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FOOD, DISTANCE AND POWER. MODELING A MULTI-FACTOR PROTO-HISTORIC LANDSCAPE IN THE PO PLAIN

1. Introduction

AMPBV simulator is a Spatial Agent Based Model (SABM) developed in Netlogo software and programming language (Wilensky, Rand 2015) to analyze, through a simulative approach, the case study of the Northern Terramare polity in the Valli Grandi Veronesi (Fig. 1). The model is the latest research tool developed as part of the AMPBV (Alto Medio Polesine – Bassa Veronese) project, active since 1982 under the direction of Prof. Armando De Guio and mainly focused on archaeological investigation through non-impact (or minimal impact) techniques (De Guio *et al.* 2015). The model purpose is to take advantage of ABM bottom-up logic to better understand the processess and the main factors that may have led the protohistoric communities of the North-Eastern Po plain, from their peak to an almost sudden collapse. The goal, in particular, is to assess the impact of climate changes on the settlements survival.

2. From the Terramare landscape to a digital environment

The rise of the Terramare culture was one of the most significant and impacting phenomena in Northern Italian Protohistory. The Terramare society acquired in short time the typical traits of a polity, with «a level of complexity comparable to a simple chiefdom» (De Guio 1997, 155). A rapid demographic increase had also led to a major territorial reconfiguration: the new settlement system was hierarchically hinged on a few larger villages ("first rank settlements") such as Castello del Tartaro, Fabbrica dei Soci or Fondo Paviani sites. The repercussions on the landscape were considerable, mainly due to intensive land exploitation for structure building and agriculture, to meet the growing necessity of food production. Traces of Terramare occupation are still detectable from both field surveys and remote sensing (Burigana, Magnini 2017); the abundant evidence collected so far in the area, as well as experimental data, served as a fundamental source of information to set some key-aspects of this complex anthropogenic system and to choose how to represent them in our model.

As in any ABM, AMPBV simulator includes, in addition to multiple agents, an environment and a set of rules defining the simulation processes (Epstein, Axtell 1996). Being a SABM, it relies on physical space as an explicit component (Manson *et al.* 2020). The main class of agents represented

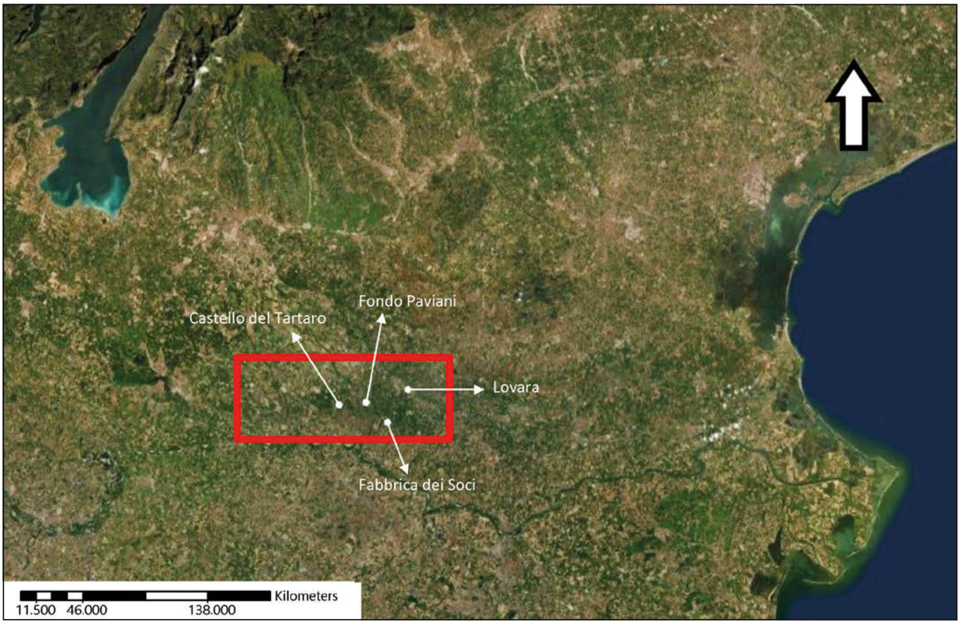

Fig. 1 – Framing and localization of the investigated area.

