Landscapes Toolkit for triple-bottom-line assessment of land use scenarios in Great Barrier Reef catchments

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EXTENDED ABSTRACT

The coastal strip adjacent to the Great Barrier Reef (GBR) is a region of high economic importance and exceptional environmental value. It contains the highest biological diversity in Australia, supports a World Heritage rainforest area and directly influences the GBR.

To ensure that future development addresses economic and social issues while enabling remediation of landscape and ecosystem degradation, a Landscapes Toolkit (LsT) is being developed as part of the CSIRO 'Water for a Healthy Country' National Research Flagship project: Repair and Sustainable Development of Floodplains in the Wet Tropics.

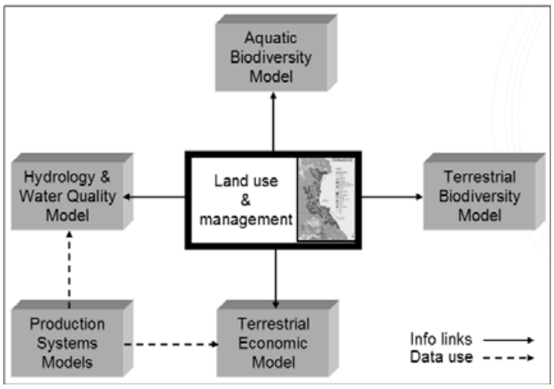

Figure 1. Schematic representation of the Landscapes Toolkit

Using The Invisible Modelling Environment (TIME) the LsT integrates disparate disciplinary approaches, knowledge and data, to allow for the spatially-explicit analysis of the impacts on environmental, social and economic values (i.e. the triple-bottom-line) of changes in land use & management. The LsT comprises disciplinary models for terrestrial biodiversity, aquatic biodiversity, production systems, hydrology and water quality, and terrestrial economics, which users can select depending on their specific concerns. These models are *passively* linked to allow for the *comparative-static* evaluation of *pre-defined* land use & management change scenarios, while users can define the corresponding type and format of output (see Figure 1).

The Douglas Shire in North Queensland serves as a case study to develop and test the LsT approach. Three land use scenarios (production, water quality and biodiversity) are developed together with the local community and are assessed for their impact based on a limited number of selected economic, biodiversity and water quality criteria. In the Water Quality scenario farm incomes, biodiversity and, to a limited extent, water quality improve as compared to the current situation, whereas in the Biodiversity scenario, terrestrial and aquatic biodiversity improve significantly while farm incomes decrease as compared to the current situation and the Water Quality scenario.

It is anticipated to use the LsT in a participatory process with stakeholders, to develop future scenarios and provide information that aid the community in deciding among multiple choices. Over the coming years the LsT will be developed to allow for the dynamic evaluation of user-defined scenarios, while in the long-term the LsT will allow for active linkages between disciplinary models to account for processes endogenous to the system. Additionally, attention will be given to uncertainty surrounding the component models' and integrated system results.

1. INTRODUCTION

The coastal strip adjacent to the Great Barrier Reef (GBR) is a region of high economic importance and exceptional environmental value (McDonald and Weston, 2004). It contains the highest biological diversity in Australia, supports a World Heritage rainforest area and directly impacts the Great Barrier Reef. The region occupies less than 2% of Queensland, yet provides 10% of the State's agricultural activity and 23% of tourism activity.

The region requires sustainable solutions for future development that address economic and social change while enabling remediation of landscape and ecosystem degradation. Preservation of the aesthetic and environmental character of the region is vital, as it is valued highly by residents and it is critical to the success of the tourism industry. Hence, the goal of CSIRO's Water for Healthy Country 'Floodplain Renewal' program is to develop land use & management solutions for coastal floodplains that drive growth in the prosperity of regional industries and communities, while supporting protection of the GBR through improved water quality and healthier ecosystems.

One of the key objectives of the Floodplain Renewal program is the development of an approach that allows for the spatially-explicit analysis of the impacts on environmental, social and economic values (i.e. the triple-bottom-line) of changes in land use & management. The proposed Landscapes Toolkit (LsT) approach will provide the focus for integration of disciplinary science within the program, to ensure that disparate disciplinary approaches, knowledge and data can easily be integrated and applied to the development of solutions for landscape and water quality protection in the GBR region.

