Dynamics of the Settlement Pattern in the Aksum Area (800-400 Bc). an ABM Preliminary Approach

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Abstract: In order to test the theories explaining the diachronic changes of the settlement pattern in the Aksum area (Ethiopia), a team, composed of African archaeologists and engineers, started an interdisciplinary research project. The project is based on the use of an Agent Based Modelling approach to create a dynamical settlement model of the earliest phases of development of the hierarchic societies in the region of Aksum (800-400 BC).

The model, based on palaeo-climatic, palaeo-environmental, geological, archaeological and ethnographical data, simulates different settlement patterns describing the rate of growth of population, the demographic density and aggregation at different scales and also considering the real distribution of resources on the ground. The preliminary results show how this approach can be useful for testing different hypothesis, as the outputs can be easily compared with real parameters observed in the available data. Moreover, new questions and issues emerged from the observation of tipping points which seem to determinate the rate and type of resilience of the simulated ecological system in the model.

Keywords: Agent Based Modelling, Simulation, Dynamic System, Aksum

Introduction

From about the mid-1st millennium BC, the area of Aksum, Central Tigray, northern Ethiopia, developed as one of several polities of the Tigrean plateau, progressively emerging as the capital city of a vast kingdom that flourished between the 1st century BC and the 7th/8th century AD (Fig.1). At its greatest extent, Aksum stretched its control as far as the Red Sea coast to the north-east, the Eritrean/Sudanese lowlands to the west and the Takazze River to the south, including during the first half of the 6th century AD part of south-western Arabia (Phillipson 2012: 47-50).

The appearance and evolution of complex societies on the highland regions of the northern Horn of Africa during the 1st millennium BC is strictly related to the interregional economic dynamics which had long before developed along the Red Sea and the Nile Valley, and that Aksum's emergence and expansion parallels its participation in long-distance exchanges (Fattovich *et al.* 2000: 21-6). Starting from the mid-1st millennium BC, Aksum was included in an exchange circuit which included the northern Horn of Africa, the Nile Valley, the Mediterranean, Southern Arabia, and, by the 1st/2nd century AD, the western coastal regions of India. The prominent role played by Aksum in these long-distance exchange activities significantly contributed to the increase of its social complexity and to the consolidation of its economic and political leadership over the Tigrean plateau.

Beside the traces of international exchanges, archaeological and historical sources provide further direct evidence of Aksum's progressive power and expansion, proving that during the 1st millennium AD the Aksumite kings erected unique monuments utilizing substantial quarrying and engineering skills and conducted victorious military campaigns in and out of Africa (Marrassini 2014).

1 The archaeological area of Aksum

Between 2005 and 2006 a systematic, comprehensive survey of the entire territory of Aksum was conducted in the framework of the Italian Archaeological Expedition at Aksum of the University of Naples 'L'Orientale' directed by Rodolfo Fattovich,[1] and of the World Bank *Ethiopian Cultural Heritage Project – Aksum branch – Site Planning and Conservation Component*, co-directed by Rodolfo Fattovich and Takla Hagos (Fattovich, Takla Hagos 2005). The data collected during these two intensive surface survey projects concurred to provide a complete archaeological map of the area of Aksum and to reconstruct changes that occurred in the ancient occupational dynamics and land-exploitation strategies in the area of Aksum in the light of the results of recent researches and of a well established chronological and cultural sequence (Bard *et al.* 2014: 285-313).

In addition, geological, geo-archaeological and environmental studies enabled the generation of thematic maps on soil productivity[2] (Schmid *et al.* 2008: 93-101), water resources distribution and slope gradient.

The combined analysis of all these data has resulted in a general reconstruction of the social, economic and political dynamics which characterized the emergence, development and decline of the so-called 'Kingdom of Aksum' and of the reasons for the location of its political core in the western sector of the generally rich highlands of northern Ethiopia. Favourable environmental and climatic conditions, namely the

[1] The survey by the Italian Archaeological Expedition at Aksum was the continuation of a project launched in 2000 by the Italian-American joint research project at Bieta Giyorgis co-directed by R. Fattovich and K. A. Bard (Fattovich, Bard 2002: 32-3).