(*sites*) are the sites local communities, which have as their primary goal their own survival. Despite being stationary, sites behave like alive entities, they communicate and relate to each other, they produce, grow, suffer, and can eventually die. According to the implemented ruleset (Fig. 2), in order to survive sites need to provide enough food to their population, by producing it or by purchasing it through exchange. As the reference food resource we considered cereals (taking into account five different crop species), as they were likely to be the main component (approximately the 70%) of nutritional intake (Cattani *et al.* 2021).

In this context, spatial distance and resources of the physical landscape, but also the exchange network play a crucial role in the balance of the system. Therefore, the environment in AMPBV simulator has been reproduced in multiple forms, taking advantage of different representation entities in Netlogo:

– A "relational landscape" of inter-sites economic power in which inter-site relations are visualized as "relational links".
– A mobility environment as a regular network of "connective links", with values based on travel cost.
– A landscape of "patches", representing the territory physical features and related to movement and resource management. Both links and patches are

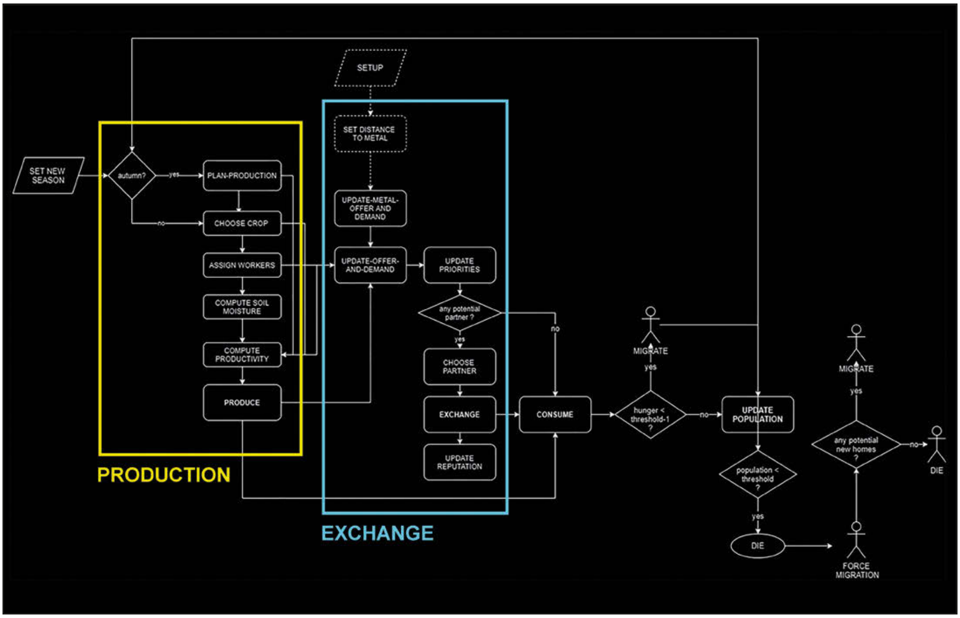

Fig. 2 – Flowchart of a full cycle in AMPBV simulator.

assigned specific attributes related to their functionalities in the simulation. Patches in particular have a set of attributes which were defined according to source data:

– high spatial resolution climate maps in raster format, as a reference for seasonal precipitation and temperatures (Fordham *et al.* 2017);
– contemporary regional pedological maps;
– post-processed Digital Terrain Model (DTM);
– archaeological and botanical data;
– paleo-hydrographic reconstruction based on geological analysis (lastly Balista 2018).

The system behavior (agent choices, alteration of global variables), affects the virtual landscape transformation, thus the patches attributes.

3. Cultivating a landscape of virtual patches

Each cycle, patches go through a seasonal update in which new local temperature and precipitation values are set. As a first step in the production process, the sites define their own catchment area by occupying the space needed, for resource exploitation, namely for grain cultivation. To attain a good production, cultivated patches need a high productivity, which is expressed as an attribute. Each patch productivity depends directly on some key local variables:

– Workers, the sites employed manpower.
– Soil fertility, a value randomly assigned to each patch at the start of the simulation that decreases each cycle with land use.
– Soil moisture.
– Local temperature.
– The crop type cultivated on the patch (patch attribute). Agents pick the most suitable species according to the current season and an estimate of soil moisture, the latter depending on both current and previous soil moisture values.