This paper provides a description of the LsT approach and discusses its position in the land use literature. The LsT is a systems approach that provides a comprehensive understanding of the landscape system by linking spatially explicit state-of-the-art disciplinary models. An application of the LsT is given for the Douglas Shire in North Queensland, Australia.

The paper is structured as follows. Section 2 gives an overview of the approaches in land use analysis and the position of the LsT. In Section 3 the LsT approach is described in detail, thereby touching on data base management, component models, model integration and the general user interface. Section 4 provides an application of the LsT to a case study in the Douglas Shire. The scenario definition approach is described and simulation results are presented and assessed. Finally, Section 5 offers concluding remarks and observations.

2. APROACHES TO LAND USE ANALYSIS

Assessment and forecasting the multiple effects of land use & management change using a spatial interface for inter-disciplinary modelling tools lies at the cutting edge of research in environmental economics and landscape ecology (see Nilsson et al., 2003; Santelmann et al., 2004; Veldkamp and Verburg, 2004).

A wide variety of spatially and time explicit land use models have been developed to understand the complex interactions between human land use & management and ecosystems states, properties and functions (Irwin and Geoghegan, 2001; Parker et al., 2003; Ojima et al., 2004). Relatively simple models provide analytical insight into the functioning and control of the system, though they often neglect processes and scales at which real world phenomena act. Relatively complex models give a better representation of the real functioning of the system, though they are analytically weak and may lead to unstable solutions because of compounding errors.

A proper understanding of the coupled human-environmental system requires nested and linked models to address a particular issue (Ojima et al., 2004). In particular, these integrated models may play an important role in aiding decision making processes. Scenario and agent-based approaches are the most commonly used types of integrated models. While scenario approaches provide insight into the consequences of multiple choices and as a result aid in deciding among these multiple choices, agent-based approaches provide insight into those decision making processes themselves.

The LsT presented in this paper is an integrated approach where a variety of disciplinary component models are linked, allowing for the spatially explicit assessment of the triple-bottom-line impacts of scenarios for land use & management change.

3. THE LANDSCAPES TOOLKIT APPROACH

The LsT comprises a set of disciplinary models (models exist for terrestrial biodiversity, aquatic biodiversity, production systems, hydrology and water quality, and terrestrial economics), which users can select depending on their specific concerns. These models are *passively* linked (i.e. through the land use & management scenarios) to allow for the *comparative-static* evaluation of *pre-defined* land use & management change scenarios, while users can define the corresponding type and format of output (see Figure 1).

Consequently, the LsT allows stakeholders to compare the impacts of alternate land use & management change scenarios on triple-bottom-line indicators like water quality, biodiversity, employment and farm incomes. Moreover, it allows scientists to quantify functional relationships between disciplinary models for specific nested (inter-) disciplinary modelling purposes. Moreover, the LsT allows for the identification of the weakest component in the system and, consequently, research priority setting.

The following sections describe, in the context of the case study for Douglas Shire, the data management process, the component models, the model integration procedure and, finally, the functioning of the general user interface.

3.1. Database management

Identification of the data sets required is a priority during the planning phase for the LsT. Each of the component modelers is polled to determine the data requirements for their model, thereby using a data pro-forma that covers issues like ownership, custodianship, metadata availability, spatial extent and scale. This information is crucial in preparing the Geographic Information Systems (GIS) data layers, determining confidence in the data as model input. The data pro-formas are used as a framework for defining the protocols and naming conventions for the data directory structure, to ensure that all models can call and receive data that are consistent between the different component models. A simple data catalogue holds the name and address for each data set with a hyperlink to each data directory.

3.2. Component models

Terrestrial and aquatic biodiversity models

Terrestrial and aquatic biodiversity associated with land use & management in the case study area is based on two components of work. The first is empirical data on the distribution of woody plant and bird species (terrestrial biodiversity) and fish and aquatic macrophytes (aquatic biodiversity) against land use. Major natural and modified terrestrial and aquatic habitats are identified, and standardized surveys at each of these sites are being conducted. These surveys are replicated within each land use type and landscape context, and in the case of birds and fish are replicated to document seasonal and time of day effects. The second component of work comprises data originating from existing databases on terrestrial and aquatic biodiversity. These vary considerably in coverage and accuracy but generally have not been collected for this purpose or necessarily concentrating on the study area.

