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An agent-based simulation model of a nutrient trading market for natural resources management

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ABSTRACT

Markets for nutrient trading, water quality and other ecosystem services are rapidly emerging across the world. A critical need is to improve the relationship between farmers' decisions and their impact on natural resources. One of the basic requirements that links buyers and sellers of ecosystem services is an agreed upon unit of trade and a way to measure it. We develop an agent-based model (ABM) which is designed to formalize the interactions between the biophysics dynamics of the natural resources and the socio-economic factors. The simulation market builds on ABM paradigms in its concepts and is coded using the Matlab programming environment. The result shows that ABM is contributing to research questions in ecological economics areas of land-use change, public auction modeling, market dynamics, changes in owners' perceived yield potential, owners' gold, farming choice and water treatment choice aspects in human decision making and behavior change.

1. Introduction

Markets for trading nutrients, water quality and other ecosystem services are rapidly emerging across the world [1]. Farm manager decisions are driven by economics. The only way money is earned is by selling farm products [2]. However, these decisions can have negative impacts on the environment. Currently, government imposes penalties to encourage farm managers to have low impact on the environment.

The opportunity for trading ecosystem services creates other sources of income for farm managers [3]. Our aim is to develop a nutrient trading market that will link buyers and sellers of ecosystem services, and establish an agreed upon unit of trade and a way to measure it. Our hypothesis is that implementation of this nutrient market will result in farmer decisions having a positive impact on the adjoining ecosystems while providing economic benefits.

Among the tools used in these various approaches, models often play a crucial part. Agent-based models (ABMs) are now widely acknowledged as suitable tools for representing and simulating complex systems dynamics [4]. ABMs allow the integration of experts' hypotheses and multidisciplinary research issues, and take into account customs and practices of rural populations for managing shared space. Our hypothesis is that a nutrient trading market can be simulated well by applying an agent-based model.

One of the basic requirements that links buyers and sellers of ecosystem services is an agreed upon unit of trade and a way to measure it. We develop an agent-based model (ABM) which is designed to formalize the interactions between

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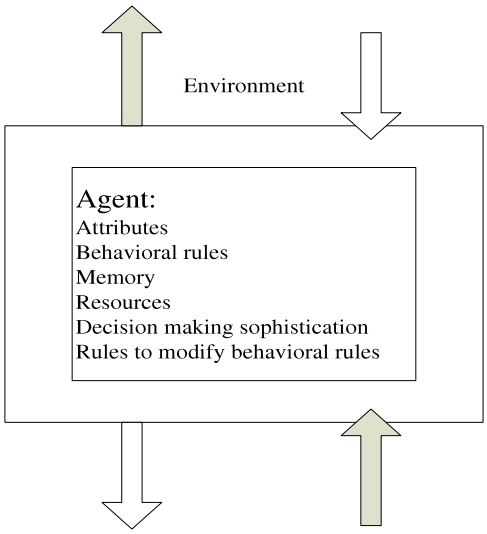

Fig. 1. An agent.

the biophysics dynamics of the natural resources and the socio-economic factors. The simulation market builds on ABM paradigms in its concepts and is coded using the Matlab programming environment. The result shows that the ABM is contributing to research questions in ecological economics areas of land-use change, public auction modeling, market dynamics, changes in owners' perceived yield potential, owners' gold, farming choice and water treatment choice aspects in human decision making and behavior change.

2. Agent-based models of a nutrient trading market

Many agent-based modeling platforms like RePast, Cormas, Mason, Matlab, NetLogo, DIAS, etc. offer a framework for creating ABMs (agent-based models). ABMs are commonly used to create complex models by integrating well understood scientific models and, at a smaller scale or within a particular scientific discipline, to create a model that may combine biophysical, social and economic models [5]. This approach is becoming increasing popular and improved methods for understanding the biophysical interactions of humans, animals and the environment is of growing concern [6–8]. Complex systems models have been developed for combining biophysical, social and economic components [5,9].

The model developed here is a relatively standard water balance model that has been included in two agent-based models and is intended to become a module for inclusion in other models.

What is an agent?

From a practical modeling standpoint, we consider agents to have certain characteristics (Fig. 1):

- An agent is identifiable: a discrete individual with a set of characteristics and rules governing its behaviors and decision-making capability. Agents are self-contained.
- An agent is situated, living in an environment with which it interacts, with other agents.
- An agent is goal-directed, having goals to achieve (not necessarily objectives to maximize) with respect to its behaviors.
- An agent is autonomous and self-directed.
- An agent is flexible, and has the ability to learn and adapt its behaviors over time on the basis of experience [10].

3. The model description and decision-making processes

The purpose of the research presented here is to demonstrate the scale dependence of the ABM constructed for south-central Indiana and identify what aspects of household-level ABMs with spatial structures similar to this model are sensitive to scale effects. Thus, in describing the model we emphasize those elements of the model that relate to the spatial structure of the model.

In order to enter effectively into negotiations and to facilitate the achievement of sustainable consensus, stakeholders need descriptive and integrative models [11]. The models should also be dynamic: firstly, regarding their components and features, in order to be adaptive models; secondly, concerning the temporal dimension, in order to become prospective models that can assist in exploring scenario impacts.