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# The effect of forest owner decision-making, climatic change and societal demands on land-use change and ecosystem service provision in Sweden

Victor Blanco[a,*], Sascha Holzhauer[a], Calum Brown[a], Fredrik Lagergren[b], Gregor Vulturius[a,c], Mats Lindeskog[b], Mark D.A. Rounsevell[a]

[a] *Institute of Geography and the Lived Environment, School of Geosciences, University of Edinburgh, Drummond Street, Edinburgh EH8 9XP, United Kingdom*

[b] *Department of Physical Geography and Ecosystems Science, Geobiosphere Science Centre, Geocentrum II, Lund University, SE-223 62 Lund, Sweden*

[c] *Stockholm Environment Institute, Linnégatan 87D, SE-104 51 Stockholm, Sweden*

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ABSTRACT

The uncertain effects of climatic change and changing demands for ecosystem services on the distribution of forests and their levels of service provision require assessments of future land-use change, ecosystem service provision, and how ecosystem service demands may be met. We present CRAFTY-Sweden, an agent-based, land-use model that incorporates land owner behaviour and decision-making in modelling future ecosystem service provision in the Swedish forestry sector. Future changes were simulated under scenarios of socio-economic and climatic change between 2010 and 2100. The simulations indicate that the influence of climatic change (on land productivities) may be less important than that of socio-economic change or behavioural differences. Simulations further demonstrate that the variability in land owner and societal behaviour has a substantial role in determining the direction and impact of land-use change. The results indicate a sizeable increase in timber harvesting in coming decades, which together with a substantial decoupling between supply and demand for forest ecosystem services highlights the challenge of continuously meeting demands for ecosystem services over long periods of time. There is a clear need for model applications of this kind to better understand the variation in ecosystem service provision in the forestry sector, and other associated land-use changes.

## 1. Introduction

Land-use and land management change have important effects on the provision of ecosystem services (ES) (MEA, 2005). Forests provide a particularly wide range of ES, including timber and non-timber products, air purification, carbon sequestration, biodiversity preservation and recreation, which make fundamental contributions to human societies and natural systems (De Groot et al., 2010; MEA, 2005). Meanwhile, pressures on the world's forests are increasing. Clearance for agriculture and timber harvesting, preservation and planting for climate mitigation, and climate-driven changes in growing conditions are all likely to interact to transform future ES provision (Buonocore et al., 2012; Zanchi et al., 2012; Alexandratos and Bruinsma, 2012; Schroter et al., 2005; Soja et al., 2007; Tilman et al., 2001). Hence, forest management strategies are being revised (e.g. Jonsson et al., 2015; Kjaer et al., 2014) and future land-use change assessed (e.g. Thompson et al., 2011) through the use of computer models in an attempt to support adaptation to changing conditions and to meet future demands for ES supply.

One of the difficulties in designing management strategies for future conditions is the need to anticipate demands for ES. Such demands are difficult to estimate (Hayha et al., 2015), and forest modelling generally focuses only on timber yields as a result (Brown et al. in press). Where a wider range of ES are considered, assessment is often based on maps of suitability (e.g. Hayha et al., 2015; Sohel et al., 2015) or vulnerability (e.g. Metzger et al., 2008; Tzilivakis et al., 2015), which need not consider ES demand. Mapping of ES supply is also performed through ES valuation (e.g. Costanza et al., 1997), which assumes demands non-explicitly. Even where ES demands are acknowledged, only services with a market value are included (e.g. Verkerk et al., 2014). As a result, no study has investigated the provision of non-marketable ES in relation to demand levels; a necessary step to identify likely and desirable changes that enable forests to satisfy societal needs for ES.

Another challenge faced by models of future ES provision is that land use and management change, which determine ES provision,

* Corresponding author.
*E-mail address:* v.blanco@ed.ac.uk (V. Blanco).

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ultimately depend on the decisions of land owners. In forestry, behavioural and cognitive factors such as owner objectives and attitudes are known to have strong influences on management choices (Andersson and Gong, 2010; Ingemarson et al., 2006; Vulturius et al. in review). However, due to lack of data and the uncertainty associated with long time horizons in forest management they are seldom incorporated into models, and never at scales larger than individual landscapes (Blennow et al., 2014; Rammer and Seidl, 2015; Brown at al. 2016). Nevertheless, in terms of potential responses to future change owners can effectively be distinguished by the definition of categories (Blanco et al., 2015; Karali et al., 2013). Such categorisations are particularly useful in agent-based modelling (ABM) of land-use change, allowing the decision-making of individual land managers to be simulated heterogeneously and across large geographical extents (Matthews et al., 2007; Valbuena et al., 2010). The adoption of such models to map the effects of human behaviour on ES is recent (Boone et al., 2011; Brown et al., 2014; Murray-Rust et al., 2011), but holds great promise to reflect the drivers and consequences of change in the forestry sector more accurately.

