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A PREDICTIVE MODEL TO INVESTIGATE THE AGRO-PASTORAL EXPLOITATION OF ANCIENT LANDSCAPES

1. Introduction

The purpose of this paper is to present a predictive model – created inside the software ArcMap using FAO's "Land Evaluation" techniques (FAO 1976) – able to identify, in a landscape, the most suitable area for the agro-pastoral exploitation. Thanks to this model it is possible to carry out a series of analyses capable of reconstructing the landscape exploited by a settlement and to predict both its animal and plant production as well as the maximum sustainable demography of the site. Before proceeding with the technical explanation of the proposed methodology, the approach – defined as "agro-economistic" (Sotgia 2021) – will be framed within the archaeological theoretical reflection.

Once the agro-pastoral model's genesis is illustrated, its application on a case study (the Final Bronze age settlements of *Ager Tarquiniorum*) extracted from a PhD research on the primary economy of protohistoric communities of Southern Etruria (Sotgia 2023) will be shown. However, the model created can also be applied to other cultural and chronological contexts with very few modifications, as underlined in the final notes that conclude the text.

2. Theoretical background

Studies about agro-pastoral production can be found in numerous researches covering all chronological periods analyzed by the archaeological discipline. That is because it is very useful to focus on this theme to make interesting historical reconstructions of the actions of ancient communities. The exploitation of landscape resources has in fact always been the main type of relationship between humans and the environment in which they live. Agriculture represents, moreover, one of the most complex levels of these relations and especially for protohistoric communities for which it is the most evident sign of landscape transformation.

This approach can be found in the works of Clarke's Palaeoeconomy (Clarke 1952) and the Cambridge School of Higgs and Vita-Finzi (Higgs 1975), as well as in some interpretations of Processual archeology about the key role of environment. Moreover, the choice to focus on the forms of agro-pastoral exploitation is due to the belief, derived from Marxist archaeology (McGuire 2002), that by examining the economic components of a society it is also possible to understand its social and political aspects.

Especially, if we consider – as in this case for the Protohistory – that political power was based above all on the administration of primary goods by the elites – as theorized by T. Earle (2015) with his concept of bottleneck, or vice-versa from the community management of these specific goods by the entire community, as pointed out by Hardt and Negri (2009) in their work on the commons.

3. Model creation

To simplify and speed up the analysis, a predictive model was therefore created, capable of identifying the most suitable areas of a landscape and a related ArcGIS tool was developed to calculate the various quantitative aspects connected to this production. The agro-pastoral model was obtained by applying to the landscape the modern "Land Evaluation". This method aims to quantify the suitability of a land for agro-pastoral exploitation with a system of descendant quality classes generated through the analysis of some environmental factors, fundamental for agricultural and pastoral practices. These factors are analysed basing both on the specific needs of the plants cultivated and of the animal species and also on the degree of development of the agro-pastoral techniques and knowledge of the communities examined. To obtain this kind of information and translate this technique in an archaeological perspective (as proposed by Van Joolen 2003 and Goodchild 2007), data coming from survey and excavation were considered: coaring, pollen diagrams, palaeobotanical and archaeozoological remains, as well as studies on premodern agricultural techniques and informations from Latin agronomists (Columella, Pliny, Varro, etc.).

In the landscape, indicators of suitability relating to agricultural exploitation are clearly visible, while pastoral exploitation can usually be derived only from the altitude of and the presence of water in the areas (Veenman 2002, 271). Therefore, initially were defined the most suitable areas for cultivation and only later a portion of these was assigned to the pastures. The model illustrated is related to the Final Bronze Age system and it is characterized by the cultivation of wheat, olive, vine, and legumes as well as to the breeding of goats, cattle, and pigs. The analysis was carried out within a GIS using various tools for the creation of raster maps formed by cells, each of which reported the degree (from 1 poor to 10 optimal) of agro-pastoral suitability relating to the various factors considered.

