Modelling Farmer Decision Making for Natural Resource Management Outcomes

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Abstract: This paper presents a conceptual modelling and simulation methodology that incorporates dryland farmer decision making into regional- and landscape-level natural resource management (NRM) planning. Decision making for many NRM on ground actions is made at the farm level so it makes sense to incorporate farmer behaviour into regional planning for meeting regional environmental objectives. Our model applies multi-attribute farmer utility functions within an agent-based simulation environment to model temporal change in land use and landscapes resulting from farmer implementation of on ground NRM actions. Farmer decision profiles are characterized using a survey of over 500 farmers. Landscape futures can also be assessed by modelling farmer responses to changes in both external drivers and policies. The dominant external drivers of land use change are related to climate and societal change, commodity prices, and technological advances. These drivers, in combination with natural resource management policy, influence farmer decision making and willingness to undertake NRM actions, which in turn determines whether or not specific regional NRM targets will be achieved under various future scenarios and provides an assessment of the biophysical, economic and social impacts of NRM actions at the catchment scale.

Keywords*:* Multi-attribute Utility Theory, Scenario Planning, Decision Making, Agent-based Modelling, Natural Resource Management

1 RESEARCH CONTEXT

This research forms a large part of the Lower Murray Landscapes Futures (LMLF) project that was conceived in recognition of the urgent need to reverse the declining environmental state of the region through better informed natural resource management (NRM) planning, policy, and decision making. The LMLF project is a multi-organisation and multi-region collaboration within the lower Murray Darling Basin, Australia. This research contributes to the second core aim of the LMLF project - the assessment of the impact of existing plans on NRM targets, and assessing the economic and social impact under future scenarios.

2 BACKGROUND

In many regions, agricultural development has provided substantial private and public benefits. However, these have come at a high public cost in the form of environmental degradation. This has often led to the erosion of natural capital and a reduction in the supply of ecosystem goods and services.

The Lower Murray region (Figure 1) covers an area of 11.9 million ha and has been subject to land clearance and agricultural development for more than 80 years. Substantial areas of irrigated agriculture and horticulture have been established based on water from the River Murray and these practices have had a distinct impact on the environment. However, in this study we focus on the dryland (non-floodplain, non-irrigated) agricultural areas where the dominant land uses include the cropping of cereals and legumes, and the grazing of natural and modified pastures, and of native vegetation by livestock, mainly sheep. Farms in the Lower Murray tend to be large. Typically, the size of cropping/grazing properties is in the order of 1,000 ha in the higher rainfall areas ranging through to large grazing properties of many thousands of hectares in the drier parts.

The most serious impact of dryland agricultural development in the Lower Murray is the clearance of native vegetation and the resultant degradation of biological diversity. The replacement of deep rooted vegetation with shallow rooted annuals has also led to increased dryland salinisation and salt contribution to the River Murray through saline groundwater intrusion. In addition, land clearance has increased the exposure of soils to wind erosion which has become a significant problem in the region.

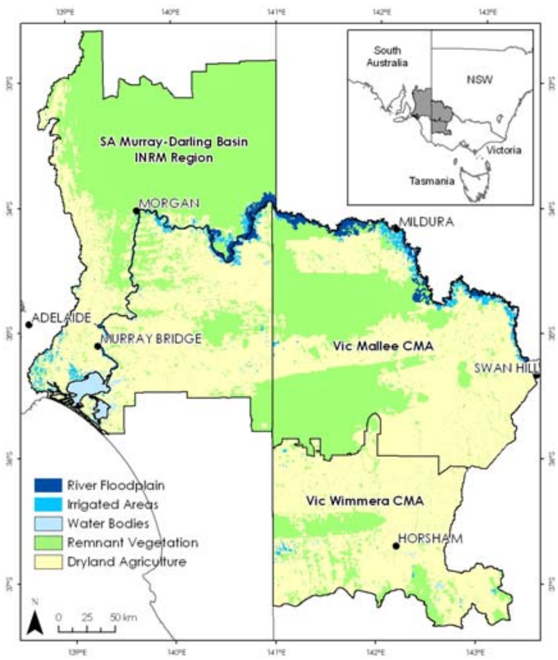

Figure 1 Location map and land use in Lower Murray region in southern Australia.

