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# The Use of an Agent-Based Model to Represent Māori Cultural Values

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**Abstract:** Cultural values are integral to indigenous Māori culture in New Zealand and are pivotal to guiding a person's preferences and priorities. Traditional concepts and beliefs have shaped the thinking of most Māori, and Māori knowledge still resonates strongly within contemporary Māori society. Cultural values therefore reflect both the long history and relationship tangata whenua (people of the land) have with a given area, location, catchment, or region and their world view. Cultural values are statements of knowledge, and shape the way Māori think about issues, form the basis for decision-making, and are fundamental for establishing aspirations, desires, and priorities. Iwi and hapu (tribes and sub-tribes) in the Te Tau Ihu region (northern part of the South Island) have been active in recording and expressing their cultural values for many years. Tiakina Te Taiao Ltd, a pan-iwi resource management organisation, has been developing cultural and environmental methods and indicators. A large amount of information and knowledge has been recorded onto Geographic Information Systems (GIS), and it is now a central tool for planning environmental and cultural projects, recording cultural values, and documenting significant cultural, heritage, taonga (treasure), and archaeological sites, amongst others.

On the other hand, agent-based modelling (ABM) has been increasingly used to assist understanding of the interactions in complex coupled human and natural systems. These models have been combined with GIS to produce Land Use–Land Change (LULC) simulations to help conventional planning and management methods of human and landscape interaction (Gimblet, 2005; Heckbert and Smajgl, 2005; Bolte et al., 2006). These simulations have been used in social sciences for their capability of providing a spatially explicit tool that formally represents landscape characteristics, land-management choices, community values, and tradeoffs between conflicting goals. They can be used as a 'bridge' between quantitative and qualitative approaches, providing both formal and descriptive landscape representations to illustrate plausible alternative futures that can assist the incorporation of scientific information into decision-making processes for sustainability (van Wyk et al., 2008). The software ENVISION (Bolte, 2007) was used to construct a LULC ABM for the Motueka catchment. The components of the spatially explicit model discussed in this paper are: landscape, landscape production metrics, and agents. The landscape component has been completed; the landscape metrics have been partially built, and the agents are still being developed. Landscape includes: current land uses, land-use capability and property boundaries. Landscape production metrics include: gross margins, employment, nitrogen and sediment leaching, carbon sequestration and water use.

This paper outlines selected model components and a participatory process to engage with Tiakina Te Taiao Ltd to assess whether LULC ABM technology can be effectively used as a tool for iwi to incorporate cultural values into spatial futures or scenario modelling and how iwi could use such tools to articulate cultural values and aspirations during discussion and negotiation with government, industry, research agencies, and community groups. The participatory process aims to elicit empirical knowledge on indigenous values to calibrate the ABM. The process consists of generating two extreme LULC scenarios using the envisioning capability of the model to collect information about the perception of stakeholders concerning the simulations. We will then jointly determine the feasibility of defining a cultural landscape metric function. The model and participatory process have been discussed with Tiakina Te Taiao Ltd, and they have agreed to participate in the process. So far, we have identified the model has been useful to enhance dialogue with Māori researchers on natural resource management processes, especially when the debate centres on landscape characteristics, possible land conversions, and high-level analysis of tradeoffs between socioeconomic and environmental goals.

***Keywords:*** *Envisioning, indigenous knowledge, tradeoffs, Integrated Catchment Management*

## 1. INTRODUCTION

Cultural values shape the way Māori think about issues, form the basis for decision-making, and are fundamental for establishing aspirations, desires, and priorities. The New Zealand Resource Management Act (1991) also emphasises the importance of the relationship of Māori with their environment and requires that all resource management decisions in the country have particular regard to kaitiakitanga (exercise guardianship or stewardship of the environment and customary values, rules, and practices).

