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# Mapping socio-economic scenarios of land cover change: A GIS method to enable ecosystem service modelling

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ABSTRACT

We present a GIS method to interpret qualitatively expressed socio-economic scenarios in quantitative map-based terms. (i) We built scenarios using local stakeholders and experts to define how major land cover classes may change under different sets of drivers; (ii) we formalised these as spatially explicit rules, for example agriculture can only occur on certain soil types; (iii) we created a future land cover map which can then be used to model ecosystem services. We illustrate this for carbon storage in the Eastern Arc Mountains of Tanzania using two scenarios: the first based on sustainable development, the second based on 'business as usual' with continued forest–woodland degradation and poor protection of existing forest reserves. Between 2000 and 2025 4% of carbon stocks were lost under the first scenario compared to a loss of 41% of carbon stocks under the second scenario. Quantifying the impacts of differing future scenarios using the method we document here will be important if payments for ecosystem services are to be used to change policy in order to maintain critical ecosystem services.



## 1. Introduction

It is widely accepted that intact ecosystems provide an array of services – from immediate and tangible benefits such as water flow regulation and provision of harvested goods through to biodiversity preservation and climate stabilisation via carbon storage in vegetation and soils (Costanza et al., 1997; Daily, 1997; de Groot et al., 2002). Although there remains much theoretical debate about the definition of such services and approaches to their valuation (Ruhl et al., 2007; Wallace, 2007; Costanza, 2008; Boyd and Banzhaf, 2007; Fisher et al., 2009) one common thread is clear: ecosystem service production and flow is spatially explicit and temporally dependent. It matters not only how much of a service is produced, but also when and where, so any economic values we assign to these services will therefore also vary across space and time.

The spatially variable nature of service generation and flow means that mapping and modelling of ecosystem services for planning purposes is becoming increasingly important (Naidoo and Ricketts, 2006; Egoh et al., 2008). Datasets have become more sophisticated, shifting from a simple benefits-transfer approach (Zhao et al., 2004; Troy and Wilson, 2006) to values derived from biophysical and economic models (Eade and Moran, 1996; Bateman et al., 1999; Mallawaarachchi et al., 1996; Soares-Filho et al., 2004, 2006). Typically, the links between models of different services are made through synoptic land cover datasets. The distribution and value of services can be expressed spatially in this way and changes modelled by altering land cover patterns and extent. Sometimes these land cover driven futures operate over large regions with notable examples from the USA including ICLUS which was developed by the Environmental Protection Agency (US EPA, 2009) drawing on the earlier work of Theobald (2001, 2005), and

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Decisions based simply on gross estimates of service values will however, be of limited use. Instead information is needed about policy-induced changes to services and the corresponding values attributed to them. Such decision making can be helped by the use of scenarios – internally consistent and realistic narratives describing potential future states (Peterson et al., 2003). Typically, these are presented as 'storylines' which are constructed using existing conditions and processes but also incorporate likely future changes in important drivers, these storylines are internally consistent and viewed as physically realistic future possibilities (Gallopin et al., 1997; Raskin, 2005). Rather than representing a specific prediction each scenario should be thought of as a description of a possible future, albeit one which is plausible given the knowledge on which they are based. Scenarios are widely used in land use planning (Xiang and Clarke, 2003; Verburg et al., 2006), climate change analysis (IPCC, 2007) and conservation planning (Osvaldo et al., 2000) and, increasingly, in ecosystem service assessment (Castella et al., 2005; Millennium Ecosystem Assessment, 2005; Walz et al., 2007).

The process of scenario-building often involves a stakeholder group which develops qualitative storylines of expected change (termed 'participatory scenario-building', Alcamo, 2009). Such approaches have the potential advantage of using a wide base of local knowledge and building broad ownership of the process and the ensuing results. But participatory approaches are time-consuming in countries where contributors are geographically dispersed, and there can sometimes be both practical and institutional barriers to sustained participation. In addition, the ideas generated by participatory scenario-building can be hard to parameterise. For example, in a recent study from Switzerland a rigorous participatory exercise relating to landscape change around the skiing resort of Davos was undertaken (Walz et al., 2007; Grêt-Regamy et al., 2008). Many interesting outputs were documented but attempts by researchers to integrate outputs into the formal modelling process were unsuccessful and resulted in them abandoning this approach and taking a "*more intuitive, concept-driven approach to scenario development*…" (Walz et al., 2007, p. 120).

