Miguel, Amblard, Barceló & Madella (eds.) Advances in Computational Social Science and Social Simulation
Barcelona: Autònoma University of Barcelona, 2014, DDD repository <http://ddd.uab.cat/record/125597>

Testing the resilience of agro-pastoralists communities in arid margins through ABM

Carla Lancelotti*†, Xavier Rubio-Campillo‡, Matthieu Salpeteur§, Andrea L. Balbo* ¶ and Marco Madella*¶ ‖
*CaSEs - Complexity and Socio-Ecological Research Group
†Department of Communication and Information Technologies, Universitat Pompeu Fabra, Barcelona
Email: carla.lancelotti@upf.edu
‡Barcelona Supercomputing Center
Email: xrubio@gmail.com
§ICTA- Universitat Autonoma de Barcelona
§IMF-CSIC, Barcelona
§ICREA and UPF, Barcelona

***Abstract*—This paper presents the latest model developed within Case Study 1 (hereafter CS1) of the SimulPast project: *Hunter-Gatherer persistence in arid margins. The case of North Gujarat (India)*. The aim of this model is to test the resilience of agro-pastoralists (AP) communities in semi-arid ecosystems. We created a simple Agent Based Model in which agents relied on a pure subsistence strategy based on domesticated plants and animals. We tested our model against previously published climatic record for the area and concluded that a pure agro-pastoral strategy was not enough to sustain the population in conditions of high climatic variability. Further tests were performed to check the climatic conditions in which this type of subsistence strategy is self-sustained in order to extrapolate the model to areas with different specificities than the one under-study.**

I. Introduction

The prevailing archaeological narrative on the dynamics of human occupation of North Gujarat during the Holocene, states that hunter-gatherer communities (HG) have occupied the territory for a long time span [1]. During part of this period, HG strategies have coexisted in close contact with incipient and more advanced AP societies. CS1 was devised to explore the causes behind the resilience of HG in this area, considering two possible factors that could perturb the system: a) climate variability and change, and b) indirect competition with groups relying on different subsistence strategies. Thus the model was split in several stages to understand the role of each of these factors and to tune the model according to the following steps:

1) The resilience of HG group is tested against climate [2]
2) The resilience of AP groups is tested against climate (this paper)
3) The two groups interacting in the same environment (next step)

A. North Gujarat: the role of Monsoon climate on human groups

North Gujarat is an ecotone in a semi-arid zone, characterised by monsoon dynamics, where small climatic shifts can have great repercussions on the environment and the availability of resources. Previous explorations have shown that strong seasonality is coherent with HG resilience and that yearly rainfall variability in these conditions has a greater effect on population dynamics than average yearly rainfall [2]. In other terms, HG populations are more affected by the uncertainty of rainfall quantity from one year to the next than from long-term climatic change.

II. The AP model

The present ABM explores the role of climate, agricultural production and surplus, and animal availability on the resilience of AP communities on a simplified version of the environment used for the previous simulations (for more details see the ODD protocol in [2]). The model was created based on ethnographic and historic data on AP societies of North Gujarat and calibrated with ecological data of small millets, the primary local crop that is still the basis of self-sustained agriculture in this area [3], [4]. The model was implemented in Python, using the Pandora framework [5] and following a number of software development practices known as eXtreme Programming (particularly Test-Driven Development and pair programming, see [6]).

A. Ground and Climatic engine

The world where the agents move is a 50x50-cells raster where cells are divided in three randomly distributed types (*dune*, *interdune* and *water*). The rainfall generated by the system follows the same distribution and data published in [2]. The environment state is tracked by the entity World, which takes care of generating the rain, updating the biomass quantity of the cells (depending on their state and type) and keeping track of the years in which each cell has been in a certain state.

1) Resources: Interdune type cells can be in one of three states: *wild*, *crop* and *fallow*. The agents derive their caloric intake form *crop* cells. The relationship rain-biomass-crop-calories is derived by ethnographic and ecological sources [7], [8] and it is based on species of small-millets. This is considered to be one of the first domesticated species in the area and it is the best adapted to the semi-arid environment of

North Gujarat. All the data considered regard rain-fed, manual agriculture, which is believed to be the closest to incipient cultivation systems. We use a single parameter for computing calories that are in fact a combination of both plant and animal-derived products (i.e. milk). We calculated that the calories that could be derived from animal by-products yearly correspond c. with the quantity of crops that are loss in each harvest [9], [10]. Thus, by not calculating crop loss we include animal by-products in a single parameter.