A study of the linkages between cultural and scientific indicators of river and stream health (Young et al., 2008) documented how iwi/hapū groups from the Motueka catchment have adapted and applied a cultural health index at sites throughout the catchment. The index includes qualitative scores for riverbank condition, riverbed composition, water clarity, water flow, water quality, channel shape, riparian vegetation, catchment vegetation, river modification/use, use of river margins and smell, with the overall cultural stream health measure calculated as the average of these scores. An assessment of the mahinga kai (cultivation sites, gardens, places of food harvest and collection) status and the traditional status of the site is also determined, along with a judgment of whether iwi would return to the site. The study found a strong correlation between the cultural stream health measure and the percentage of the catchment above each site in native forest, and also weaker relationships with water clarity, a macro-invertebrate community index, and the concentration of faecal indicator bacteria. The study concluded that scientifically and culturally based indicators, along with community-based approaches, potentially provide an enriched understanding of the environment with each offering a slightly different worldview about the health of freshwater systems. This study demonstrated how different forms of assessment and monitoring could be used side by side by local government, community, iwi and hapū, and research agencies.

While agent-based modelling (ABM) is widely used internationally in Land Use–Land Change (LULC) studies, most notably by the Global Land Project[1], the concept of using ABM for land-use change scenarios in a New Zealand context has not been generally explored. Agents are software entities with at least the following basic properties: autonomous behaviour; ability to sense their environment; ability to act upon their environment; and rationality (Woolridge and Jennings, 1995). ABM, also known as multi-agent simulation (MAS), is a dynamic simulation technique concerning individual agents and their interactions with each other and their environment and has been recognised in social science as the best computational tool to enable researchers to model social phenomena (Gilbert, 2007). The processes behind human decision-making are highly uncertain. Individual circumstances, preferences, social networks, cultural values, timing, risk profile, sensitivity to environmental deterioration, economic goals, attitude towards future generations, etc., are all involved in the actual decision of changing land use. LULC ABM attempts to gain more knowledge into these processes by formalising behavioural rules to be followed by individual simulated agents. The main aim of LULC ABM is the study of the collective effects of individual actions, used to help our understanding of the interactions in complex coupled human and natural systems (Parker, et al 2003; Jager and Mosler, 2007). LULC ABM provides us with a tool that recognises diversity in decision-making and diversity in evaluating land-use options. Its main function is therefore to represent individual decision-makers with distinct individual set of values, and customise evaluating criteria for land-use options, to represent tradeoffs visually.

The 'Motueka ABM' was developed as a support tool for visualising and communicating alternative land-use change scenarios and the economic, environmental, social and cultural tradeoffs associated with them. The model is part of a wider set of quantitative tools developed for the Integrated Catchment Management programme[2] (ICM), a government-funded research programme. The Motueka ABM combines a range of components with varying degrees of accuracy, precision, and level of abstraction to explore future landscape changes. It does not attempt to be a predictive tool, but rather an explorative tool to be integrated with a participatory process with stakeholders to obtain the benefits of formal precision and the illustrative power of models and GIS for effective resource management (Costanza and Ruth, 1998; Castella et al., 2005).

[1] http://www.globallandproject.org/

[2] More information can be accessed at: http://icm.landcareresearch.co.nz/

### 1.1. Participatory modelling for ABM calibration

Complexity in agent's behaviour varies considerably. For example, it can be defined by simple heuristics (Guzy, et al. 2008) or by complex cognitive processes based on psychological theory, such as the *consumat* approach proposed by Jager et al. (2000). ABM calibration relies on formalisation of empirical data. Five groups of commonly used methods have been identified by Robinson, et al. (2007). One of them is companion modelling, or participatory modelling in which researchers join with stakeholders in a modelling process cycle to ensure the robustness of a model (Moss, 2007; Windrum et al., 2007; Tesfatsion, 2008). We are proposing the use of ENVISION landscape simulations (Bolte, 2007) to elicit stakeholder's response to future landscape change. This process loosely fits within the companion modelling approach identified by Robinson, et al. (2007), and is aimed at establishing the feasibility of defining a cultural metric for landscape evaluation. The role of visioning in planning for natural resources is exemplified by Miller, et al. (2007) and Ball, et al. (2008), from the McKaulay institute.

