A Conceptual Model for Simulating Farmer Decisions and Land Use Change

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EXTENDED ABSTRACT

The development of many agricultural regions is uncertain due to current and future changes in economic, social and ecological factors and the complexity of human-landscape interactions. The largest impact on landscapes in agricultural regions is through land use by farmers. To study the long-term viability and possible emerging behaviour of an entire landscape including farmers, a conceptional model for the development of a multi-agent human-biophysical simulation model is introduced.

The model integrates a domain model with three external individual biophysical, social and economic models. The domain entities and interactions of entities are described in the domain model. Farmers are considered as one of the domain agents who communicate, select and adopt management strategies. Data exchange between the domain model and other external models is through a model controller.

A concept of ‘Capacities and Constraints’ of biophysical, economic and social components is proposed as an underlying framework for the model to manage the resources of components. A Course of Action (COA) approach is used to describe the simulation of yearly farming activities and processes incorporating time-slicing of farmer activities during the year.

We present a conceptual model which builds the basis for a simulation model to analyse the long-term viability of an agricultural region with scenarios on land-use change, salinity risk perception and management, future climate change, the introduction and adoption of new technologies, changes in policy, markets, social networks, social value evolution, and township functions. The model will enable the stakeholders such as farmers, their advisers, catchment managers and policy makers to understand the consequences of farmer decision-making and various management approaches on long-term viability of an entire agricultural region.

1. INTRODUCTION

Natural change and human utilization are both important reasons for the evolution of landscapes. However, human activities often have more immediate impact on landscapes (Turner 1993) and can result in land degradation. In the Western Australian wheat belt, when the land was cleared for agricultural production at the rate of 'one million acres a year' in the 1960s, the risk of salinity was known in a general way, but some of the unintended consequences are still emerging. These include the loss of millions of hectares of land due to salinity, stream and groundwater pollution and salinity, damage to infrastructure, loss of biodiversity, and the impact on communities and their health. It is estimated that 21% of the farm land maybe affected by salinity, 20% has been influenced by seasonal surface waterlogging and soil acidity in 2000 (Alexander 2000). Land degradation has reduced farm productivity and impacted on the farmers decision making.

Katanning in the Western Australian wheat belt was selected as a case study for developing a multi-agent based human-landscape model to simulate the past 40 years land use change and predict the trajectory for the next 50 years. The aim of the model is to investigate the implications of farmer's decision making processes in landscape management, and its impact on regional profitability and local community resilience. This paper introduces a conceptual model for a multi-agent based simulation of the interactions between farmers short and long term decisions and biophysical, economic and social processes in an agricultural region.

2. CASE STUDY AREA

The study area is located in the Blackwood catchment in the southwest of Western Australia (Figure 1). It covers 307,000 ha and includes five shires with about 4,000 people. The average farm size is about 1,500 ha. The climate is Mediterranean with warm dry summers and cool wet winters. Average growing season rainfall between May to October is 290mm in the east and 350mm in the west of the region (Brockman 2001).

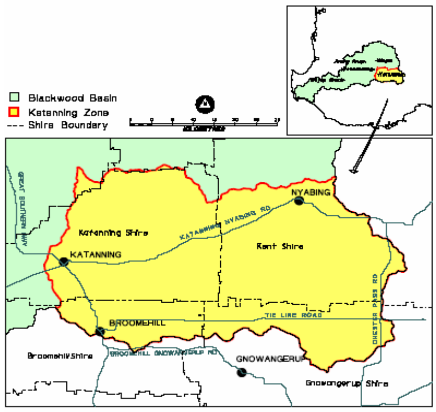

Figure 1. The study area: Katanning region in Western Australia

Economic, social and ecological data were collected from 1990 to 2003 to assist understanding of the drivers of farmers' decision making in the Katanning region. GIS technology is used to display the land use changes over time and the salinity risk area. Yearly changes of pasture and cropping area were compared with wool and crop market prices, farm operating costs and profits. Consultation with agricultural researchers, farming consultants and farmer interviews were used to understand farmer attitudes and behaviours to market changes, environment management, investment, technology uptake, risk management and policy evaluation.

The proposed model design considers land use and land cover changes for each farm according to farmer decision making processes based on soil conditions, productivity, climate and weather information, topography, past and projected farm profit, market price, and attitude of farmers to change.

3 MODEL STRUCTURE

3.1 Model Integration

The proposed multi-agent human-landscape model will contain one domain model and three external individual biophysical, social and economic models.

The biophysical model will be used to simulate the water balance, soil nutrition, and crop and pasture growth. SWAT (Neitsch 2002), a soil and water dynamic model will be used to simulate the catchment water dynamics and the interactions between land cover and other biophysical factors at paddock scale.