These two data sets then become the raw data inputs for calculating "surrogates" for the distribution of biodiversity against land use to enable integration with other data types and models within the LsT. A surrogate may, for example, be the number of otherwise undetected species a particular terrestrial or aquatic habitat contributes to the region's total biodiversity score (i.e. its complementarity, Margules and Pressey, 2001), or it might be the completeness of a key ecosystem process based on the presence of component species (Kanowski et al., 2004).

Production systems models

The most important agricultural production systems in the study area are modelled using crop growth and beef cattle production models (Keating et al., 2003; Hengsdijk et al. 2000). These relate input use to yields as well as impacts such as soil cover associated to different Management Practices (MPs). This information feeds back into the Terrestrial economic model and the hydrology and water quality model.

Sugarcane production is a major land use in the study area. Input-output data for different MPs are generated using the APSIM crop modelling tool (Keating et al., 1999). The APSIM sugar module simulates, for a uniform block of cane, per hectare cane and sucrose yield, CCS content, crop biomass, soil cover, soil water balance, and nitrogen uptake and partitioning to leaf and cane stem. Model simulation results are determined by soil, management, genetic and climatic factors.

Beef cattle input-output data for different MPs are generated using the PASTOR pasture-livestock modelling tool (Hengsdijk et al., 2000). PASTOR simulates, for a uniform block of pasture and stationary herd, per hectare metabolizable energy and crude protein yield, supplementary feed supply, herd feed requirements, and associated levels of beef production and soil cover. Again, simulation results are determined by soil, management, genetic and climatic factors.

Hydrology and water quality model

Sediment loads associated with land use & management in the case study catchments are estimated using the Sediment River Network Model (SedNet). SedNet is a model originally developed by CSIRO for use in assessing water quality in the major catchments throughout Australia (Prosser et al., 2001). It is now being applied at regional scales such as river catchments, using more detailed inputs.

SedNet models estimate river sediment loads, by constructing material budgets that account for the main sources and stores of sediment. SedNet models use a simple conceptualization of transport and deposition processes in streams. Sediment sources, stream loads, and areas of deposition in the system can be simulated. The contribution to the river mouth from each sub-catchment can be traced back through the system, allowing downstream impacts to be put into a regional perspective (Bartley et al., 2004).

Terrestrial economic model

Socio-economic consequences associated with land use & management change in the case study area are estimated using the Terrestrial Economic Model (TEM). The TEM uses a farm household modelling approach, developed to assess how different types of land and resource users likely respond to changes in their decision environment (Singh et al., 1986). The TEM estimates production, income, resource use and employment at the farm household and regional level, by constructing farm household models for the most important types of land users in the case study area. Farm household types are characterised according to their objectives (income and leisure), available agricultural production systems and management practices (generated by APSIM and PASTOR), as well as agro-ecological and socio-economic constraints (based on Bohnet, 2004). Regional estimates are obtained by aggregating results from the farm household models, based on the number of farm household types in each of the catchments (Roebeling et al., 2004).

3.3. Model integration

Land use & management change scenarios are central in the LsT. Following the creation of a change scenario (detailed in Section 4.1) a land use shape file for the study area is created, which is then provided as input to the component models.

For the aquatic and terrestrial biodiversity models, each land use & management is assigned a diversity index. For each landuse class an index value ranging from 1 to 10 is applied for terrestrial animal and plant biodiversity as well as fish biodiversity. The application of these biodiversity indices to the different land use & management scenarios, in turn, allow for the assessment of impacts of land use change on biodiversity.

For the hydrology and water quality model, each land use & management is assigned a cover factor, based on existing SedNet, APSIM and PASTOR modeling for case study area. Production systems and management practices are given varying cover factors dependant upon scenario rules. Cover factor grids are created for each land use & management scenario for input into the creation of hillslope erosion grids, which form the final input for the calculation of sediment loads in SedNet.

For the terrestrial economic model, first the location of all farm types is established. This farm layer is intersected with the soil type and land use & management layer, and these attributes are then used to calculate the area of each soil type per land use for each farm. Combined with the production systems and management practices information from APSIM and PASTOR, this information is used as input in the farm household models to calculate socio-economic indicator values.

