Simulating deforestation trends of Dzalanyama forest reserve in Malawi using a spatial agent model

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Abstract: Spatially referenced multi-agent simulations (MASs) show particular promise in exploring regional spatial geographic phenomena by deriving deeper understanding of the individual entities' behavior. Several parameters are recognized to influence agents of deforestation's decision making to deforest and in the tropics many of these parameters are agriculture-based. Using a farming household as the main agent, this study simulated the inefficiencies of the crop production theories being practiced in the areas surrounding Dzalanyama forest reserve in Lilongwe, Malawi and how they translate into its deforestation. The farming household agricultural land distribution plays a significant role in the households' capacity to achieve food sufficiency, which when it fails the household engages in off-farm activities that include charcoal production (deforestation). The study showed that the contribution of the farming inefficiencies is significant and is more pronounced under the current situation where the rewards from charcoal selling (deforestation) are very low. Formalization of the charcoal production has demonstrated potential to curb the deforestation in the study area among other advantages. The study has also shown potential of MAS to produce spatial maps apart from the quantities of the deforestation.

Keywords: multi-agent simulation, agent based simulation, tropical deforestation, farm-based decision making, geo-computation

1. Introduction

Tropical deforestation is a complex environmental problem often comprising of several micro interacting spatial subsystems. While physical environment strongly influences where tropical deforestation occurs, it is evident that it hinges on agricultural activities (Kaimowitz and Angelsen 1998). This is therefore an attempt to simulate deforestation trends of Dzalanyama forest reserve by exploring the crop production dynamics of the individual households in the surrounding area. We seek to derive deeper understanding of the deforestation by simulating the inefficiencies of the crop production theories being practiced at the individual farming households and explore potential policy intervention scenarios to curb the deforestation.

2. Background

Dzalanyama forest reserve, located 60km south west of Lilongwe, Malawi's capital city, sits on a range of hills bearing the same name. It covers 935 km2 and shares its borders with two other districts of Mchinji and Dedza on the Malawi side with the whole of its western border forming the national boundary between Malawi and Mozambique (Munthali and Murayama 2011).

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With increased urban demand for charcoal and perennial household food shortages in the study area there are marked land cover transitions in the vicinity of Dzalanyama. The forest cover as of 1990 was 65, 775 hectares of which 22,031 hectares were lost by the year 2010.

3. Data sources and methods

Massive forest loss is evident in the area from the combined influence of: 1) the households' inability to meet their food and/or cash requirements from agriculture, their main activity, due to among other factors population growth and poverty; and 2) the households' engagement in charcoal production (deforestation) as a coping mechanism against the resulting food and/or cash deficiencies of (1) above.

3.1 Data sources

To simulate the household activities a field survey was conducted from which 3,533 households were randomly selected and interviewed. The following socio-economic data were collected: household size; total land under cultivation; total land under maize (corn) cultivation; land under other crops; annual total maize yield (food); accessibility to hybrid seed and fertilizers; estimated annual income; accessibility to good farming methods; income generating activities (IGAs) the households engage in apart from cultivating their land; labour and land availability; soil condition; and education level of head of household.

3.2 Methodology

This simulation is an abstract representation of the forest reserve landscape, the subsistence farming households and the processes and entities that link them.

It hypothesizes that the subsistence agriculture crop production theories being implemented by the households in the communities surrounding Dzalanyama forest reserve impacts the overall deforestation trends of the forest reserve itself. To test this hypothesis three entities were developed: i) farm household agents that grow the crops and engages in off-farm activities (casual labor, charcoal production and other small scale businesses) as a coping mechanism in case of food and/or cash deficits from the crop production; ii) Extension worker agent representing a government agricultural expert tasked with the duty to impart new and better farming techniques to the farming households; and iii) Kiln agent, representing the physical location on which charcoal is produced in the forest reserve. It responds to demands to produce charcoal from households and eventually effects the deforestation of the forest reserve.

4. Results

The deforestation trends for Dzalanyama forest reserve were simulated over a 40 year period beginning the year 1990. The price of charcoal was pegged at MWK2000 (~US$8) (current estimated market value), number of extension workers was half the recommended ratio of 1:1524 (Malasa, personal communication, 14 April 2011) and 31,200 recipients of subsidized farm inputs.

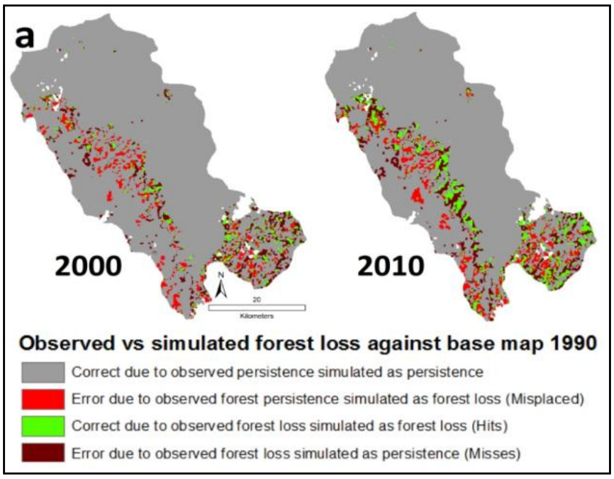

Figure 1 Simulated versus observed forest loss spatial distribution

12, 207 ha of forest were simulated as lost against

13, 639 ha observed in 2000. The quantities accumulate to 19, 459 ha simulated against 22, 031ha observed by the year 2010. Statistically, the simulation stands at a standard Kappa value of 0.731 and 0.629 when compared with the observed land cover map for 2000 and 2010 respectively.