These difficulties can be overcome and here we move from participatory exercises in developing future scenarios to a formal modelling framework, and apply it to a test case of carbon storage in four mountain blocks of the Eastern Arc Mountains, Tanzania. This is a useful case-study area, firstly, Tanzanian policy-makers have highlighted carbon storage as being of topical policy interest, because the concept of Reduced Emissions from Deforestation and Degradation (REDD) is being considered for inclusion under the UN Framework Convention on Climate Change and Tanzania is a pilot REDD country (Miles and Kapos, 2008). Secondly, this is one of a number of ecosystem services being studied in the same area, so eventually this method will be used to consider the trade-offs and synergies between different ecosystem services (Burgess et al., 2009).

This paper is in three parts. Firstly, we discuss the scenario-building process within the context of the Tanzanian study area and describe our method for extracting quantitative information from qualitative narratives formulated to describe two socio-economic scenarios of change. Secondly, we provide spatial representations of these two scenarios as alternative land cover projections mapped for eastern Tanzania. Thirdly, to illustrate the consequences of these possible land cover changes for a particular service, we use these maps as inputs to a simple carbon storage model and quantify how these alternative scenarios influence the amount, location and value of carbon stored in our focal study area.

## 2. Method

### 2.1. Study area

Our study is both regional (covering most of eastern Tanzania) and local (covering four of the mountain blocks which make up the northern part of the Eastern Arc Mountains). Our land cover maps were developed for the wider region, whilst the carbon storage model was applied to the local study area.

The study region covers nearly 340,000 km$^2$ (Fig. 1). It is a mixed landscape comprising a patchwork of bushland, scrub, swamps, mangroves, deciduous and open woodland (miombo), wetlands and evergreen tropical forests, mixed with small-scale cultivation and settlements. Parts of the coastal strip are densely populated and include Tanzania's largest and fastest growing city, Dar es Salaam. Topographically, the study area can be split broadly into the eastern coastal plains (0–350 m) and the western highlands and plateaus rising to over 2000 m. In addition, the coastal zone and mountains are wetter (1000–2200 mm yr$^{-1}$) while the interior zones are drier with some areas receiving as little as 370 mm yr$^{-1}$.

Running almost north to south through this region are the Eastern Arc Mountains (EAM), 13 separate mountain blocks covering a combined area of over 35,000 km$^2$. These mountains are important centres of biodiversity with high levels of species endemism both for plants and animals and recognised as globally important conservation areas (Lovett and Wasser, 1993; Mittermeier et al., 1998, 1999, 2004; Stattersfield et al., 1998; Burgess et al., 2007; Menegon et al., 2008; Myers et al., 2000). Approximately 22% of the total area of the EAMs has some state restrictions on permitted activities (forest reserves, nature reserves or national parks).

Besides their value for biodiversity, the EAM provide many ecosystem services. These include services provided to the local inhabitants of the mountain settlements, such as the provision of energy (firewood), building materials (poles and thatch) and food (fruit, tubers, honey, bushmeat), as well as services provided to those distant from the mountains themselves. These include the regulation of water flows from the EAM to downstream agricultural areas and the major population centres of the coast (where the water is used for hydro-electric power generation as well as drinking and industry) and the provision of wood for charcoal which fuels the majority of urban households in Tanzania. At a global level the EAM contribute to climate regulation through the storage of carbon.

### 2.2. Data

The key dataset used in this paper is a land cover map derived from a 1997 survey by Hunting Technical Services (Hunting Technical Services, 1997). The original has been updated by local experts and tropical biologists and now contains 30 land cover classes at a resolution of 100 m and has been given a nominal date of 2000. More recent land cover products including Globcover (Bartolomé and Belward, 2005) and Africover (FAO, 2008) overestimate the forest and woodland classes in the study region and were felt to be less representative than the earlier but Tanzanian-specific Hunting dataset. The land cover dataset was supplemented by the following spatial datasets:

- Elevation and slope – derived from the USGS Shuttle Topography Radar Mission (STRM) (Farr et al., 2007);
- Protected area outlines – derived from the latest version of the World Database of Protected Areas (WDPA, 2009);
- Road and rail networks – digitised from the available 1:50,000 topographic maps;
- Settlements – villages digitised from the 1:50,000 maps;