3.4. User interface for land use simulation

The LsT has been authored in the programming language C#, which supports rapid object-oriented development without sacrificing power and control. It is based on The Invisible Modelling Environment (TIME), which is a software development framework for simulation models (Murray et al., 2004). TIME includes support for the representation, management and visualization of a variety of data types, as well as support for testing, integrating and calibrating simulation models. Using TIME, a General User Interface (GUI) was developed for the LsT in order to make data sets and scenario results accessible to users without requiring GIS software for visualization.

The GUI contains a number of directories and menus. The 'Base data' directory contains the base run scenario model input and results data for all component models. The 'Scenario' directory contains the different land use & management change scenarios. Each scenario provides information about the scenario as compared to the base run scenario, and allows for the selection of component models and associated output data.

The GUI provides two ways for visualizing base and alternative scenario results. First, maps for the base run and alternative scenarios can be viewed, while a difference map is available to highlight areas of major change. Zoom and text-tip tools are available to view locally specific indicator values.

Second, summary data are given for minimum, average, maximum and total indicator values.

4. APPLICATION TO DOUGLAS SHIRE

The Douglas Shire in North Queensland provides a unique setting for application of the LsT. The agricultural landscape, which forms less than 20% of the total Shire area, is surrounded by World Heritage Areas, the Wet Tropics rainforest and the GBR (Bartley et al., 2004). The need for greater protection of the GBR, a declining local sugar industry and pressures to subdivide agricultural land for urban expansion in the Douglas Shire, provides challenges and opportunities for local people, but also for planners, natural resource managers and policy makers.

4.1. Defining future land use scenarios

To create pathways for a sustainable future a participatory planning approach was chosen to develop future land use scenarios together with the local community. In contrast to forecasting or predicting the future, scenarios are vivid stories that are constructed to describe alternative futures that might be very different from the present (Nassauer & Corry, 2004,). In community workshops landscape visions for 2025 were developed together with local citizens. These workshops provided local citizens with the opportunity to discuss their preferred future. Common themes included (Bohnet, 2004): i) sugar industry survival; ii) land use diversification options and alternative management practices, iii) water quality, iv) protection of the environment, and v) rural residential subdivisions.

Priorities for the future were identified by the participants based on these themes and different sets of underlying assumptions, which were then used to define three future scenarios for 2025: Production, Water Quality, and Biodiversity. Note that these futures are not simple digital maps of land use & management change that can be measured against current land use & management; they represent landscape outcomes of different human (community) priorities for agricultural land in the Douglas Shire (Bohnet, 2004). The underlying assumptions for each of the scenarios offer elements that are incorporated into the future scenarios. For example, riparian buffer zones and reduced stocking rates were suggested in community workshops as measures for improving water quality. These were then integrated into the Water Quality scenario. We use the current agricultural area as the change unit, as the surrounding areas are under World Heritage status, and the current land use & management as baseline against which future scenarios are measured.

Scenario 1: Production

In the Production scenario it is assumed that maintaining agricultural activities provides a means to "keep the rural feel of the area" that is highly valued by locals as well as tourists and to confine rural residential subdivisions. Sugarcane production is maintained on soils that are highly suitable for growing sugarcane, but converted to grazing on soils that are unsuitable for sugarcane. Proposed changes in management include legume fallows in sugarcane and reduced stocking rates (from 2.25 to 1.75 head/ha) in the grazing system. To prevent soil erosion, agricultural land on slopes steeper than 20% is replaced by regrowth.

Scenario 2: Water Quality

The Water Quality scenario is based on participants' views that agricultural land will need to be managed in such a way that there is substantially less sediment and nutrient run off from farming land. Besides the establishment of 100m wide riparian buffer zones along all rivers and main creeks, changes in land management from current to improved Management Practices (MPs) were suggested by workshop participants. In the sugarcane system changes include: from no fallow to legume fallow, reduction in N application from 165 kg/ha to 130 kg/ha, improved cane drain management, and the application of minimum tillage. In the grazing system changes include: reduction in stocking rate from 2.25 to 1.75 head/ha. Again, agricultural land on slopes steeper than 20% is converted to forest regrowth.

Scenario 3: Biodiversity

The Biodiversity scenario is based on participants ideas that both native flora and fauna have intrinsic values. It is assumed that wide riparian buffer zones and the establishment of coastal wetlands could provide a multitude of ecosystem services, including the provision of habitats as well as filter and buffer functions. The core of this scenario is therefore re-establishment of wetlands along the costal strip, establishment of 100m wide riparian buffer zones along all rivers and main creeks, and as in the previous scenarios conversion of agricultural land on slopes steeper than 20% to forest regrowth. Further land use changes include the conversion of sugarcane land to grazing. Management changes include: reduced stocking rates (from 2.25 to 1.75 head of cattle/ha) were suggested to enhance biodiversity.

