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Modelling farmer decision-making to anticipate tradeoffs between provisioning ecosystem services and biodiversity

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ABSTRACT

In this paper, an agent-based model of heterogeneous farmer decision-making was coupled with an individual-based model of skylark breeding populations, and applied to a small intensive arable catchment in Scotland. The impacts of farmer decisions on a tradeoff between food and bioenergy production, and skylark numbers, were simulated under the assumptions of three socio-economic scenarios until the year 2050. Bioenergy and food production had a significant negative effect on adult and fledgling skylarks. In a business-as-usual context, the production of food and bioenergy increases smoothly, and the number of skylarks is more stable over time than in other scenarios. Food production was higher in an economic liberalisation scenario, due to intensive management and higher yield performance. This explained the low average number of skylarks found at the landscape level in this scenario. The number of skylarks was highest in a sustainability-oriented scenario, but a sharp decrease was observed from 2035 onwards due to the large area planted with bioenergy crops. The different values for economic, environmental and social attributes of farmer decisions played an important role in the land use mosaic, the implementation of ecologically-related actions and on the provision of ecosystem services and biodiversity. Overall, results suggest that a re-assessment of policy targets and design is necessary to maximise environmental management efficiency at the catchment level by taking into account the heterogeneity in farmer objectives and the tradeoffs in ecosystem services provision. The novel approach of coupling an ABM with an IBM is encouraged in further land use related studies.

Introduction

Land use and cover change (LUCC) is a major concern for the sustainability of farming areas, biodiversity levels and the provision of ecosystem services responsible for human welfare. Agricultural landscapes are largely shaped by human actions driven by socio-political and environmental stimuli (Antle et al., 2001; Lambin et al., 2001), and host a number of species that underpin the provision of ecosystem services. These species are under constant threat following changes in farming practices and management styles.

Land-related policies have been modified to prevent environmental degradation, but the reforms have created unexpected issues undetected in common *ex-ante* analysis, i.e. land abandonment and intensification of arable land use after the Fischler Reforms in 2005 (Acs et al., 2010; Doxa et al., 2012; Holland et al., 2011). In the near future, the Common Agricultural Policy (CAP) will tend towards liberalisation, which will create increasing reliance on fluctuating commodity prices and a possible switch from food to non-food production (Tranter et al., 2007), and lead to uncertain impacts on the long-term economic and ecological sustainability of farming areas (European Commission, 2010). The anticipation of consequences due to changing conditions (i.e. market, policy, climate) can be improved through the understanding of how actors within the system make decisions and when changes will occur.

Indeed, the heterogeneity of land-use activities and management observed at the landscape level has relevance in *ex-ante* analysis, but cannot be explained by common methodologies (i.e. linear programming). In the Agent-Based Modelling (ABM) approach, this landscape heterogeneity is seen from a bottom-up point of view where each actor (i.e. each farmer) is considered to react autonomously and cognitively to external pressures (e.g. Berger, 2001; Janssen et al., 2000; Murray-Rust et al., 2011). In the same way, ecological, individual-based models (IBM) can simulate species population from the behaviour and life cycles of the individuals under different LUCC scenarios (e.g. DeAngelis et al., 1998; McLane et al., 2011; Topping et al., 2003).

Too often, the impacts of policy on farmer decisions and LUCC (explored via ABMs), and the effect of LUCC on biodiversity and ecosystem services (explored via IBMs) are studied separately. In general, the current ABMs and IBMs lack transparency in some of

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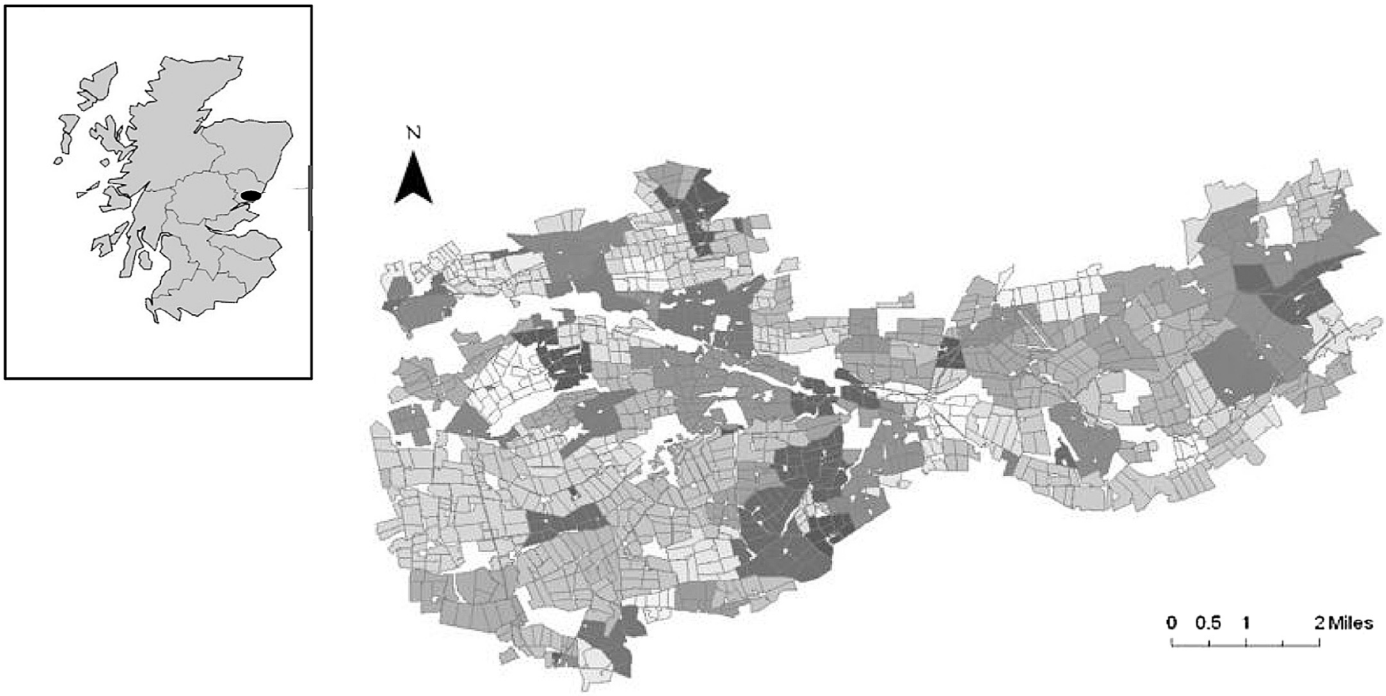