NRM policy in Australia takes a strong sustainability approach and is administered at the regional level. This approach involves the setting of thresholds or minimum standards formulated as Resource Condition Targets (RCTs) and articulated in regional NRM/Catchment Management plans. Targets are prescribed for a variety of objectives including biodiversity, salinity, wind erosion and soil health. Management Action Targets (MATs) are also established which aim to achieve the RCTs. Targets range from highly specified quantitative levels to vague aspirations. Whilst target setting and regional planning signals are a strong beginning along the path to sustainability in Australia's agricultural regions, the targets require substantial expansion and enhancement in light of the current knowledge about environmental management [Bryan *et al.* 2005]. The LMLF project aims to assist in this process [Crossman and Bryan 2006].

However, there is a major impediment to reaching RCTs in the Lower Murray region. Land tenure in the Lower Murray region is predominately under private ownership and management (78%). The cost of the NRM actions required to meet regional targets is prohibitively high and not likely to be met under current levels of government funding [Bryan et al. 2005]. Hence, if regional targets are to be met, natural resource management actions will need to be undertaken largely by private individuals on private land. Without a market for ecosystem services, landholders face substantial costs from undertaking NRM actions including establishment costs and opportunity costs from foregone agricultural production. The benefits of these actions are, however, largely public. Hence, the widespread uptake of NRM is unlikely unless benefits can be derived from NRM actions at a sufficient level to offset the costs incurred.

An understanding of the impact of regional natural resource management plans on reaching targets, and of the economic and social impacts of these plans is essential to guide future planning iterations by regional NRM agencies. In this study we describe a modelling framework designed to simulate individual landholder decision making with regard to undertaking natural resource management actions in response to external drivers and policy responses. The framework enables the level of uptake of NRM actions to be estimated and spatially extrapolated to the region. Simulated NRM actions can then be assessed against regional targets and the economic and social impacts assessed. The framework also enables visualization of landscape futures through map-based outputs and levels of key indicators to support decision making.

3 ECONOMIC BEHAVIOUR

Farming is predominantly a business enterprise in the Lower Murray. Land management decisions by farmers are dominated by expected economic returns, tempered by attitudes to risk. Models of farmer decision making are commonly used to predict changes in agricultural production and associated economic and environmental impacts. These models are often based on the idea of farmers as self-interested, rational economic actors and utility maximisers who optimally respond to available information. However, this normative foundation of economic modelling has been under increasing scrutiny for failing to predict key facets of observed economic behaviour [Gintis 2000, Kahneman and Sugden 2005].

Numerous endogenous and exogeneous factors affect individual decision making within an agricultural and natural resource management context. These factors include heterogeneous risk preferences, variable perceived loci of individual decision making, pro-social and environmental preferences, institutional transition, variable capacity and willingness to innovate, the proportion of the gains of trade relative to existing farm income, and the influence of social norms and tradition [Pannell 2004, Vanclay 2004, Cary et al. 2002, Gintis 2000, Ostrom 1998]. The outcome of this is often a deviation from the normative predictions of traditional economic models. The concept of bounded rationality has been proposed to explain these deviations [Kahneman 2003]. We propose a conceptual modeling framework that considers many of these aspects of farmer decision making with regard to NRM.

4 PROBLEM STRUCTURE

Most of the cleared areas and substantial areas of remnant vegetation in the study area are privately managed for agricultural production. Hence, farmers play a key role in NRM. Catchment or regional level Resource Condition Targets cannot be achieved through top-down regulatory approaches. Rather, achievement of regional environmental targets depends upon the sum total of diffuse agricultural production and land management decisions made by individual farmers.