Except for workers, calculated accordingly to the number of inhabitants and the number of cultivated patches of a site, the mentioned variables are directly or indirectly related to climate. An attribute particularly sensitive to climatic variations is soil moisture, which has a fundamental role in the production process, being also involved in the agents predictivity and adaptivity (in the choice of the cereal species to grow) (Burigana, De Guio 2022). Local precipitation has a different impact on a patch soil moisture depending on local soil texture class. The soil textures were extracted from contemporary data, by merging regional soil maps of Veneto and Lombardia into a unified raster image. The regional maps soil information refer to the first meter in depth from the current ground level. Although we know that the surface and to some extent the composition of the soil has certainly changed after more than 3000 years of human activity, it was deemed acceptable to use contemporary data. Indeed, in several archaeological areas investigated and excavated in recent years, Bronze Age stratigraphic units were found to be already exposed at the surface, which is mainly due to the repeated plowing of mechanized agricultural activity. Average values of field capacity, saturation point and capillary fringe thickness were derived from the soil texture data as key-parameters for calculating soil moisture through a very simplified water balance formula:

Soil Moisture = precipitation + groundwater – evapotranspiration

in which groundwater (considering a depth of 1 m and an extent of 1 ha) is the sum of the water in the saturation zone, whereas the water in the capillary fringe (half the saturation point plus half the field capacity local values) and evapotranspiration is calculated according to Hargraves (Hargraves, Samani 1982, 1985) as:

$$\text{ET0 (mm d-1)} = 0{,}0023\ \text{R0}\ (\text{T}+17{,}8)\ \Delta\text{T}\ 0{,}5$$

General precipitation and temperatures, integrated into the model as global variables (globals), are the outcome of a random draw at the beginning of each new cycle (taking into account a seasonal reference value).

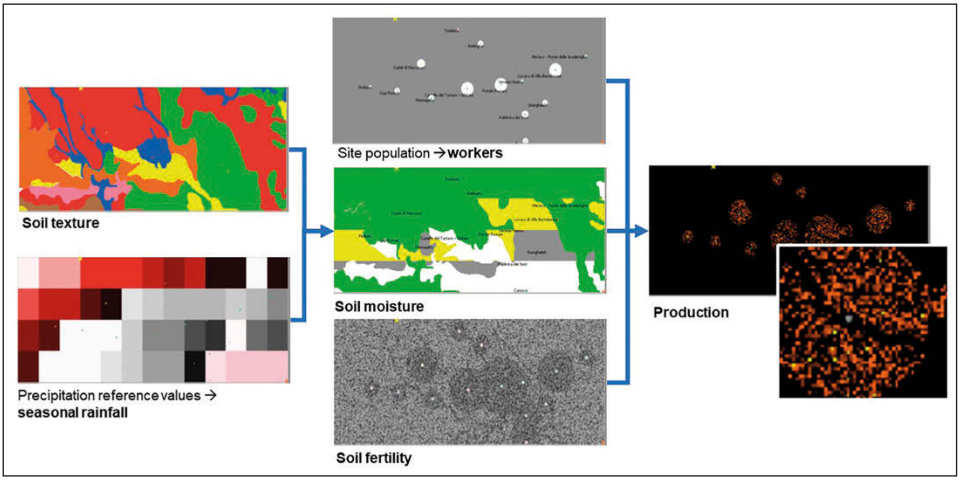

Fig. 3 – Information layers involved in the agricultural production process.

The resulting value is subsequently transmitted to each patch and adjusted according to the local climate zone. Both the reference values and the spatial distribution of climatic zones are derived from the seasonal climate maps, implemented as a georeferenced source data by means of Netlogo GIS extension. Soil moisture (along with the other parameters mentioned above) impacts each cultivated patch production differently, depending on the compatibility of the cultivated species. As a result of the whole production process, a new information level emerges (Fig. 3), working as a sort of resource map in which the sites can convert their cells production in expendable calories for their population.

4. Weaving link landscapes

Archaeological record suggests that, in addition to local production, Terramare communities were involved in economic and political relations between sites (intra-polity relations), as well as with other polities (inter-polity relations), in which they exchanged food, but also raw material, handicraft and a variety of other goods. We should assume that in many cases man labor was also a term of trade, being employed massively both in field work and in the construction of large structures and infrastructures (De Guio *et al.* 2015). Since it is likely that the settlements also relied on profitable connections (which may have been crucial at some point) for their survival, a schematic representation of the exchanges between sites has been attempted. In modelling a prediction of how sites choose to trade (and with whom they choose to trade), we took into account both adaptive behaviour of agents in assessing travel costs and political-economic influences based on past trade. Both of these aspects were represented in the AMPBV simulator in the form of networks.