[2] Soils classification has been also compared to the traditional system of soil evaluation presently used by local farmers.

FIG. 1. MAP OF ETHIOPIA AND GEOGRAPHICAL POSITION OF AKSUM.

abundance of water resources and productive soils (Sernicola 2008: 157-67; Sernicola, Sulas 2012: 562-3; Sulas *et al.* 2009: 2-15; Takla Hagos 2010: 139-56, the occurrence of a relatively stable humid phase between the 5th century BC and the 5th century AD (Machado, Gonzalez, Genito 1998: 312-21), and the effectiveness of a long established economic system based on mixed agricultural products and domesticated livestock allowed some Aksumites to invest their economic surplus in gaining control over the procurement and long-distance distribution of African goods and products. In this perspective, Aksum's location at the hub of a radiating network of river valleys along which a complex system of intra-regional and inter-regional communication and exchange routes developed undoubtedly played a significant role.

FIG. 2. THE AKSUM AREA.

2 A new approach: Agent Based Model (ABM)

In order to better test the archaeological theory about the evolution of the settlement pattern and the emergence of a progressively more centralized hierarchical society in the area of Aksum, a new approach based on ABM has been undertaken.

ABM is a useful method for simulating dynamics of a system's behaviour and observing the direction of change in respect of a case of study (Lake 2014; Wurzer *et al*. 2014)). It is based on agents that in archaeological research are frequently considered human beings (individuals or groups). Agents have knowledge, experience and reasoning and they act in artificial environment and interact reciprocally and with environment. This feedback produces a set of behaviours that define how the system evolves. In an archaeological and historical perspective, human beings, through interaction, create a network characterized by cluster of aggregates that change over time. ABM makes the archaeological data interpretations more explicit by codifying through rules time, environment and agents.

Furthermore, computer simulation generates a virtual human aggregation in a artificial environment whose patterns then could be compared with the archaeological hypothesis. To reach this target it is necessary to model our archaeological knowledge starting by defining a temporal and spatial resolution. At this stage of the research we focused on the passage between the pre-Aksumite and the Proto-Aksumite periods (ca. 800-50 BC), the latter being the formative phase of the subsequent Aksumite kingdom and culture.

GIS analysis carried out in a previous research on the area showed that since the 1st millennium BC, settlement locations were always selected according to three major environmental factors (Fig. 3):

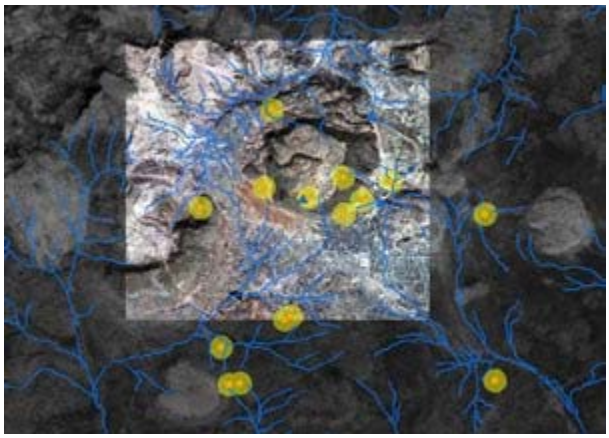


Fig. 3. Settlement pattern along the river network during the Proto-Aksumite phase (elaborated by Sernicola 2008).

Fig. 4. Modern compound.

A. close proximity to water resources (all settlements were located no more than 250m from rivers, streams or water cisterns);

B. close proximity to productive soils (all settlements were located within or along the borders of more fertile soils generated by volcanic rocks);

C. slope gradient (Sernicola, 2008; Sernicola, Sulas 2012).

Data from field survey and GIS-based settlement pattern analysis were fundamental for the implementation of the ABM simulation as they provided information on the different types of settlements, their density and quantitative changes through time.