The spatial accuracy using the combine tool in ESRI's ArcGIS for 2010 stand at 50% with a worst case scenario of 45% (Hits in Figure 1).

Based on the successful simulation for 2000 and 2010, we predicted future forest loss for 2020 and 2030 using the status quo conditions and a scenario that assumes an increase in the reward from charcoal of 50% (Figure 2). The quantities involved are shown in Figure 3 alongside Markov chains predictions.

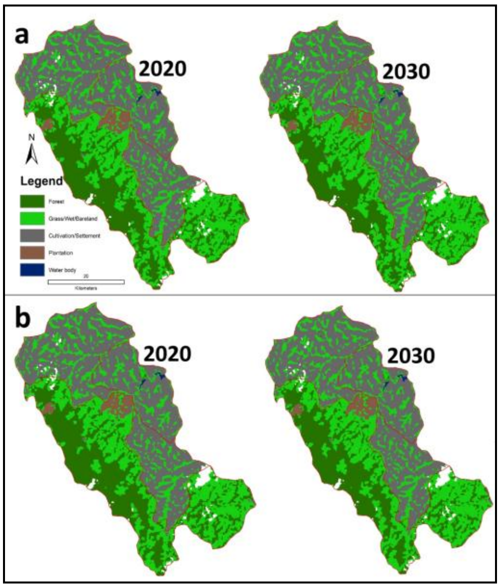

Figure 2. Predicted Land use/cover a) status quo conditions; and b) with a 50% increase price of charcoal

The status quo conditions predict forest loss of 23, 100ha by the year 2020 that accumulates to 26,721ha in 2030. Increasing the price of charcoal beginning year 2010 reduces the predicted forest loss to 21,676ha in 2020 and 24,060ha in 2030.

5. Discussion

The results are encouraging as an alternative approach to modeling tropical deforestation trends. A multi-agent simulation approach in which subsistence households in the study area make independent decisions to grow crops to sustain their households and how they cope with any shortfalls has demonstrated literary comparable results in tropical deforestation modeling studies. Individual decision making based on household composition, cash endowment, access to subsidized farm inputs and access to sustainable farming methods has shown great capabilities of MAS to encourage further exploration of this modeling approach in deforestation.

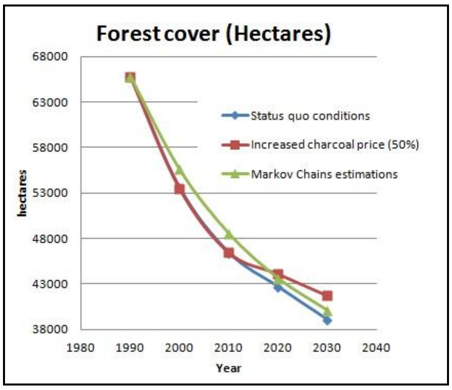

Figure 3 Quantities of forest loss predictions 2020 and 2030

Increasing the price of charcoal (by 50% to MWK3, 000) had a positive impact on the predicted amounts of forest loss in 2020 and 2030. In 2020 the accumulated forest loss reduced by 1,424ha (~6%) and grew to 2,661ha (~10%) in 2030. This represents a growing reduction trend in forest loss in the long term and an accumulated gain (or sustenance) in forest cover of 4%. The raise in the income generated from charcoal as proposed in the simulation suggests a possible way out in mitigating the consequences of food deficiency induced charcoal production on deforestation.

However, increasing the price of charcoal literary would not be easy to be realized given the economic dynamics of the study area where the supply usually exceeds the demand at any given time thereby forcing the prices down. This is also notwithstanding the fact that the economic situation of the urban market is volatile making feasibility of charcoal price raise a near impossible task. It is also a very politically sensitive issue for any sitting government to pursue as charcoal is used by the majority of the voters.

We however still tested this scenario not to necessarily push for an increase in the price of charcoal at the consumer end but rather to present a simplistic understand of the positive influence a handsomely rewarding charcoal production for the charcoal producer would have on the overall system dynamics of managing deforestation of Dzalanyama Forest Reserve. As Kambewa et al. (2007) did observe, the resultant deforestation in most forest reserves in Malawi is not necessarily because the total charcoal supply is out of balance with the wood stocks; but rather due to failure to provide incentives to manage wood production in a manner that allows regeneration in and around charcoal producing areas. The increased price of charcoal simulation result substantiates this assertion. From the perspective of boosting central government revenue, Kambewa et al. (2007) went further to propose a formalized charcoal market. Our result provides backing to indeed push for the formalization of the charcoal production but from the stand point of its impact on mitigating deforestation. The proposition to formalize the production is therefore aimed at raising the percentage that accrues to the producer by enforcing some regular structure in the charcoal value chain.

Substantial sustainable forest management efforts in the study area and Malawi in general are hampered by limited resources. As such, apart from improving the individual households' cash flow, with extra revenue collected, the charcoal production formalization process has the potential of making more resources available to enforce sustainable forest management interventions in the long run.

6. Conclusion

The simulation has built on the strength of MAS as a replicative tool to develop deeper understanding of the situation of the deforestation trends of Dzalanyama Forest Reserve. Although these results are encouraging in themselves, there is plenty of room for improvement. While the quantities involved may be satisfactory, the spatial dimension needs improvements. Inclusion of more physiographic factors, for instance elevation, would boost the determination of the optimal areas where the deforestation occurs.

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