It was important to line up the model with a social learning process to ensure the establishment of a meaningful context for its use (Allen and Kilvington, 2005; Kilvington and Allen, 2007; Fenemor et al., 2008). ENVISION was used because it provides clear, transparent specifications of how the different components and their relationships are built into the model, resulting in assumptions being not only meaningful but also transparent and intuitive.

Our proposed participatory process consists of i) providing Māori research partners with background information on the creation of two extreme scenarios concerning current sheep & beef pasture (Figure 1), the GIS layers that help define land change potential and landscape production metrics (Table 1); ii) showing both scenarios and discussing their environmental and socio-economic scores (Figure 2); iii) discussing how each scenario would score culturally, and the reasons for it; iv) discussing the feasibility of defining a function within the landscape production metrics that would reflect those cultural views; v) formalising the cultural metric into the model, to see how the two extreme scenarios score against it; and vi) discussing how comfortable iwi would feel about using this approach, if the representation is too simplistic, if it could misrepresent cultural values, and if this tool would be useful to articulate cultural values and aspirations during discussion and negotiation with government, industry, research agencies, and community groups. The model and participatory process have been discussed with Tiakina Te Taiao Ltd, and they have agreed to participate. It is envisaged they will also be involved in the processes of scenario generation, and agent definition and calibration.

## 2. MOTUEKA AGENT-BASED MODEL

The Motueka ABM is a simulation model aimed at answering 'what if' questions on LULC scenarios in the catchment, to help resource management evaluation of individual choices and policies. The Motueka ABM was developed using the ENVISION software which functionality is explained in great detail in Guzy, et al. (2007). This section will therefore certainly leave big gaps in technical details, concentrating instead on a description of the model components to be used by the participatory process.

The core of the analysis is landscape dynamics as a result of human decision-making and the trade-off analysis associated with those decisions. The model enables researchers to put together a compilation of assumptions based on existing ICM and iwi GIS databases, demographic and econometric predictions, social and cultural behaviour, structural conditions and institutional arrangements, in order to interact with stakeholders (Dymond et al., 2006; Cao et al., 2008; Harmsworth, 2008). Model components discussed in this section are: ***landscape*** – including current Motueka catchment's biophysical characteristics; ***landscape production metrics*** –a collection of socioeconomic and environmental performance measures for alternative land uses in the catchment; and ***agents*** – simulated human influences affecting the landscape. The ENVISION model includes other components partially built for the Motueka ABM and are not discussed in this section, such as: ***autonomous processes*** **–** current and projected external factors affecting the landscape (i.e. regional-sectors economic projections, demographic change); and ***policies*** **–** framework guiding and constraining land-use and land-management decision-making. Policies capture rules, regulations, and incentives promulgated by public agencies in response to social demands for ecological and social goods, as well as factors used by private landowners/land managers to make land and water use decisions.

### 2.1. Landscape

To define Individual Decision Units (IDUs) used to simulate land-use change, the Motueka ABM uses GIS databases and biophysical models to create an accurate representation of land capability, current land cover and land-use change potential options for each IDU. An IDU results from the combination of: ***current land cover –*** the model uses this information to define 17 current land uses: urban; bare ground; alpine herbfield; water; cropland; vineyard; orchard; pasture (sheep and beef, dairy cows, deer); tussock grasslands; wetland plants; scrub; broadleaved indigenous forest hardwoods; sub-alpine shrubland; exotic forest (mainly pine forests); and indigenous forest; and ***land-use capability*** – in a synthesised scale from 1 to 8. This classification mainly indicates soil fertility potential index (in a descending order). It is a combination of base and top rock types, soil types, slope, erosion potential, and water retention; ***agricultural properties boundaries*** –used to determine the main economic activities carried out by the agricultural properties in the catchment, e.g. cropping, sheep and beef farming, dairy farming, forestry and logging, viticulture, other agriculture, lifestyle blocks, or non-agriculture (including reserves and natural forest). Figure 1 shows the current land cover in the catchment and two extreme scenarios for sheep and beef pasture to be used in the participatory process.