Geo-archaeological investigations suggest a remarkable stability and resilience of the landscape in the region of Aksum over the whole 1st millennium BC/1st millennium AD period (Ciampalini *et al.* 2008: 18-27; French *et al.* 2009: 218-33). Results from pollen analysis point to a vegetation cover characterised by a predominance of herbaceous species and small trees; palaeo-zoological and archaeological evidence demonstrates that during the pre-Aksumite period local communities already relied on the ox-plough agricultural complex and suggests the presence of a relatively wide range of cultivated crops.

Regarding the choice of agent and their relative granularity (individual, group, population), which involves specific logics of interaction, settlement pattern reconstruction suggests that during the 'pre-Aksumite' period (ca. 800-400 BC), the settlement pattern at Aksum was characterized by scattered isolated compounds, hamlets and small villages (Sernicola, 2008; Sernicola, Sulas, 2012). The difference between these three levels of aggregation depends on the size of the sites, witnessed by archaeological investigations, and in a social view on the number of households. For these reasons we decided to identify as low level of aggregation the household.

Available materials from surface surveys and archaeological excavations point to the absence in the area of a strong political focus in this period although a social hierarchy presumably existed, as suggested by the presence of structures with more massive walls and administrative devices in the pre-Aksumite levels at Kidane Mehret (Phillipson 2000). In this first phase, during which a hierarchical society (traditionally identified as D'MT)[3] emerged and declined on the Ethiopia/Eritrean highlands,[4] Aksum was apparently a minor centre based on agriculture with respect to nearby sites,[5] where evidence of temples and other monumental buildings has been recorded. In our model we assumed all inhabitants of the Aksum area were farmers, because no archaeological evidences testify a hierarchy.

The agents have properties that qualify them as households; these properties are relevant in defining set of rules of interaction (agent-agent and agent-environment) that generate the set of behaviours.

As pre-Aksumite and Proto-Aksumite social structures are still scarcely known, the archaeological evidence has been integrated with ethnographic evidence (Fig. 4). Particularly, the ethnographic investigations conducted in 1974 provided significant, additional information on the social environment: general dimension of households, creation of new households, public spaces, kinship relations and neighbourhood policy, and subsistence economy. So far very few can be said on ancient land tenure strategies due to the paucity of available historical data.

The results of simulations in terms of demographic growth, number of aggregations and type of aggregations are compared with archaeological data corresponding to the Proto-Axumite period.

Between 400-50 BC, during the Proto-Aksumite period, a changed settlement pattern possibly mirrors substantial social and economic changes. The increase in the number of settlements and of their spatial aggregation, the appearance

[3] For the debate on the so-called 'Pre-Aksumite' culture and for a comprehensive, updated discussion on the D'MT, see Fattovich 2012: 1-60 and Phillipson 2009: 257-74.

[4] Having its religious/political core at Yeha.

[5] I.e. Seglamen and Hawelti, respectively 12km to the south-west and 15km to the south-east of Aksum.

on the hilltop of Beta Giyorgis of a monumental residential complex and of a royal cemetery point to a tendency towards a social hierarchy in the area. The presence of a wide range of imported items from the Nile Valley suggests that this process is probably related to the gradual increase of the role played by Aksum in inter-regional exchange networks.

3 Methods

In order to understand the dynamics involved in the formation of the Proto-Aksumite society, some essential aspects of the rural population have been analysed. In particular we took into account climatic and environmental factors which focus on mechanisms stimulating aggregation process. The model describes agents farming the landscape, aggregating in settlements, sharing resources with other agents or settlements and moving to new locations. A bottom-up design technology has been used in modelling the evolution of settlement systems. This approach is mainly based on pre-decided set of rules for individual behaviour and local interaction, starting from a set of rural settlements.