Decisions made by farmers in the Lower Murray affect the extent, intensity, and types of agricultural production. They also determine the extent and type of NRM actions undertaken including vegetation management, revegetation, the adoption of conservation farming techniques (no till) and alternative farming systems (e.g. agroforestry). The decisions by farmers to undertake NRM actions can have many benefits for multiple NRM objectives including biodiversity, river and dryland salinity, wind erosion potential, and soil health. In addition, farmer decisions have economic impacts such as a change in economic returns and subsequent economic flow on effects, and social impacts such as farm size expansion and out-migration, demographic change, changes in employment, labour markets, rural services, and social capital.

Futures analysis involves the perturbation of levels of external drivers and the modeled development, implementation and adoption of economic and NRM policy in response to these changes. External drivers include climate change, commodity prices, technology, and societal changes. Policy options include market-based instruments, information and extension, the development of biomass-based industries such as renewable energy generation, and impediment free access to a carbon market. The model captures farmer responses to changes in levels of these external drivers and policies.

A number of modelling tools and techniques are combined to analyse this complex problem including Geographic Information Systems, Benefit-Cost Analysis, Input-Output modeling, and Multi-Criteria Decision Analysis. In this paper we focus on the farmer decision making module which we formulate as an agent-based model [Ligtenberg 2001, Parker et al. 2002] (see *Actions* in Figure 2)

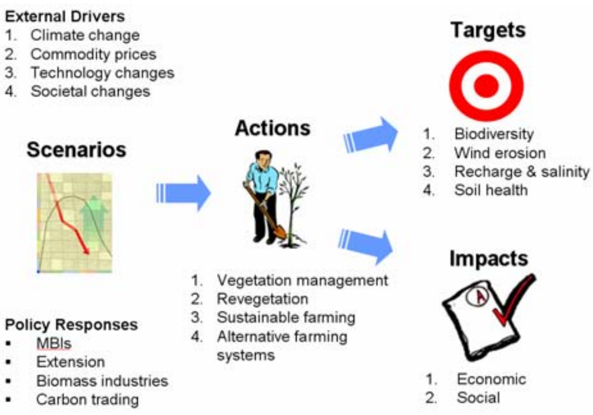

Figure 2 General problem structure. External drivers and institutions influence the level of uptake of natural resource management actions and land use change by landholders. The degree of achievement of NRM targets is then assessed and the social and economic impact of land use change is quantified.

5 LAND USE AND NRM DECISIONS

For the purposes of this model, dryland farming areas are dichotomised into either cleared land uses or remnant native vegetation. Cleared areas support farming systems characterized by cropping/grazing rotation which varies over the study area depending on biophysical and other constraints. All remnant native vegetation on private land is considered to be grazed by livestock to some degree.

The decisions presented to our farmer agents include whether to undertake an NRM action, what action to take, and where to take it on their farm. The actions available at each grid cell depend on the land cover/use of the cell (Table 1). For areas of remnant vegetation, farmers have only one land management decision to make – whether to take no action (i.e. continue grazing) or undertake vegetation management (i.e. reduce stock, control weeds, restore and enhance remnant vegetation etc.). On the cleared areas of their farm five management actions are available to farmers. Farmers can elect to take no action (i.e. continue farming using traditional techniques), adopt conservation farming techniques, revegetate for biodiversity, plant deep rooted perennial fodder crops for livestock grazing, or plant trees for agroforestry (i.e. biomass, woodchip, timber, pulpwood).

On-Farm Land Cover	NRM Actions
Remnant Vegetation	Take No Action
	Vegetation Management
Cleared Areas	Take No Action
	Conservation Farming
	Revegetation
	Perennial Fodder
	Agroforestry

Table 1 Natural resource management decisions available to farmers.

6 DECISION MAKING UNITS

The fundamental decision making unit of the agent-based model is the farm property. Individual farmers are charged with the land use and management decisions and these decisions are applied over the geographical area of farm properties. We use a raster data structure in this model based on 1ha grid cells.