Fig. 1. Location of the case study, the Lunan catchment, in Scotland, and farm (shaded colours) and parcels boundaries within the catchment (SIACS, data 2007). (1590 parcels, min = 0.03 Ha, max = 85.86 Ha).

the component sub-models that drive simulation outcomes. This can be improved by integration, or coupling, of an ABM of LUCC with an IBM, which offers greater potential to understand processes and feedbacks between human and natural systems (Luus et al., 2011) and to study the indirect effect of policy on ecosystem services through farmer decision making (Milner-Gulland, 2012; Sutherland and Freckleton, 2012). Only a few studies have presented results from such a combination (Bithell and Brasington, 2009; Jepsen et al., 2005; Verburg and Overmars, 2009), but the decision maker agents were not heterogeneous, which limits the relevance of such models since not all land managers react similarly to policies (Beilin et al., 2012). Indeed, the nonlinear interactions between farmer decisions and the ecosystem, often acting at different spatio-temporal scales, cannot be considered independently since they involve feedbacks. In particular, these feedbacks occur in respect of a wide variety of ecosystem services and on species by providing or removing habitats (Antle et al., 2001; Liu et al., 2007). For instance, farmland specialist bird species (e.g. skylark, lapwing, yellowhammer), which require specific farmland habitat to nest and to feed, have decreased faster than other types of birds and drastically since the 1970s due to the intensification of agricultural land use (Donald et al., 2002; Siriwardena et al., 1998). Simultaneously, intensive agriculture allows a larger production of food, which is an important ecosystem service. Therefore tradeoffs between several services and with biodiversity levels must be considered.

This article reports on the integration of an agent-based model of farmer decision-making with an individual-based model of skylarks applied to a spatial (Geographic Information System (GIS)) database representing a Scottish intensive arable catchment. The model represents relationships between external pressures (market, climate, and policy), heterogeneous farmer decisions about farming practices, and the effects of these on provisioning services (food production, renewable energy), and an indicator of biodiversity (skylark local population). A set of simulation experiments was carried out based on three socio-economic scenarios to test the adaptation and responses of agents to changing contexts and the effects of this on provisioning services and biodiversity.

Materials and methods

Study site

The study area comprises 132 km^2 of a mostly arable catchment in the Tayside region, East Scotland (Fig. 1). One hundred fifteen active farmers manage the land with a mix of land use activities, essentially cereals and root crops (65%), and grasslands (35%) (Scottish Government, 2007). The study area is one of the few places in Scotland where intensive cropping occurs due to a relatively flat and fertile soil. Intensive cropping takes place on 9% of Scottish agricultural land and generates 34% of agricultural outputs (Scotland's Environment, 2014). Farmers in the catchment share similar biophysical conditions, agricultural activities and market prospects, while avoiding the problem arising from variations observed at larger scales.

This site has been intensively studied as it represents an example of a catchment with a number of typical indicators for Scottish farming and shows fragility in terms of water and air quality (Vinten et al., 2009). Since 2003, the catchment has been designated as a Nitrate Vulnerable Zone (NVZ),[1] which puts constraints on how farmers manage their land (Scottish Executive, 2003).

The catchment also includes a Site of Special Scientific Interest (SSSI) under the Nature Conservation (Scotland) Act 2004 (Rescobie and Balgavies Lochs), active fisheries, and the Balgavies Scottish Wildlife Trust reserve. In addition, the catchment forms part of the Scottish Environment Protection Agency's Monitored Priority Catchment Project, which aims to establish monitored baselines against which the effectiveness of diffuse pollution mitigation measures can be assessed (Vinten et al., 2009). Thus, the catchment and the broader region are of particular interest to policy makers.

[1] The Environment Agency has designated conservation zones, the NVZs, to reduce the risk of nitrate polluted waters (EU Nitrate Directive 91/6/76/EEC and the EU Water Framework Directive 2000/60/EC). Restrictions include reduction of the amount of fertiliser used and limited fertiliser and animal waste application periods.