B. The AP agent

The agent is modelled as a couple with possible offsprings and the demography tracked yearly, based on the number of days in the year when the agent does not meet her caloric needs (starvation rate).

1) Agent creation and demography: Agent creation and demographic tracking follow the same model as presented in [2]. Each agent is composed of two individual, which, at the age of 15 look for a possible partner, defined as a individual of a different agent who is also older than 15. If any such individual is found, the two ”leave” their respective agent to form a new one. Agents have each year a stochastic probability *x* of generating new individuals.

2) Agent behaviour: Agent behaviour is focused on resource management. For this reason it includes 3 types of actions:

1) Search a suitable place where to settle: defined as a dune cell that has in the home range the number of plots needed for the agent to survive. The required quantity of plots (being each plot a cell) is based on yearly rainfall and the number of individuals that form the agent.
2) Manage farm activities: harvest the calories from the plots. *Wild* cells can be transformed in *crop* once the agents select them as their potential plot, they are maintained and used as *crop* for two years (if needed) and then abandoned at which point they turn into *fallow* for one year before converting back to wild and be available as plot.
3) Manage animals: in those cases when the agents do not meet their caloric intake with the crops they can use the calories provided by the meat of the animals in their herd.

III. Experiments

We run experiments to test the following parameters:

1) Agents mobility: how much the agents are willing to move in the landscape to find a suitable place to settle (as defined above). We evaluated whether the number of tries that the agents were allowed to look for a suitable place to settle and any influence on the population survival.
2) Climate uncertainty and storage: the effect of climate prediction and the possibility to store surplus. We tested the importance of short-term storage strategies to deal with high variability in rainfall patterns.
3) Reliability of a pure AP subsistence strategy: the amount of calories that need to be provided by sources other than the AP strategy in order for the population to survive. We investigated the limits of reliability of a pure AP strategy in the face of high rainfall variability and the climatic conditions needed for this threshold to increase/decrease.

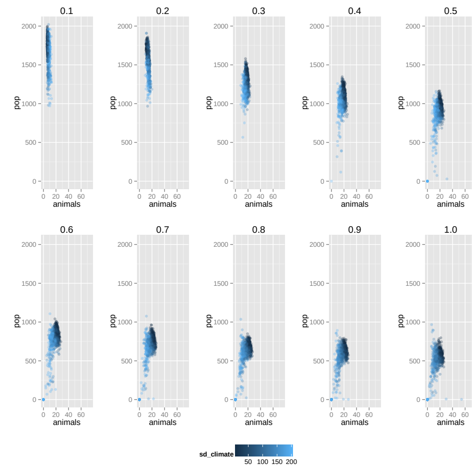

Fig. 1. Average population and quantity of animals depending on climate and how pure the AP strategy is. The lighter colour indicates sd of rainfall closer to the real; reliability on the strategies goes from 0.1 (only 10% of the needed calories are obtained form the AP strategy) to 1 (the entire caloric need in covered by a pure AP strategy

For each experiment 100 simulations were run for 5000 time steps (5000 years) with an initial population of 100 agents.

IV. Results

Results of the experiments showed that:

- Mobility is not an issue. Agents do not have difficulties in find a suitable place to settle and when they are allowed to try it twice, the population soon reaches the carrying capacity of the system.
- It is fundamental for the agent, in order to cope with the climatic variability of this system, to be able to store part of their harvest for at least one year. The simulations were tuned so that the agents were aiming at achieving 0.5 more than their requirements each year so that, in case of a ”bad” year they could survive.
- Notwithstanding this, for their survival agents could relay approximately only on getting 0.6 of their needed calories form the AP strategy (including both plants and animals). The remaining 0.4 calories needed to come form another source, different form their own cultivated plants or domesticated animals (Fig. 1).