Farms were identified using the SA digital cadastral database (DCDB) and the VicMap Property GIS database. Properties were identified by aggregating land parcels belonging to the same land title reference in SA. For Victoria, land parcels belonging to the same land title were already aggregated in the VicMap Property GIS database. In this study we define the dryland areas as all privately managed non-floodplain areas with a mapped land use of cereal cropping or grazing. Farms were identified by overlaying the properties data with areas mapped as dryland agriculture in a land use database.

There are over 142,000 individual property titles across the Lower Murray region, including urban areas. The number of individual privately owned and managed properties identified engaged in dryland agriculture is 31,977. Farm properties identified in the GIS range in size from 1 ha to 236,000 ha. All properties with an area smaller than 350 acres (approximately the size of the old “block” unit) were considered unlikely to be managed as a stand alone farm. Hence, properties smaller than 350 acres were considered to be leased or share-farmed and added to the title of the nearest farm property > 350 acres. The spatial distribution of dryland farming properties is presented in Figure 3.

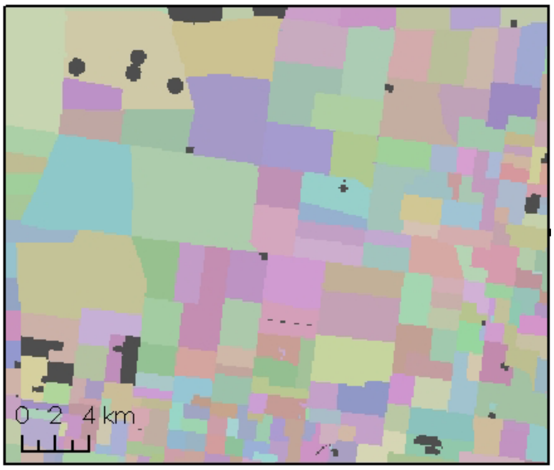

Figure 3 Example of farm properties as spatial decision making units in part of the north-western Wimmera. Dark grey areas are remnant vegetation, irrigated agriculture, and other non-dryland agriculture land uses.

7 MULTI-ATTRIBUTE UTILITY

The farmer decision model determines which grid cells on each farm are subjected to which NRM actions based on multi-attribute utility theory. Elements of farmer utility are dominated by economic considerations such as income from agricultural production and opportunity costs. However, farmer multi-attribute utility functions also include consideration of the biodiversity, salinity, and wind erosion benefits of NRM actions. Decisions to undertake NRM actions at each cell are based on expected gains in marginal utility calculated using a multi-attribute utility function, where:

$$EU_{ij} = \sum_{k=1}^{n} f(w_k p_k u_k)$$

for $i = 1, 2, ..., l$, $j = 1, 2, ..., m$

where l = number of grid cells in farm
m = number of NRM actions
n = number of attributes of utility
w_k = weighting for utility attribute k
p_k = probabilistic risk of utility attribute k
u_k = utility score for attribute k

Farmers have multiple (n) attributes of utility. Farmers then decide whether or not to adopt NRM actions at locations of their farm according to the marginal increase in EU. Farmers with different decision profiles have different weights associated with the various elements of utility. Factors driving this heterogeneity include those mentioned in Section 3 that have been postulated to cause deviation from rational, profit maximizing, self interested behaviour. In summary, the makeup of utility functions changes in line with differences in financial situation, information, knowledge, and the preferences and attitudes of individual farmers towards risk, the environment, and the community, amongst other things.

Extending the concept of multi-attribute utility in farmer decision making is the concept of diminishing marginal utility. This concept captures the preference of farmers for a heterogeneous landscape over single land uses and the desirability of having at least some natural capital on farm. Diminishing marginal utility is state-dependent and refers to the marginal utility of the next hectare of NRM action decreasing as a function of the amount already undertaken. The concept is particularly relevant to revegetation. As an example, farmers with little or no remnant vegetation on their farm may be much more likely to engage in revegetation actions than farmers with a substantial proportion of their farm under remnant vegetation (Figure 3).