4.2. Assessing future land use scenarios

Future land use scenarios are characterized by changes in land use & management as compared to one another and the current situation. Based on a selected number of criteria, land use scenarios are assessed for their impact on economics (farm income), biodiversity (fish and animal biodiversity) and water quality (sediment loads).

A challenge in summarizing the results of the disciplinary models is to decide how to compare "apples and oranges" (Santelmann et al., 2004, p.364). In order to retain as much detailed information on the outcomes from the disciplinary models as possible – for further discussion and use in making informed decisions – we present results on a common scale for comparison. Each of the disciplinary models provides one endpoint for each scenario and the current situation which allows relative changes between the current situation and the different scenarios to be compared (Figure 2).

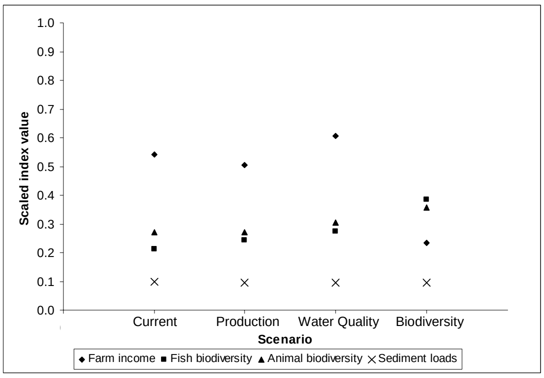

Figure 2. Base and scenario simulation results

The results from the hydrology and water quality model indicate that changes in land use & management envisioned in all scenarios lead to a relatively small reduction in sediment loads exported from the Shire area. This is not surprising as less than 20% of the area is used for agricultural purposes, while most agricultural activities in the Shire take place on relatively flat land and coastal floodplains. Nevertheless, the Water quality scenario indicates that water quality improvements can be combined with an increase in farm income.

Farm income varies slightly in the Production and Water Quality scenario when compared with each other and the current situation. The Water Quality scenario leads to positive income effects as the improved MPs are financially attractive to sugarcane farmers (Roebeling et al., 2004). In the Biodiversity scenario farm income decreases significantly (more than 50%) as compared to the current situation.

Fish biodiversity increases slightly from the current situation to the Production Scenario. In the Water Quality scenario fish biodiversity is higher than currently and when compared with the Production scenario. Not surprisingly, fish biodiversity is highest in the Biodiversity scenario.

Animal biodiversity is also highest in the Biodiversity scenario when compared with the current situation and the Production and Water Quality scenario. In the Production scenario terrestrial animal biodiversity is similar to the current situation and slightly lower than in the Water Quality scenario.

5. CONCLUSIONS

In this paper we presented the Landscapes Toolkit (LsT) approach, as developed within the context of CSIRO's Water for Healthy Country 'Floodplain Renewal' program. The LsT is a systems approach that provides a comprehensive understanding of the human-environmental system by linking spatially explicit state-of-the-art disciplinary models and, in turn, allows for the spatially-explicit analysis of the impacts of land use & management change on environmental, social and economic values (i.e. the triple-bottom-line).

Although in its' early stage of development, we have demonstrated that integration of approaches, information and data from disparate disciplinary models can successfully be used in the development of solutions for landscape and water quality protection in the GBR region. Moreover, the LsT demonstrates great potential and flexibility for inclusion of additional component models that provide further information important in the search for more sustainable futures.

It is anticipated to use the LsT in a participatory process with local people, planners, natural resource managers and policy makers. Not only may the results of the LsT lead to a re-adjustment of existing or development of new future scenarios by the involved stakeholders, but also can discussions with the stakeholders reveal what kind of additional information would aid in deciding among multiple choices.

Over the next years, the objective is to develop a LsT that *passively* links disciplinary models and that allows for the *dynamic* evaluation of *user-defined* scenarios. Users can set and combine a wide variety of scenarios, and can define the corresponding type and format of output. In the long-term, the LsT will allow for *active* linkages between disciplinary models, to account for processes endogenous to the system. In addition, attention will be given to the uncertainty in component models' and integrated system results.

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