V. Discussion

The present model is based on very simple agropastoral communities that practice a pure subsistence strategy and do not interact. The aim was to model a very incipient stage of agriculture and test its sustainability in an environment with very high climatic variability. The study-area chosen is and was in te past characterised by monsoon rainfall and is subjected to some of the widest extremes in terms of annual rainfall quantity, being at the same time very prone to droughts and flooding [2]. The inter-annual climatic variability is such that the probability for the AP agents to incur in two or more consecutive years whereby the rainfall amount falls outside the limits for plant growing is extremely high [2]. The logical consequence is that the population cannot survive based solely on a pure incipient agropastoralist strategy (as defined by the current model). It is to be noticed that in our model we used very tolerant values for the parametrisation of both plant ecological requirements as well as agents needs and workload capacity. Based on the results of our experiments, in order for the population to survive, at least 0.4 of the caloric intake need to come from a source different from the cultivated plants/domestic animals (e.g, trade, exchange, hunting and gathering etc). The archaeobotanical record has provided hints of possible exchange in the form of small quantities of wheat and barley grains recovered from some of the settlements excavated in this area (see [11] and bibliography therein).This has important implications for the historical interpretation of the dynamics of occupation of North Gujarat during the Holocene. Indeed, if we hypothesise that small farming communities that based their survival on the plants and animals most adapted to the area cannot rely completely on a pure AP strategy, large and complex settlements in this area had to rely on imports of food form outside probably much greater than what can be expected form the archaeobotanical record.

VI. Conclusions and Future Developments

The model presented testifies the importance of tackling the issue of subsistence strategy reliability when constructing narratives about past societies. Indeed, our work shows that in semi-arid areas with highly variable climatic regimes, a pure agropastoralist subsistence strategy was not sustainable. The next step in the exploration of this model will include testing the interaction between agents with different subsistence strategies and introducing mechanisms of interactions amongst agents. This will enlighten what are the most resilient strategies to cope with resource and climatic uncertainty as well as inform of what are the conditions in which pure strategies are most effective.

Acknowledgment

Funding for this work was provided by the SimulPast Consolider Ingenio project (CSD2010-00034) of the former Ministry for Science and Innovation of the Spanish Government. The authors would like to thank Guillem Francés and Alexis Torrano for the many fruitful discussions and all the members of CaSES (Complexity and Socio-Ecological Dynamics Research Group - 2014-SGR-1417) for the constant support.

References

[1] Ajithprasad, P. 2004. Holocene adaptations of the Mesolithic and Chalcolithic Settlements in North Gujarat. In Yasuda, Y. and Shinde, Vasant, Monsoon and Civilizations. Roli Books, New Delhi, pp. 115–132.

[2] Balbo, A. L., Rubio-Campillo, X., Rondelli, B., Ramírez, M., Lancelotti, C., Torrano, A., Salpeteur, M., Lipovetzky, N., Reyes-García, V., Montañola, C., Madella, M. 2014. Agent-based Simulation of Holocene monsoon precipitation patterns and hunter-gatherer population dynamics in semi-arid environments. J. Archaeol. Method Theory. 21(2), 426-446.

[3] Hill, P. 1989. Dry Farming Families. Hausaland (Nigeria) and Karnataka (India) Compared. Cambridge University Press, Cambridge.

[4] Shah, A.M. 2002. Exploring Indias Rural Past. A Gujarat Village in the Early Nineteenth Century. Oxford University Press, Oxford.

[5] Pandora dev. Team 2014. Pandora: an Agent-Based Modelling framework for large-scale distributed simulations. http://xrubio.github.io/pandora/

[6] Rubio-Campillo, X. and Lancelotti, C. (submitted). Extreme Modelling: developing social simulations with agile practices. JASSS.

[7] Put, M. and van Spengen, W. 1988. A comparative analysis of cereal production and consumption patterns in semi-arid India. J. Rural Stud. 4, 377-388.

[8] Hulse, J.H., Laing, E.M., and Pearson, O.E. 1980. Sorghum and the Millets: their Composition and Nutritive Value. Academic Press, New York.

[9] GLDB, Gujarat Livestock Development Board. http://gldb.org.in/cattle. Accessed June 2013.

[10] Ngere, O., McDowell, R.E., Bhattacharya, S. and Guha H. 1973. Factors influencing milk yield of Hariana Cattle. J. Anim. Sci. 37, 457-465.

[11] Pokharia, A.K., Kharakwal, J.S. and Srivastava, A. 2014. Archaeobotanical evidence of millets in the Indian subcontinent with some observations on their role in the Indus civilization. . Archaeol. Sci. 42, 442-455.