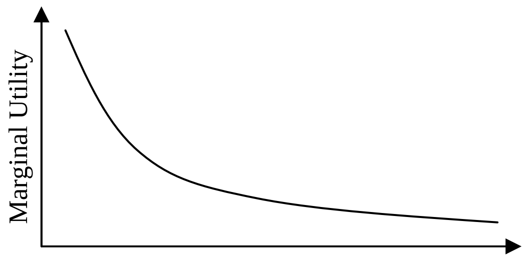

Figure 3 Example of diminishing marginal utility for revegetation.

8. CHARACTERISING FARMER DECISION PROFILES

To provide an empirical basis for the multi-attribute utility functions underpinning in the farmer decision models a survey of dryland farmers was conducted. A census approach, surveying all 1,156 dryland farmers (with properties >10 ha) in the SA MDB has been completed. Using a mail-out questionnaire, the objective of the survey was to characterise the different types of farmer decision profiles [Solano et al. 2006] according to their attitudes and likely behaviours with respect to agricultural production, land and natural resource management, innovation, education, risk, and the environment.
The questionnaire was initially developed and pre-tested in a field application of a market based approach to manage high levels of river salinity. The mail survey was administered using a modified Dillman method. This method includes an introductory letter, questionnaire, a reminder post card, re-sending of questionnaire to non-respondents, plus the use of real stamps on the return envelopes, hand signed letters, and a monetary incentive for participation. A high response rate of 54% has provided a data set of sufficient statistical power to conduct a comprehensive factor and cluster analysis, used to develop the farmer decision models.

The initial factor analysis (using principle components) has identified nine attitudinal constructs, including innovation levels, business priorities, level of tradition, perceived locus of decision making, social norms, capacity and willingness to learn, environmental attitude, and time and capital constraints. All constructs are characterized by factor loadings of > 0.4. Preliminary hierarchical cluster analysis has identified 5 discrete farmer decision profiles, characterized by between segment mean Eigenvalue distances of 3.125 – 10.174. These decision profiles can be described as:

1. Time rich environmental innovators
2. Community influenced traditional farmers
3. Enterprise focused, individual decision makers
4. Capital and time constrained long term farmers
5. Socially motivated non-farmers

The characteristics of farmer decision profiles were described in terms of elicited behavioural and demographic characteristics and including farming practices, environmental participation, computing skills and business acumen and practice. Identified farmer decision profiles and their variation in economic and land management decision making, behavioural response to market information, likely participation rates, levels of risk behaviour, and the influence of social norms will be formally established using field based experimental economics techniques.

Following verification, farmer decision models will then be built. The agent-based simulation model of the Lower Murray will be populated with typical hypothetical farmers with control over individual farms as decision making units. Rules will be constructed regarding the likely NRM decisions of farmers based on the derived decision profiles and this will be extrapolated over the study area. Landscape futures will then be assessed as the collective simulated NRM responses of individual farmers to changes in external drivers and policies. The aggregate NRM outcomes of NRM policies under various external drivers can then be assessed against stated targets.

10. CONCLUSION

This paper presents background conceptual design of a farmer decision making model for simulating natural resource management actions over the

Lower Murray region in southern Australia. Achievement of regional NRM targets in the region is dependent upon large scale land use change and adoption of natural resource management actions by farmers. The decision making models derived in this study are based on farms as a fundamental spatial unit over which farmer agents have control. Land management and NRM decisions are made based on multiple attributes of utility and are subject to diminishing marginal utility. Farmers were also characterized according to various social, economic and environmental factors using a survey and cluster analysis revealed 5 major types. This information will be used to parameterize and populate a spatially explicit regional simulation of landscape futures under various states of external drivers and policy environments. Regional scale assessment can then be used to assess the achievement of NRM targets. This kind of modelling provides an alternative to traditional economic modelling for understanding landscape futures.

11. ACKNOWLEDGEMENTS

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