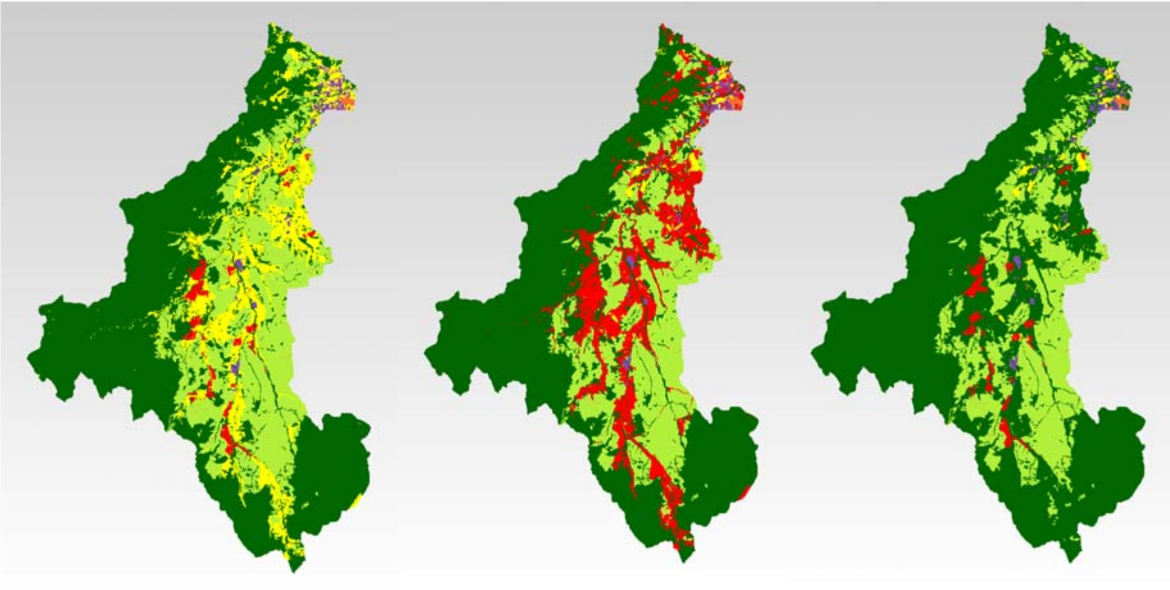

**Figure 1.** Scenarios for sheep and beef pasture (dark green – native forest, pale green – exotic forest, yellow – sheep & beef pasture, red – dairy pasture). Left: current land-use; centre: sheep & beef pasture to dairy pasture; right: sheep & beef pasture to forest.

### 2.2. Landscape production metrics

These indicators are associated with each land-use and are typically calculated on a per hectare basis. Table 1 shows a selection of production metrics for a selected number of land uses quantified for the Motueka catchment. They represent a simplified 'score' for each land-use. When applied at a catchment level, they can be used dynamically to compute overall environmental and socio-economic scores that allow for the definition of landscape scarcities to which agents will respond, as represented in Figure 2. For example, Nitrogen leaching, sediment yields, and E.coli concentration metrics

**Table 1** Sample of production metrics for selected land use options in the Motueka ABM.

| Production metric | Sheep & beef pasture | Dairy pasture | Exotic forestry |
|---|---|---|---|
| Nitrogen leaching (kg/ha/yr) | 0.54 | 7.79 | 3.97 |
| Sediment (t/km2/yr) | 490 | 425 | 210 |
| Max. water take (m3/ha/wk) | 0 | 350 | 0 |
| 95% E.coli (cfu/100ml/ha) | 0.015 | 0.026 | 0 |
| Gross margin ($/ha/yr) | 432 | 2608 | 450 |
| $ Output ($/ha/yr) | 567 | 2976 | 500 |
| Employment (jobs/100 ha) | 0.5 | 5 | 0.25 |
| Carbon sink rate (t/ha/yr) | 0 | 0 | 8 |

were used to define the freshwater and marine scores; gross margins and economic output were used to define the economic score, while employment was used as the basis for the social score. In a similar way, defining a cultural production metric could be used to compute a catchment-scale cultural score, or 'cultural health index'. This cultural metric could also incorporate spatial considerations (i.e. distance to rivers, neighbouring parcels' land-use, vegetation corridors, cultural health as % of river length, etc.).

