivating reforestation in South Africa (Chisholm, 2010).

The influence of financial incentives on land use, and in turn, the influence of land use on ecosystem services, involve complex *many-to-many* relationships (Bryan, 2013). Each financial incentive can influence multiple land uses, and each land use can affect multiple ecosystem services. These influences can be positive or negative. Hence, the aggregate impact of multiple incentives across multiple ecosystem services through their influence on land use is difficult to predict (Bryan, 2013). Although seldom explored, understanding these interaction effects is necessary to ensure the efficiency of financial incentives for ecosystem services in agro-ecosystems including capturing synergies and avoiding tensions (White et al., 2012). Here, we present the first quantitative, integrated exploration of the interaction of multiple financial incentives and their impacts across multiple ecosystem services.

We assessed the impact of financial incentives on ecosystem services through their effect on land use profitability—a key driver of land use change (Irwin and Geoghegan, 2001; Lubowski et al., 2008). We took a spatial approach in identifying areas with *land use change potential* (areas where an economic opportunity exists for land use change) under a range of financial incentive (price) scenarios. We then assessed the impact of this potential change on multiple ecosystem services. This type of approach has been compared to more sophisticated land use change forecasts and shown to provide timely insight at a level of detail sufficient for informing policy decisions (Antle and Stoorvogel, 2006; Antle and Valdivia, 2006). Similar approaches have been widely used to assess the impact of financial incentives on the supply of services from agro-ecosystems for land uses such as bioenergy feedstock (Bryan et al., 2008, 2010a, 2010b) and reforestation (Dymond et al., 2012; Flugge and Abadi, 2006; Harper et al., 2007; Hunt, 2008; Paterson and Bryan, 2012; Townsend et al., 2012).

Focussing on the 15 million ha agricultural region of South Australia, we quantified the supply of four ecosystem services (food and fiber production, carbon sequestration, fresh water provision, habitat for local native species) from three land uses (existing agriculture, carbon monocultures (single species *Eucalyptus* plantations), environmental plantings (ecological restoration of mixed native species)) using a range of biophysical process models. We calculated the net economic returns from each land use over 40 years from 2010 to 2050 in net present value (NPV) terms, given the presence of exogenously-determined incentive prices for the supply of these services. We assessed 1875 scenarios including all combinations of the five prices for each of the four services, and assessed model sensitivity using three economic cost parameter settings (high, median and low). For each scenario, we identified areas with land use change potential based on net economic returns and quantified the impact of these changes on the four ecosystem services. We quantified the effect of incentives using Spearman's rank correlation analysis and visualized the interactions between influential incentives on each ecosystem service. The implications of incentive interactions on policy efficiency in agro-ecosystems are discussed.

2. Methods

2.1. Study area

Land use in the study area is dominated by mixed cropping/grazing systems, interspersed with patches of remnant natural land (Fig. 1). Climate is Mediterranean in the south grading to semi-arid in the north, and soils are nutrient-deficient. The region is responsible for around 18% of Australia's cereal production and

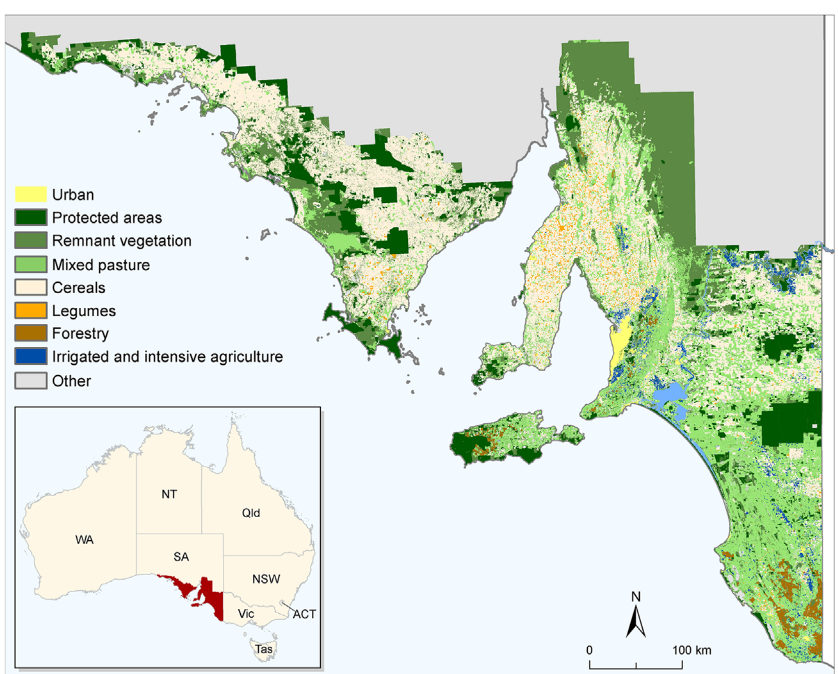

Fig. 1. Location map and major land uses in the study area—South Australia's agricultural regions.