4.1 *Travel cost assessments in the connective network*

To simulate movement cost in a physical environment we created a regular network of links (connective links, Fig. 4) georeferenced to our reference map data. Each of these links has an attribute (weight) whose value depends on the local landscape attributes, meaning spatially located features facilitating or hindering movement. Having considered, among these, the terrain slope (although in the lowlands it is not such an impactful factor on movement as in other contexts) we processed our DTM source image to get rid of the most evident "background noise" of modern elements, such as roads, canals, visible straight tracks, and also the present course of the Adige River. The weight of the connective links is calculated as the product of slope friction (quantified

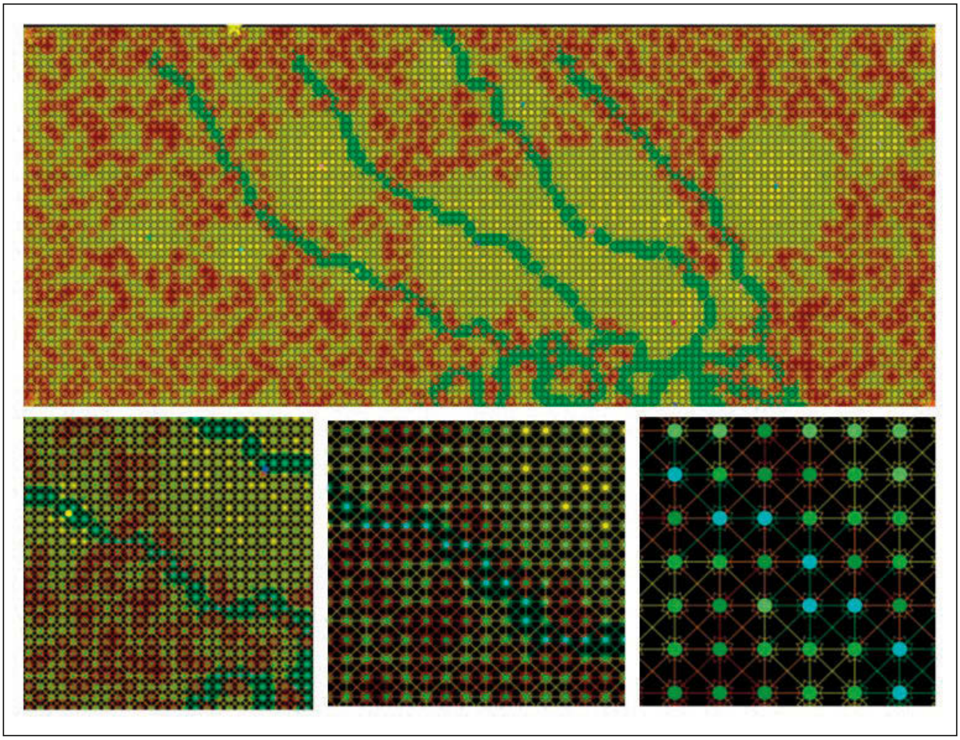

Fig. 4 – Multi-scale visualization of the connective links network.

as metabolic energy cost of walking (CW), according to Minetti *et al.* 2002) and the PAR (Physical Activity Rate, calculated as the ratio of energy cost to basal metabolic rate, see Vaz *et al.* 2005) estimated for human movement in different landscape types, including water:

Connective link weight = terrain type PAR * slope CW

Water patches play an ambivalent role, as rivers require a significant amount of energy to cross but, on the other end, they can be useful navigable waterways. To reconstruct the protohistoric rivers we used both the paleo-hydrological maps and remote imagery, in which we observed soilmarks and cropmarks spatially associated with the coeval settlements.

