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Biocomplexity of deforestation in the Caparo tropical forest reserve in Venezuela: An integrated multi-agent and cellular automata model

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Abstract

A multi-agent model of social and environmental complexity of deforestation was developed for the Caparo Forest Reserve, Venezuela. It includes three types of agents: settlers, government, and lumber concessionaires. Settlers represent people of limited economic resources that deforest and occupy reserve land to grow crops and eventually claim property rights of this land. Their agricultural practices generate unintended environmental problems. The concessionaires extract lumber using management plans approved and monitored by the government. The agent model links to a cellular automata simulation of the natural system. Representational tools include Galatea (multi-agents), Actilog (rule description), and SpaSim (cellular automata). Three scenarios were explored for government policies: hands-off, pro-forestry and agro-forestry. Results agree qualitatively well with history of land-use change in the area. Old-growth forest is replaced by logged and secondary forest but the rate at which this transformation occurs varies by scenario. These results suggest that some of the agent's behaviours and forest management plans should change to promote sustainability of the forest reserve; e.g., broadening government's role to improve management plans and monitoring, and to prevent invasion of reserve land by improving living conditions of potential settlers outside the reserve. These and other alternatives will be modelled in future work.

Keywords: Biocomplexity; Multi-agents; Simulation; Deforestation; Tropical forests; Venezuela

1. Software availability

Name of software: GLIDER (simulation language and environment); it works under Windows and Linux. Developers: CESIMO and IEAC. Universidad de los Andes (ULA).

Contact address: Tel.: +58 274 2401116; fax: +58 274 2401115. E-mail address: sananes@ula.ve.

Availability: free download from http://afrodita.faces.ula.ve/glider.

Name of software: SpaSim; it works under Java Virtual Machine (JVM).

Developers: CESIMO (N. Moreno, M. Ablan), ULA.

Contact address: Tel.: +58 274 2402879; fax: +58 274 2402872. E-mail address: morenos@ula.ve.

Availability: free download from http://cesimo.ing.ula.ve/investigacion/proyectos/spasim/spasim/.

Name of software: GALATEA (it includes ACTILOG); it works on any Java Platform. Tested on Linux and Windows

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ME, NT, 2000 and XP (latest version of ACTILOG requires any PROLOG).

Developers: CESIMO and SUMA (J. Dávila, M. Uzcátegui, K. Tucci), ULA.

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Availability: in-house software for use in research and consultancy; see http://cesimo.ing.ula.ve/investigacion/proyectos/galatea/galweb/.

2. Introduction

The purpose of this study is to develop multi-agent and land cover models to help understand the biocomplexity of tropical forests, using as a case study the Caparo Forest Reserve in western Venezuela. The result is the BIOCAPARO model, which seeks to (1) understand the land cover dynamics that have occurred in the reserve, (2) simulate, through the development of scenarios, different land-use change policies, and (3) evaluate the implications of these policies for the sustainability of the forest reserve. These methods are very important tools that could help the preservation of Venezuelan forest reserves that have been subject to deforestation and degradation processes of considerable magnitude during the past decades (FAO, 2003; Centeno, 1997).

Biocomplexity means here the dynamic and complex web of relationships between human and natural ecosystems. This interaction is crucial in the field of integrated resource management where emphasis is placed on the sustainable use of the resources and resolving conflicting interests of stakeholders (CIFOR, 1999). Multi-agent simulation has been proposed as one of the tools for the study of ecological complexity (Bousquet and Le Page, 2004) and is increasingly used in environmental and ecosystem management (Hare and Deadman, 2004; Bousquet and Le Page, 2004).

In the framework of the taxonomic classification of models proposed by Hare and Deadman (2004), the BIOCAPARO model would be spatially explicit, with no social interaction and with agents that have multiple strategies for intrinsic adaptation. These agents have a belief-desire-intention (actually, belief-goals-preferences) architecture and the environment mediates their interactions. The main ecological process simulated is forest secondary succession, which is implemented as cellular automata model (Hogeweg, 1988).

Several different approaches have been reported in the literature to model deforestation. Most spatial explicit models are empirical, based on extrapolations of the patterns of change observed over the past, with a limited representation of the driving forces of this change (see for example, Mas et al., 2004). The combined multi-agent and cellular automata model presented here allows the representation of the human decisions that drive the land use/cover changes with the advantage of a spatial representation that is able to capture, at least in principle, the location and magnitude of the changes.

Examples of multi-agent models of tropical deforestation include: LUCITA (Lim et al., 2002), SYPR (Manson, 2002) and MameLuke (Huigen, 2002). Despite the fact that these models represent the same processes, they differ in their conceptual underpinnings. In the same manner as these other models, the primary agents of BIOCAPARO model are the colonists or settlers: people of limited economic resources that practice slash and burn agriculture and that arrive at the reserve aiming to improve their economic status and to obtain the property of the land that they have occupied. However, in the Caparo case study the settlers are illegal occupants of the forest reserve. This, together with the difficulties of accessing the site makes it difficult to conduct direct surveys of the settlers. For this reason, the agents are modelled using information from results of previous research (Sánchez, 1989; Rojas López, 1993; CESIMO, 1998).

This study is part of the larger project ‘‘Biocomplexity: Integrating Models of Natural and Human Dynamic in Forest Landscapes across Scales and Cultures’’ that includes another forest reserve in eastern Venezuela and two sites in Texas, USA (Acevedo, 2003). The explicit modelling of human actions and their interaction with ecosystems will provide policymakers information about the impact of their decisions on the future composition, structure, and functionality of local ecosystems. It will also facilitate a more informed analysis of the long-term consequences of private choices and public policies on the natural systems in which human systems are embedded and with which they interact (Monticino et al., 2004). It is also hoped that these models will provide the foundations for a unified process theory for agent-based simulations of biocomplexity.

In the following four sections, we provide a brief description of the Caparo Forest Reserve (CFR), the model agents, the interactions between agents and the environment and the model implementation. The last two sections present the results, conclusions and comments on future work.

3. Study area and conceptual model

According to the Holdridge classification, the forests of the Caparo Forest Reserve (CFR) are in the transition between dry tropical forest and humid tropical forest. The CFR was created in 1961 and its original purpose was to support the development of the logging industry in the zone, while preserving one of the more productive forests of Venezuela (CESIMO, 1998). It is located southeast of the Barinas State, in the Venezuelan western plains region. Its extension is 176,434 hectares (ha), and it has been divided into three units to facilitate its management (Fig. 1).

The study takes place in Unit I, an area of 53,358 ha, which itself includes a special area called the experimental unit, which is used for research and educational activities. Currently, only 7000 ha of forest remain in the reserve and it is all located in the experimental unit. Nevertheless, this area is still not exempted from deforestation due to the agrarian settlement process.

Many factors have contributed to deforestation in the CFR: forest management practices that did not attempt to preserve the ecological integrity of the forest of some lumber concessionaires; contradictions between different governmental