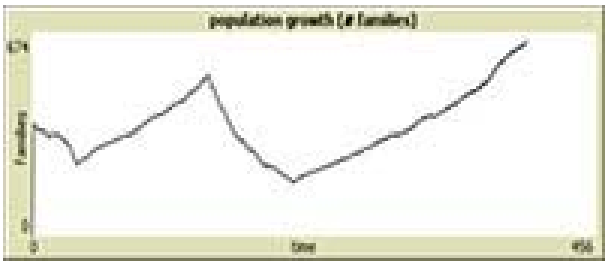
The model or the settlement area of Axum was implemented by Netlogo, a programmable modelling environment for simulating natural and social phenomena. This software has been already used to build many models to simulate the interaction between environment and human in a specific time-span (Janssen 2009)

We may briefly sum up the characteristics of the model according to the categories of ODD methodology (Grimm *et al.* 2006), which stands for 'Overview, Design concepts and Details'. Of these categories, the Overview category is broken down into three sections: Purpose, State Variables and Scales and Process Overview and Scheduling; and the Details category has 3 sections: Initialization, Input and Submodels.

Purpose. Three concepts are defined: i) The 'compound' as an isolated household. It does not share its space with other agents and has no neighbours; ii) The 'hamlet' as an organized space consisting of more than one household. In the simulation, hamlets correspond to patches that include a number of agents >1; iii) a 'village' as an agglomeration of hamlets. Archaeological researches showed that these different types of spatial aggregation co-existed; we can find isolated compounds populated for a long period by a single household, and meantime aggregations of multiple households in hamlets or villages. The purpose of the Agent-based model is to find possible simple explanations of the dynamics that result in new hamlets and villages, starting from a near-random distribution of families in compounds.

State Variables and Scales. The geographical space is represented by a grid of 100 x 100 cells. Each cell or patch reproduces the natural environment of Aksum region, with plains, hills, and a network of rivers. Moreover, patches are characterized by natural and agricultural resources which can be exploited by the population. The moving agents are the Families. They reproduce and move within the geographical space according to processes defined as follows. In the simulation time zero corresponds to the Pre-Aksumite period (ca. 800 BC). The model runs for 400 years in annual time steps, until the Proto-Aksumite period. During this time-span the population organize itself in groups. Each aggregate, such as compound,

Tab. 1. Growth rate of household based on the parameters: mobility rate 0.1, growth rate of population 2, and periods of drought and epidemics.



hamlet and village, includes only one agent moving in a 2D virtual landscape Process Overview and Scheduling. There are four processes defined: i) 'harvesting': updating of resources of the agent. The amount is equal to the productivity of the patch where the agent lives in. ii) 'reproducing': updating of household of reproductive age according to the number of the members. iii) 'settling': 90% of the new households occupies the patch near to their family of origin, sharing the same landscape and the same resources. A percentage equal to the mobility rate is localized away from the family of origin. iv) 'aggregating': families, without resources, are aggregate to the neighbours.

Design Concepts. Families are the moving agents, while territorial cells are the fixed agents (patches) of the simulation. The parameters controlling the simulation are: i) two shock events: drought (2 values: ON/OFF) and epidemy (2 values: ON/OFF); ii) mobility-rate (3 values: 0.01 (minimum), 0.05 (intermediate), 0.10 (maximum)); iii) birth-rate (3 values: 2, 3, 4 years). These parameters control the following variables: i) the demographic growth of agents; ii) the explorative capability of agents; iii) the exploitation capability of agents; iv) the resilience of agents. Experiments aim at testing the space of all the possible 'behaviours' of the models.

We made 18 different experiments, according to significant combinations of parameters. Any experiment was replicated 50 times. Each run lasted 400 ticks. For each run we collected the average and the variance of the following variables: i) total number of agents; ii) the number of isolated compounds; ii) the number of hamlets; iii) the density agents. These outputs have been tested through a bilateral T-Student test in order verify the accordance between the 'field' value and the 'virtual-lab' value. Most significant experiments were characterized by a birth-rate equal to 2, mobility-rate equal to 0.1 and shock events ON.

Initialization and Input. Inputs of simulations are Natural-Resources (soil productivity and water resources) and Families. Both these variables are distributed on the territory' cells. Families may share the same patch if the soil productivity and proximity to water resources (< 250 m) let them to survive. The Montecarlo method has been introduced to avoid the deterministic effects of simple assumptions.

No submodels are present.