The following factors were examined:

– The slope of the land, as it affects productivity.
– The altitude (with relative maximum and minimum temperatures attested), which acts on the physiological activity and on the regulation of the development of the flora.

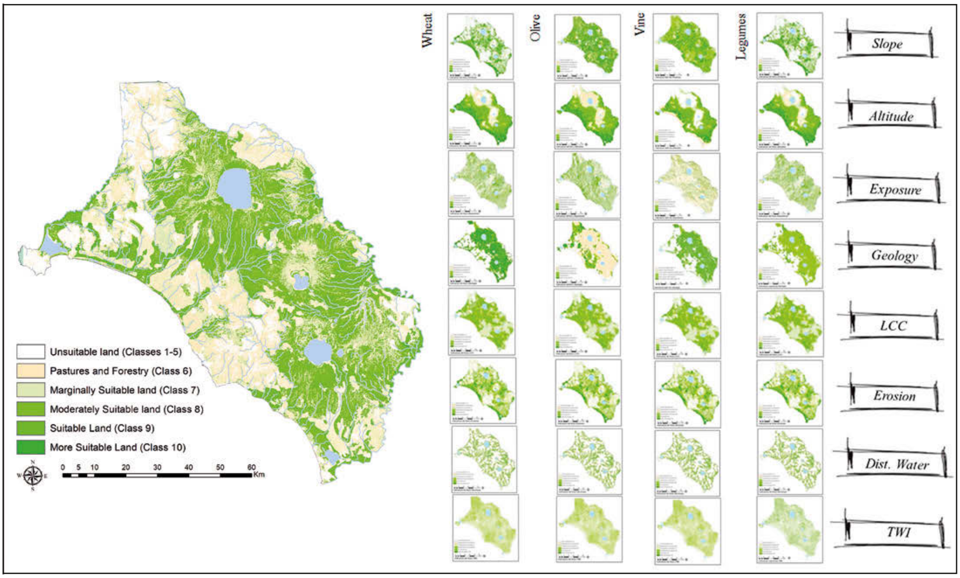


Fig. 1 – Definitive agro-pastoral convenience land model and single factorial maps considered.

– The exposure to sunlight, necessary for the fundamental photosynthesis of plants.
– The geological component of the soil considered both in terms of physic-chemical properties suitable for different crops, and in terms of easy workability of the soil.
– The land propensity/capability for agro-forestry-pastoral production without degradation.
– The distance from the water resource indispensable for the life of every plant organism.
– The presence of water in the soil calculated by the Topographical Wetness Index (Sørensen *et al.* 2006).
– The effect of the erosive phenomenon on the landscape.

All the factors were initially considered autonomously, through the creation of convenience maps (Fig. 1), and later considered all together through a particular multi-criteria analysis: the Analytical Hierarchy Process. In the next lines, the various steps taken to obtain the definitive agro-pastoral model will be generally illustrated, while in Figs. 2-3 the detailed values relating to the different plant species are reported.

Regarding the geology of the soils, after digitizing manually the geological map from one to five million of the area, and converting the polygon to raster,

	Wheat	Olive	Vine	Legumes
Slope				
Analytic Hierarchy Process	17	18	18	15
0 – 1 %	10	1	1	10
1 – 2 %			10	
2 – 8 %	10	10	9	10
8 – 13 %	7	10	8	7
13 – 25 %	5	10	7	5
25 – 35 %	2	6	7	2
> 35 %	1		1	1
> 55 %		1		
Altitude				
Analytic Hierarchy Process	7	10	4	3
0 – 33 m	10	10	6	10
33 – 100 m	10	10	10	10
100 – 200 m	9	9	9	9
200 – 300 m	8	8	8	8
300 – 400 m	7	7	7	7
400 – 500 m	6	6	1	6
500 – 600 m	5	6		5
600 – 700 m	4	6		4
700 – 800 m	3	1		3
800 – 900 m	2			2
900 – 1000 m	1			1
Exposure				
Analytic Hierarchy Process	7	9	9	6
Nord	1	6	10	1
Nord-Est	6	1	10	6
Est	10	1	6	10
Sud - Est	10	1	6	10
Sud	10	6	6	10
Sud-Ovest	6	10	1	6
Ovest	1	10	1	1
Nord-Ovest	1	10	1	1
Geology				
Anlytic Hierarchy Process	31	29	27	34
Alluvial Deposits	10	5	7	8
Travertines	4	10	4	4
Lavas	10	6	10	8
Clay	8	8	8	10
Limestones	5	10	5	10
Sands	2	6	10	2
Marlstones	8	10	8	10
Sandstones	2	5	2	5
Conglomerati	5	5	5	5
Conglomerates	5	8	5	5
Clastic sediments	2	2	2	2
Land Capability Classification				
Analytic Hierarchy Process	29	24	22	29
I	10			
II	9			
III	8			
IV	7			
V	6			
VI	6			
VII	6			
VIII	1			