Two kinds of locations that certainly require a more intensive activity to traverse are forests and muddy grounds. In the simulator, muddy patches are identified as the cells with the highest values of soil moisture. As for forests, although significantly reduced by the end of the Late Bronze Age (Cremaschi 2017), they but still occupied a significant amount of space, especially outside the sites closest catchment areas. We have not yet attempted a precise reconstruction of the forest cover; forest patches are assigned randomly during the setup procedure, according to a percentage set by the user (so far, we tested considering a 40%). Unlike river locations and land elevations, forest cover and muddy soils in AMPBV simulator are characteristics that can change over time depending on the behavior of the system. Both land use and climatic variations, in fact, can transform the patches, which can take on label such as “mud”, “grass” or “forest”. The inter-site weighted distances, and thus the shortest paths connecting each site to the others, are updated each cycle according to Dijkstra algorithm (Dijkstra 1959), implemented in Netlogo extension Network Analysis.

4.2 *Building reputation in the relational network*

The last instance of our multilevel environment is an “economic power landscape” (or “mindscape”) where the multitude of relations between sites is represented as a network of “relational links”. The value of these links “reputation” attribute increases proportionally to the number of successful exchanges occurred between the two linked sites. Because reputation is an eligibility criterion (along with weighted distance and supply-demand compatibility) when choosing an exchange partner, sites that have gained more reputation over time have a greater chance of exchanging in the future, thus a greater chance of survival in case of low individual production. Sites in AMPBV simulator can exchange food (cereals), metal and workers. To correlate “goods” so differently commensurable, supply and demand for each are expressed as percentage values, relative to the general availability and necessity within the entire system.

For food, these values depend on the reserve and the local population. There may be a shortage or surplus of workers, depending on the adult population and the number of patches to be cultivated. In the case of the metal, availability is calculated as "purchasing power" taking into account the distance to the Alpine copper mining areas, while demand depends on a "redistribution potential" of the raw material (i.e. reputation with agents located further away from the copper route) and local need (given by the number of inhabitants). Thus, the supply and demand for food and workers depends essentially on the outcome of the production process, while for metal, both physical and economic connectivity is crucial, associated partly with production (which transforms the landscape), but mainly with the outcome of the exchange process.

5. Testing and preliminary results

The model is still undergoing tests and technical adjustments, but some preliminary analyses have already been carried out for an initial assessment of the impact of climate on our complex artificial system. In a first survival test, three simulation scenarios were compared by inducing a temporary climate crisis (3 years of drought) at different times (after 5, 20 and 35 years from the start). In general, soil moisture certainly emerges as a factor that is very sensitive to climatic fluctuations, but the comparative analysis also revealed other determining factors for polity survival. While inducing climatic stress after only 5 years showed good resilience, with site survival comparable to the simulation without stress, a different situation was recorded in the other two scenarios, where collapse occurs in less than 10 years. This can be explained by a greater vulnerability of the system, given the impoverishment of the soil at a chronologically more advanced stage.

Lower fertility also implies a greater need for productive space: sites see reduced production possibilities at a time of maximum extension of their catchment areas. It is likely that an unexpected climate change had a more critical impact on an area already compromised by intense colonisation. Moreover, it is possible that, with the local production crisis, the survival of the sites depended more on their political-economic ties. Further analyses, at a more advanced stage of experimentation, will hopefully yield more results. The data collected so far, in any case, suggest the importance of space and landscape representation in its complexity as both a physical and social element. ABM allows us to observe the dynamic evolution of a multifactorial and multi-informative environment, but also to understand the evolution of its different constituent elements and their interaction with the active agents of the system.

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ABSTRACT

The paper illustrates the creation and integration of the environment as a multilevel landscape in AMPBV Simulator, a spatial Agent-Based Model (ABM) developed in NetLogo programming language. The model was conceived with the aim of investigating, through a simulative approach, the events and the circumstances (both anthropic and environmental) that presumably led, between the end of the Late Bronze Age, in the 12th cent. BC, and the beginning of the Final Bronze Age, the protohistoric communities of the Southern Verona plain (known as the Northern Terramare polity) from a climatic phase of maximum development and articulation to an anti-climatic phase of sudden collapse. The study context is an interesting application for an investigation through ABM, both because of the complexity of the case scenario, in which several interrelated actors and factors must have played an important role, and because of the availability of a number of geographical and archaeological data providing both a term of comparison and an excellent information base. With the development of an artificial environment and by modeling processes potentially critical for the fate of the Terramare system, the aim is, on the one hand, to give such a complex study case a new tool for historical analysis and, on the other hand, to experiment Agent-Based Modeling and assess its potential as a methodology for archaeological investigation in the Po Plain.