These scores are under constant review, and they will be discussed in the participatory process. While there is reliable knowledge on some production metrics for some land uses in the modeled landscape (i.e. average economic returns from agriculture, forestry and aquaculture; annual nitrogen and sediment yields discharged to the Motueka river due to different land uses and their geographical differences; carbon sequestration potential; direct employment generated by agriculture, forestry and aquaculture), it is difficult to build homogeneously the direct advantages and disadvantages of other land-use options, and it is also difficult to translate some metrics into a spatial metric (metric/ha).

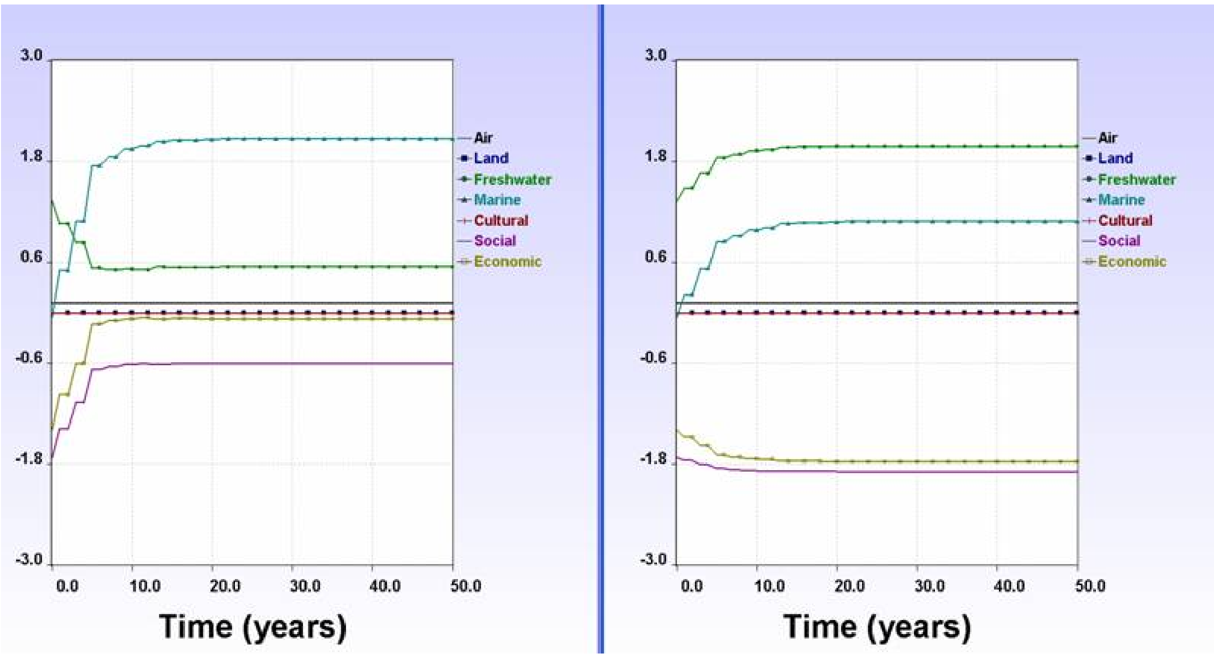


**Figure 2.** Scores for scenarios. Left: sheep & beef pasture to dairy pasture scores; right: sheep & beef pasture to forest scores.

### 2.3. Agents

Agents in ENVISION only interact with each other indirectly, affecting each other though their actions; they do not communicate with each other nor show learning capacity (Guzy et al 2008). It can be argued that agents in ENVISION offer limited behavioural complexity, however, the software provides with an extremely flexible and transparent system to define very detailed IDUs, and the evaluative framework used to 'score' land-use options, as well as excellent visualisation capability.

