Agriculture, Ecosystems and Environment 161 (2012) 55–69

Contents lists available at SciVerse ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

An agent-based model for analyzing land use dynamics in response to farmer behaviour and environmental change in the Pampanga delta (Philippines)

F. Mialhe[a,b,*], N. Becu[c], Y. Gunnell[d]

[a] Department of Geography, Université Paris Diderot 7, CNRS UMR 8586, 2 rue Valette, 75005 Paris, France
[b] Department of Geography, Facultés Universitaires Notre Dame de la Paix, 61 rue de Bruxelles, 5000 Namur, Belgium
[c] Department of Geography, Université Paris Panthéon-Sorbonne 1, CNRS UMR 8586, 2 rue Valette, 75005 Paris, France
[d] Department of Geography, Université de Lyon, CNRS UMR 5600, 86 rue Pasteur, 69365 Lyon Cedex 07, France

ARTICLE INFO

Article history:
Received 21 November 2011
Received in revised form 14 May 2012
Accepted 18 July 2012
Available online 13 August 2012

Keywords:
Agent-based modelling
Aquaculture
Paddy
Land-use change
Pampanga delta
Farmer behaviour

ABSTRACT

Agent-based models (ABMs) are increasingly employed to understand land use change in agro-ecosystems. Here we use an ABM named CHANOS to capture how a range of variables influences decision-making processes among farmers with respect to their choice of cropping system, and to analyze the resulting changes in land use patterns. The model is experimental but is empirically based and nourished by field data acquired in the Pampanga delta, Philippines, where rice cropping and aquaculture have been competing over the last 40 years at the expense of natural habitats. Among the variables we include agent behavioural profiles but also forcing factors relevant to the natural, economic and political settings of the system: e.g. continuous (deltaic land subsidence) and discrete (typhoon events) environmental processes, external market forces, and changes in government-driven agricultural policies. Assessing the relative weights of these factors was performed through a detailed analysis of decisional outcomes. The farmers fall into three behavioural categories: rational, collective minded and boundedly rational. Likewise, four different environmental dynamics are driven respectively by no deltaic subsidence, steady subsidence, accelerating subsidence, and subsidence punctuated by additional external variables such as listed above. Twelve scenarios were elaborated by combining the agent behaviour algorithms with the environmental dynamics. Results reveal three categories of land-use change: an extension of paddy over natural habitat, of aquaculture over natural habitat and paddy, and a succession of periods alternating between paddy and aquaculture. Several indicators show that the rational agents are the most reactive and adaptive to environmental changes.

Collective-minded agents act independently from environmental changes. Their ability to cope with change is limited and adaptations take longer to propagate. Boundedly rational agents reveal adaptive capacities but are less reactive than rational agent. CHANOS thus provides a dynamic tool for understanding the social fabric and behavioural processes behind land use change.

1. Introduction

Land-use change (LUC) can trigger different environmental changes such as biodiversity loss, local and regional climate change, soil degradation and enhanced carbon emissions (Huigen, 2004; Lambin et al., 2001; Meyfroidt et al., 2010; Lambin and Meyfroidt, 2011). Societies are affected by these changes through the erosion of ecosystem services, food shortages, a higher vulnerability to natural hazards, and may more generally experience a reduction in well-being (Turner II, 2010).

A major tool for understanding and forecasting LUC is computer modelling. Among modelling methods, the appeal of agent-based models (ABMs) is that these allow the exploration of interactions between micro- and macro-level structures, e.g. the farmstead level and its wider environment (Huigen, 2004). Simple rules and specific process–response interactions between social and natural elements can lead to emergent and often unpredictable spatial patterns or time delays (Bandini et al., 2009). Thus, the aim of many ABMs is to study how micro-level processes affect macro-level outcomes within social-ecological systems (SES) that are complex, unpredictable, adaptive and often evolve in a non-linear way (Berkes et al., 2003; Jager et al., 2000; Matthews et al., 2007). Because LUC emerges from a wide set of decisions taken at different scales, ABMs are tools well suited to the study of LUC.

Existing ABMs dedicated to LUC are concerned with the exploration of the causes and the consequences of LUC, e.g. on landscape

* Corresponding author. Current address: Department of Geography, Facultés Universitaires Notre Dame de la Paix, 61 rue de Bruxelles, 5000 Namur, Belgium. Tel.: +32 485363424.
E-mail address: francois.mialhe@fundp.ac.be (F. Mialhe).

0167-8809/$ – see front matter
http://dx.doi.org/10.1016/j.agee.2012.07.016

patterns or biodiversity (Verburg et al., 2004; Veldkamp and Verburg, 2004). In agrarian systems, farmers are central decision makers. Thus an important component of LUC models when applied to agrarian systems is the decision-making process of the farmer, or agent. Modelling this behavioural component can be based on behavioural theory and/or on empirical data (Smajgl et al., 2011; Macal and North, 2010). Jager et al. (2000) have developed the so-called consumat approach, in which the behaviour of people when facing a consumer decision is not merely motivated by economic optimization but relies on multidimensional optimizations. Drawn from theories in social psychology, this is based on the assumption that people do not always seek to optimize outcomes outside of open competitive situations (Jager et al., 2000; Janssen and Ostrom, 2006). Another assumption is that people learn from one another's behaviours, particularly when they are beset by uncertainty (Jager et al., 2000).