Farm assets, profits from sale of products, consumption and investment in terms of household financial flows, access to market price information, and banking information will be described and modelled in an economic model.

A social model will simulate social values of at individual farmers, household and community levels. It will include a social network of farmers. The farmer social capital and perception will be described, such as trust, emotion, risk management, objective norms and lifestyle linked with farmer age. Education and experience will be considered as major social factors for farmers short and long term decision making.

The domain model will integrate biophysical, social and economic models together through a model controller (Christiansen 2000). The data application is built in the domain model and the data exchange between models is through a model controller.

The major entities and their non-linear relationships are described in the domain model, such as Farmer, Government, Atmosphere, Land Cover and Household. The farmer decision making process will be simulated through the domain model as farmer agents interacting with other factors, and the information resources required by the decision makers are derived from the external models.

3.2 Hierarchies

The biophysical component is considered at paddock and landscape levels while the social component includes individual farmer, community and society levels which build a social network. Economic components contain household finance flows and market levels. Policy drivers impact on social networks (Figure 2).

The simulation process in the proposed model will use a time ordered event-queue so that the processes involved in different entities of the three main components are able to evolve their states independently. For example hydrology dynamics are updated daily while farming activities process durations vary due to the different durations for completing a task.

4. SIMULATION OF DECISION MAKING PROCESSES

4.1 Main Drivers of Decision Making

Current land use and land cover in an agricultural region are the consequence of decisions made by farmers and policy makers in the past. Based on the data analysis over the last 14 years in the Katanning region, main factors impacting on farmer's decision making on land use change are biophysical, economic and social. These include climate variability and change, environmental risk perception and management, the introduction and uptake of new technologies, market price, federal, state and local policies, and social values (Figure 2).

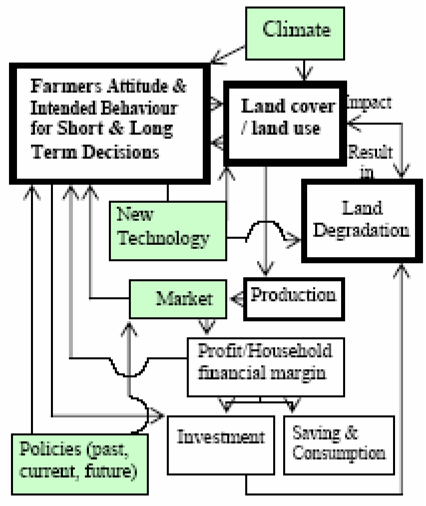

Figure 2. Interaction between farmer decision making and major factors

Decision making processes have been studied by cognitive scientists and psychologists from a social point of views for many years (Sebestyen 1962; Irle 1982). The simulation of cognitive processes considering natural resource management has been suggested only in recent years. Since the relationships of factors are non-linear, and have multi-dimensions in a self-organization system, a factor change can result in whole system change. The relationships can be nested, looped or in hierarchy causing the boundary of each component to be fuzzy. Agent-based simulations have been proposed to handle the complexity of human-landscape systems (Parker 2003).

4.1. Scenarios of decision making process

The proposed model will simulate the processes of: individual farmers land use management, communication between individual farmers and the community, household financial flows and management, the attitude of farmers/household to the markets, the interactions between farmers and local towns, the impacts of climate on crop yields, livestock and water balance. Individual farmers as 'farmer agents' (Campbell et al. 2005) will response to particular situations based on their attitudes and situation rules or have goals based on beliefs and rational plans (Doran 2000).

Most of the farmers in the Katanning region have a farm diary to help them with their basic annual planning, but then modify their decisions to meet the variations that arise in any particular year. We used the concept of a farm diary as the basis for farming activities together with time slicing during the year. The resource information of decision making is quantified in the Capacities and Constraints concept, and the processes of main farming activities are simulated by Course of Action.

4.2. Courses of Action

During a year, farmers do a set of farming activities, such as buying seeds and livestock, sowing, repairing machinery, applying fertilizer and herbicides, harvesting, selling products, banking, and participating in community activities. Each activity may involve different natural, social and economic resources.

A Course of Action (COA) approach proposed for this model is similar to that developed by Christiansen (Christiansen 2000). It simulates the process of each main farming activity. Each COA has a list of participants for a process, the resources managed by each participant, and the duration of the process. Each instance of a farmer will have a similar set of courses of action, but the resources available and the state for each farmer will determine the outcome of the COA's. COA's are initiated when the required participants and the resources available. A process has time start and finish points, and a successful action is finished within a given duration. For instance, when a Farmer Agent in the model initiates a 'sale' COA, the performance will depend on the availability of the participants (farmer agents, sales agents), the resources owned or managed by participants (market price, attitude of the farmer agents to the market, products of crops or livestock, bank balance), and this action will be finished in a particular duration.