4 Results

Thanks to this approach we tested aggregation in an ecological perspective. Simple rules of individual behaviour and local

Tab. 2. Simulation results with mobility rate 0.1, growth rate of population 2, and periods of drought and epidemics.

	HOUSEHOLDS	COMPOUNDS	HAMLETS	DENSITY
MEDIA 50 RUN	899,06	6,2	27,34	8,9906
VAR	197534,4249	28	253,3718367	19,75344249
SIGMA	444,4484502	5,291502622	15,91765802	4,444484502
μ0 =	726	6	12	7,7
t=	2,753342924	0,267261242	6,814456004	2,05331352
g1	0,90	1,04	0,71	0,90
g2	0,32	0,10	-0,25	0,32
g1/s1	2,58	2,97	2,03	2,58
g2/s2	0,46	0,15	-0,36	0,46
intervals	[793; 1004]	[4.9; 7.5]	[23.6; 31.2]	[7.9; 10]

interaction explained the self-organization of the system and specific parameter values the quantitative distribution of settlements. High mobility rate 0.1, high growth rate of population 2, and periods of drought and epidemics reproduced rather well a plausible distribution of settlements during the examined 400 years, very similar to the reconstruction taken by the archaeological evidences (tab 1 and tab. 2). The exploration dynamics explain the high mobility rate and give rise to exploitation capacity of resources, producing self-organization of the agents. The high demographic growth, depending on the reproduction rate, is normal in an ancient rural community, which needs labour force. The simulation shows a growth rate of 2 showing an acceptable value of the population over the Proto-Aksumite period. The ethnographical studies on the rural traditional households in the Tigray region, which have a lifestyle similar to the Aksumites in terms of space organization and land management, suggest a growth rate of 3.

The graph in Tab. 1 shows the growth rate of the households over all Pre-Aksumite period. The line in the graph is one of the possible trajectories that the system can assume after each run based on a particular set of values. In this simulation the values of variables sent on mobility rate =0.1, reproduction=2 and shock events=ON, have produced an interesting patterns that, notwithstanding it includes some negative points, seems show a constant increasing of the population. While the shock event push down the growth rate of households, the reproduction and the mobility indexes represent the capability of the system to adopt a flexible behaviours able to equalize the increasing.

The mobility allows the agents to explore all the space, producing not only the formation of new settlements or isolated compounds but, in our case, the growth of particular sites as well as the formation of hubs. The high mobility rate is a crucial factor explaining the movement of individuals or groups in the territory. The agents explore and exploit new opportunities. According to archaeological data, the Aksumite economy was based on the farming management, the use of large mammals (oxen) to plough the fields, and small mammals (goats and sheep).

As the ecological rules appear to better explain the settlement pattern of early Proto-Aksumite time, most likely the élite component did not influence the land tenure and the aggregation of the rural system. The archaeological evidences record no élite administrative/residential buildings at Aksum between 800 and 400 BC suggesting that other areas (Yeha, Matara, Seglamen, Houlti) served as political foci at that time. Only between the late pre-Aksumite and early Proto-Aksumite period (ca. 500-400 BC) traces of a local élite progressively appear as a starting point of a process of progressive hierarchy which culminated with the emergence of Aksum as a capital city (Sernicola 2008; Sernicola, Sulas 2012). Probably the presence and increase of the élite component was a product of self-organization of the system, the growth rate of population and aggregations that, in a complex network, induced the formation of preferential hubs.

6 Conclusion

The results reached in this first preliminary work are encouraging. In the future we plan to investigate when the system reached the threshold and innovations became necessary for carrying out the growth of the system and developing its hierarchical structure. For doing this, it is necessary to take into consideration further aspects, such as land-management strategies, joint efforts, exchange networks. Furthermore, the properties of agents will be implemented by considering also different specializations (potters, lithic workers, merchants, etc.). Climatic fluctuations will be introduced as well. All these elements, codified as set of rules and/or parameters, would provide different behavioural scenarios. Our goal is to increase the number of simulations in order to observe the possible evolution(s) of the system, outline the trajectories of the changes and, hopefully, observe the emergence of new properties and relationships within Aksum's ancient socio-natural system.

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