The need for improved modelling of the forest sector is clearly illustrated by countries such as Sweden, which have large forest areas that are economically and culturally important, and which are likely to be significantly affected by climatic change. Sweden has 69% forest cover (SLU, 2015), of which approximately 50% is owned by individual owners (Swedish Forest Agency, 2015) with diverse objectives. In 2011, forestry accounted for 2.2% of Swedish GDP. We therefore adopt Sweden as a case study for the development of a forest management ABM that accounts for land owner decision-making and is capable of appraising provision of a wide range of ES under projected future levels of demand. We apply this model at national scale under combined socio-economic and climatic scenarios (Shared Socio-economic Pathways and Representative Concentration Pathways – SSPs-RCPs; O'Neill et al., 2014, van Vuuren et al., 2011 2014) from 2010 to 2100. The purpose of this exercise was to explore: a) future ES provision and how ES demands may be met, b) land-use change, and c) changes in land owner objectives, in the Swedish forestry sector.

## 2. Methodology

To explore future ES provision and land-use change in Sweden, focusing on forestry, we developed the CRAFTY-Sweden model, based on the CRAFTY agent-based modelling framework (Murray-Rust et al., 2014) (see Appendix A for the model ODD protocol). CRAFTY allows the representation of large-scale land-use dynamics, based on demand and supply of ES (e.g. timber, food). Demand is given exogenously while supply depends on the productivities and behaviours of modelled agents, and the productivities of agents' locations (described by capitals representing the availability of resources such as infrastructure, human capital and crop suitability). Geographical space is represented as a grid of cells, each of which has defined levels of a range of capitals. Each cell may be managed by a single land-use agent, which uses the capital stock available within the cell to provide services according to its own production function. The competitiveness of a given level of service provision can be calculated on the basis of societal demands, overall supply levels and 'benefit' functions, which describe the monetary and non-monetary value to society of service production. Agents make decisions based on their current competitiveness and participate in an allocation procedure with potential new agents that may result in land-use change. We use agent functional types (Arneth et al., 2014; Rounsevell et al., 2012) (hereafter agent types) for the definition of agent production and behaviour. This approach helps to characterise agent typologies that define general characteristics of agents, from which individual agents can subsequently be drawn.

### 2.1. Model description

In CRAFTY-Sweden, agents include different types of forest owners and farmers. Farmers were defined to simulate the competition for land between forestry and agriculture. Forest owner decision-making involves four key components: 1) owner objectives and associated management practices, 2) the time of felling, 3) an estimation of the future benefits agents expect to obtain from their land-use, 4) and their willingness to abandon, change management or hand over land to a different owner considering their competitiveness. Farmers consider all but the second component. Using land productivities and infrastructure, modelled forest owners are able to produce timber from different tree species, carbon sequestration, biodiversity, and recreation, while modelled farmers choose to produce one or more services among cereal, meat and recreation (Fig. 1).

In the following, we describe the development of the land owner

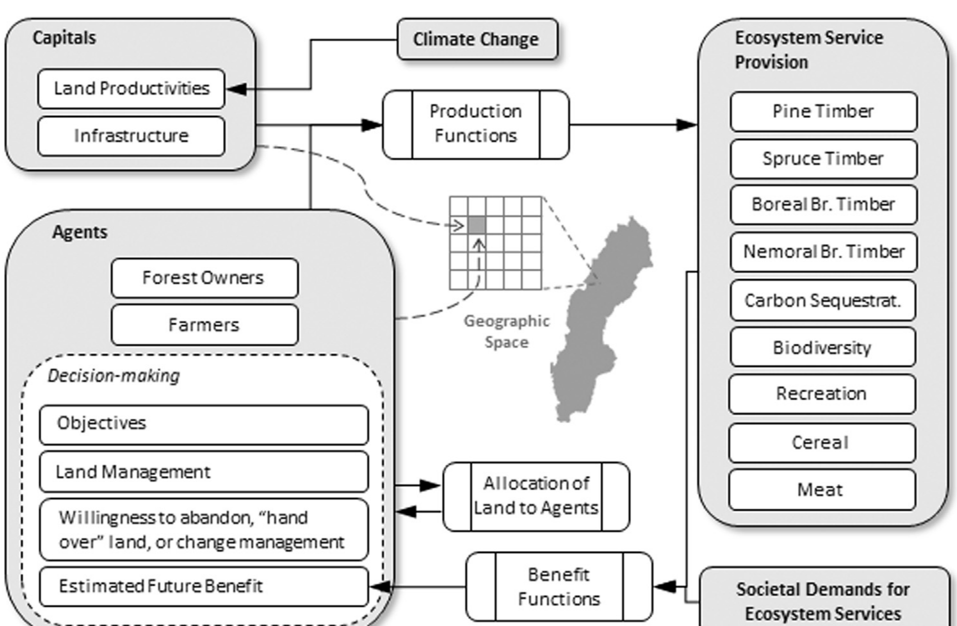


**Fig. 1.** Schematic representation of the structure of the CRAFTY-Sweden model showing flows (solid lines) and associations (dashed lines) between components.