For farmers, decisions about cropping and farming systems are both influenced by internal (e.g. cognitive capacities and social capital) and by external drivers (e.g. presence or absence of government subsidies, variations in global markets or the environment) (Acosta-Michlik and Espaldon, 2008). Decisions result from a combination of profits and satisfaction seeking, showing that farmers are not perfectly rational decision makers (Polhill et al., 2010). Reaching a rational decision would be further complicated by variables such as access to useful resources or to information (Lambin et al., 2001; Acosta-Michlik and Espaldon, 2008). Non-monetary factors, such as cultural barriers, can also contribute to modify the strategies on which decisions are based (Polhill et al., 2010).

This paper aims to assess the influence of both internal and external variables on decisions made by farmers regarding their cropping systems and how these decisions generate LUC. It also seeks to improve our understanding of the social fabric behind land use change processes by examining a range of decision-related social and economic outcomes that hinge on adaptive mechanisms. The real environment on which the model is based is located in the Pampanga river delta (Philippines), where in recent decades a transition from agriculture to aquaculture and a conversion from natural habitat to aquaculture have occurred. However, the ABM we present here, called CHANOS (*Changement d'Occupation du Sol*), relies both on empirical and on experimental data. The use of experimental data was necessary because obtaining accurate data about environmental processes and systematic information from farmers concerning land-use decision processes is not a simple task (Smajgl et al., 2011; Bakker and van Doorn, 2009).

2. Study area

The study area is a portion of the Pampanga delta located in Pampanga province, Luzon Island, Philippines (Fig. 1). The climate is tropical with a monsoon season from May to October, which is also the typhoon season. ENSO events (El Niño Southern Oscillation) affect the area by lengthening the dry season. Natural subsidence of the delta provokes the diffusion of seawater to inland areas. Its recent acceleration is due to human actions such as groundwater mining, floodplain constriction as a result of urban planning, the reduction of river discharge because of flood control devices such as dams, and the construction of fish ponds that have desiccated the moisture-retentive upper layers of the soil (Rodolpho and Siringan, 2006). Between 1991 and 2001, subsidence rates varied spatially between 2 and 8 cm year^{-1} (Soria et al., 2005).

The two municipalities of Masantol and Macabebe, with a population of ~120,000, encompass the study area. Until the 1970s, the main land use and land cover categories were rice, aquaculture, and natural habitat (open marshland and mangrove or nipa swamp). Since then, aquaculture has expanded dramatically over all other types of land use, thus becoming the dominant form of land use within a period of 40 years. In the entire Pampanga delta, the total area under aquaculture increased from 3900 ha to 33,000 ha between 1965 and 2008 (+595% in the case of Macabebe, +817% in the case of Masantol: Mialhe, 2010). Several aquaculture farming systems coexist today, the main ones being extensive polyculture (shrimp, crab, tilapia, milkfish) and semi-intensive monoculture (tilapia or milkfish). Fish farms range from small- (1 ha and less) to large-scale (>100 ha), with a variety of tenure arrangements (Mialhe, 2010).

In addition to tectonic subsidence in the delta, farmers have faced seasonal events such as brutal changes in salinity, difficulties in collecting molluscs and gastropods used as fish feed, increasing costs of pond maintenance, and dike erosion in the context of floods or typhoons. The fluctuation of productive areas is not just affected by seasonal changes. Other periodic factors such as epidemics, market price fluctuations, episodic conflict among stakeholders and the unequal diffusion of farming-related innovations also impact on the total surface area and distribution pattern of cropping systems. The satellite image in Fig. 1 was obtained soon after the 1991 Pinatubo volcanic eruption, revealing the parts of the delta affected by lahars. After 1991, the decline in fish farming was the consequence both of encroachment on the delta by volcanic debris and of rainfall anomalies (Mialhe, 2010). Despite a post-eruptive upturn in aquacultural activity, fish farming in 1993 had only regained its 1989 footprint, indicating a pause in the previously ongoing growth spurt. This is explained by the occurrence of secondary (rain-triggered), post-eruptive lahars several years after the eruption. This caused a further massive transfer of debris to the western municipalities of the delta, clogging river channels, plugging drainage canals, and disrupting much of the resource base. Increased production costs in the wake of these sporadic events were felt as late as 2008.

During the 1960s and until 1976, fish ponds were clustered in a belt no more that 10 km wide along the coastal delta front. After 1976, however, aquacultural surfaces increased substantially. By 1989, pond density had increased and spatial distribution had expanded for the first time to more than 20 km inland. In 1991 and 1993, pond density in the outer delta belt decreased but expansion into the hinterland reached a 25 km radius from the seashore.

Until the 2000s, alongside rice or fish monoculture the cropping system in the Masantol area alternated between rice during the dry season and fish farming during the rainy season. This pattern reflected the urge to maintain some subsistence crops. However, aquaculture has since taken over as a perennial activity, with mixed farming being driven continuously further north and now subsisting only in the innermost confines of the Pampanga delta.

3. Model description

3.1. Field-based underpinnings

A livelihood framework was used to design surveys and questionnaires submitted to the farmers during extensive field visits. Use of such a framework allows a comprehensive analysis of household assets, vulnerabilities, strategies and outcomes. An agronomic survey was also conducted in order to characterize and evaluate the agronomic performance at both plot and farm scales. Social psychology theories of human behaviour (Jager et al., 2000) were adapted to our local empirical findings about behaviour among Pampanga farmers. In CHANOS, the main objective of farmers is to attain satisfaction through the completion of several objectives. All of these basic principles were implemented at the agent level. The description of the model in the following sections adheres to the ODD (overview, design concepts and details) protocol (Grimm et al., 2006, 2010). Netlogo, a program developed at the Center for