4.3. Capacities and Constraints (CAC)

Farmer as the decision makers in a modelled agricultural region consider the context provided by the states of other entities or agents of a biophysical, social and economic nature in their decisions. Each 'farmer agent' has finite resources available for use and is regulated with rules which determine how these resources can be used within the context of the state of the simulation (agent's capacities). The 'farmer agents' can be constrained by their access to these resources in the simulation and by their own time resources as determined by the farm diary time slicing. The availability of economic, social and ecological resources required for a decision forms the capacities, and the maximum utilization of these resources forms the constraints. The simulation will represent the heterogeneous conditions impacting on farmer decision making, and how the 'farmer agents' response to availability of various resources.

CAC provides a framework to determine the range of resources required for each decision making. The actual decision within the determined range will be stochastically derived and weighted according to preference of the agent. Emergent behaviors can arise from the complex interactions of factors and the stochastic decision making process over time.

Course of Action is used to simulate the process of major decisions/activities, Capacities and Constraints is applied to quantify the resource information involved in the decision making, and the information from each resource supplier is provided by the simulation outcomes from biophysical, social and economic external models or from the domain model. Figures 3 is an example to show biophysical factors relevant to the decision making processes in the biophysical model.

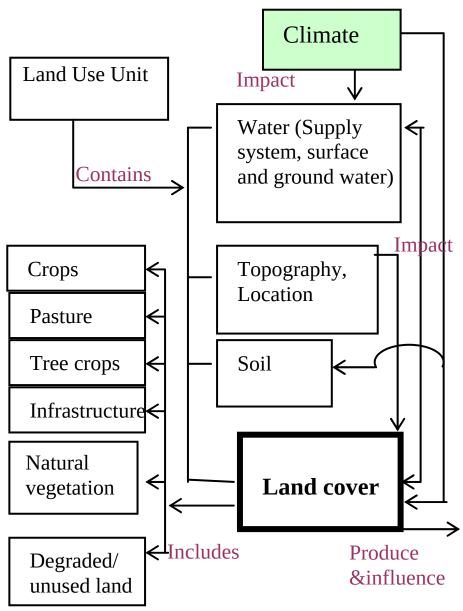

Figure 3 Biophysical Capacities and Constraints

5. SENSITIVITY ANALYSIS AND VALIDATION

The development of the proposed multi-agent human-biophysical simulation model will study the sensitivity of outcomes to changes in human-biophysical behaviours and their interactions in agricultural regions. The sensitivity of the model to probabilities, thresholds and distribution of major parameters such as outside drivers like rainfall change, market price, new crops, and the internal factors like social perceptions will be tested.

The model will be built with data from the last 14 year. The last 40 years data on land use change (mainly clearing and subsequent agricultural use) in the Katanning region will be used to validate the model.

6. DISCUSSION AND PROPOSED APPLICATION

The model will be used to understand the consequences of farmers' decisions about land use on the long-term viability of an entire agricultural region. Aspects of land cover changes, land management and technology adaptation, risk perception/ management by farmers, policy drivers, market impacts, climate variability and change, and wider regional/global socio-economic trends will be simulated with the model. The model will also build the foundation for a version that specifically supports "games" of simulated outcomes to enable stakeholders to play and understand the consequences of various management approaches. In the future, this will improve decisions regarding land use change. The model will be used to explore and answer questions like: How can we improve the long-term viability of agricultural regions within Australia? – where 'Long-term viability in agricultural regions' is characterised by outcomes such as the sustainability of profit at enterprise level, economic sustainability of a region, the environmental sustainability versus economic profitability trade -offs, the degree of pollution of groundwater, the percentage of degraded land (salinised, acidified, eroded), the ability to absorb or adapt to change (resilience) and the maintenance of biodiversity. Outcomes in this context arise from changes such as landuse change by farmers (management and technology adaptation), risk perception/management by farmers, policy drivers, market drivers, climate variability and change, and the wider regional/global socio-economic trends.

The model integrates the external biophysical, social and economic models with a domain model through a model controller which makes the simulation more flexible. The model controller enables data exchange for the updated data between external models and the domain model. Any changes inside an external model are independent from the structure of the domain model, therefore the external model can be modified separately with no impact on the domain model.

In this paper, we have discussed the approach of using Course of Action as the basis of farming activity simulations which allows representation of how the resources are managed and transferred by different participants while managing a farm over time. The Capacities and Constraints (CAC) concept is introduced as an underlying framework to quantify the resource information required by the farmer decision makers for farming activities in land use change in the context of the biophysical, social and economic components of the Katanning region. The modelling approaches represent the dynamics and processes of real-world agricultural systems and link the decision making with a heterogeneous landscape, so the key mechanisms and drivers of decision-related processes can be identified, with the aim of better informing decision makers about future biophysical, economic and social reports.

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