Agents in ENVISION are characterised by the values they hold on landscape production and the locations (IDUs) for which they have responsibility to make policy selection and implementation. Agents make these decisions using a combination of two approaches: altruistic decision-making, based on landscape feedbacks that reflect landscape-level scarcities, and self-interested decision-making, based on alignment of land change options with their own values. In both approaches, simulated actors respond to scarcity signals sent by the landscape metrics, and use simple heuristics as the base of decision making, which is a common approach in ABM (Schluter and Pahl Wolst, 2007). Figure 3 shows the simulation setup screen for the Motueka ABM used to define catchment-scale priorities. Each land-use option has one production metric corresponding to each of the catchment's overall 'metagoals' (environmental and socioeconomic scores). If actors are altruistic, they will respond to the collective 'health' signals, in which case they are likely to make a decision to mitigate perceived scarcities.

### 2.4. Using ENVISION to illustrate Atua domains

A different use of the Motueka ABM that we could consider is the visualisation of environmental and socio-economic tradeoffs using Māori cultural frameworks such as the Atua domains (based on Māori departmental gods, spiritual deities, supernatural beings) that stratify and integrate ecosystems and environments (terrestrial, coastal, marine, etc.). Young, et al. (2008) documented the current Motueka river cultural health index that uses cultural indicators to assess river and stream health according to these Atua domains. It is then possible to assume that the domains of significant gods: Tangaroa, Tane Mahuta, Haumietiketike, Rongomatane, Tūmatauenga and Tawhirimatea (Young, et al 2008, p14) could be characterised, or weighted, against the evaluative framework built in the Motueka ABM (Figure 3). We could then define and visualise land-use change scenarios that best reflect a particular Atua domain.

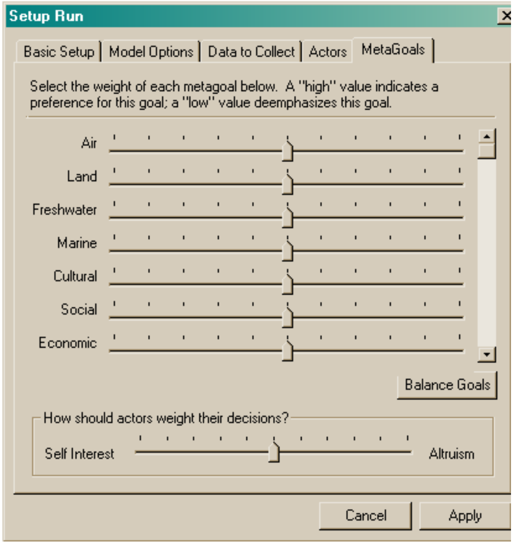


**Figure 3**. Simulation setup for the Motueka ABM, showing the relative importance of environmental, socioeconomic and cultural goals

## 3. CONCLUSIONS AND FUTURE WORK

We propose that the Motueka ABM could be an effective tool for cross-cultural, multi-disciplinary, multi-stakeholder research to provide information and knowledge that will improve the management of land, freshwater, and near-coastal environments with multiple, interacting, and potentially conflicting uses. We believe the model could offer a way to extend the concepts developed by Young, et al. (2008) in the Motueka River, potentially developing a 'cultural health index' to include landscape at a catchment scale. The Motueka ABM can draw on existing biophysical, socioeconomic and potentially cultural information and use it in a decision-making context by defining assumptions that are transparent and intuitive, yet meaningful. The model could be used as a tool to illustrate differences in individual preferences to consider land-use changes and the collective results of individual actions.

We also propose that the suggested participatory modelling process using envisioning technology with our Māori researchers at Tiakina would be effective to elicit the empirical traditional knowledge needed to calibrate the ABM. If we assume this to be correct, we could subsequently use the same method to explore the definition and calibration of agents in the model, and we could define and visualise land-use change scenarios that best reflect cultural goals and aspirations for the catchment.

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