	Wheat	Olive	Vine	Legumes
Distance from water				
Analytic Hierarchy Process	3	4	9	6
< 100 m	1			
100-500 m	10			
500 -1000 m	6			
> 1000 m	1			
Topographical Wetness Index				
Analytic Hierarchy Process	3	4	9	6
1-3	10	10	1	1
3-5	8	8	7	10
5-10	7	7	10	7
> 10	1	1	1	1
Erosion				
Analytic Hierarchy Process	3	2	2	1
Class I Land with a slope of less than 3% where erosion does not occur	10			
Class II Land with slope between 3% and 10% in which less than 30% of the original surface is eroded.	8			
Class III Land with a slope between 10 and 18% in which more than 30% of the original surface is eroded	6			
Class IV Land with a slope greater than 18% in which the original surface is completely eroded.	4			

Figs. 2-3 – Values of agricultural suitability of the individual factors analyzed for the various species considered.

a file with 10 m cells was created with the different types of soils present. Each of these was assigned, with "Reclassify" tools, a score from ten to one according to descendant ability to support the different cultivation as described by the agronomic studies considered. The same procedure was followed to define the soil capacity classes of the landscape. Although this is a contemporary parameter, Land Capability Classification (LCC) was chosen because it considers some physic-chemical data difficult to find elsewhere. It is also underlined that in the last three thousand years the characteristics of the soils must not have changed much. After digitizing the map of the area and creating a raster file with 10 m cells showing this information, a decreasing score was assigned to the classes according to their ability to support agricultural or pastoral activities as proposed by Soil Conservation Service of US Department of Agriculture.

The percentage of slope was calculated for each land of the area, starting from a DEM at 10 m provided by the TINITALY (Tarquini *et al.* 2007) project and using the "Slope" function of ArcGIS. Generally, a slope greater than 30% is not recommended for crops, while a slope of up to 10% is considered optimal. However, in the specific case of the olive tree, too low of a slope is not good as the plant grows well even in soils with a steep slope. Starting from the same DEM at 10 m, the classes of suitability related to the land elevation have been created, through the reclassify function of the GIS subtracting a point every 100 m of altitude to the maximum value of 10. This, because every 100 m of increase in elevation on the mountains, the vegetation periods and blooming plants are delayed by 4 to 6 days.

Concerning exposure to sunlight, ArcGIS provides a whole series of tools that can calculate the terrain orientation automatically. The "Aspect" tool was used and the whole area was divided according to the land exposure. The value of suitability was assigned following the indication of the contemporary agricultural studies that show how the territories facing S get better exposure than the ones facing N. For the distance factor from watercourses, buffers of 100 m, 500 m and 1000 m were generated on these rivers and lake, considering them as the area of "suitability" for agricultural exploitation. The different suitability was considered in this way: to simulate the fact that too much water is harmful to plants, a score of 1 was assigned to the soil inside the first buffer. The highest value was assigned to areas within 500 m and a lower one to those within 1000 m. Finally, the latter buffer was considered the maximum distance for agricultural exploitation.

The humidity degree factor is also linked to water and more precisely to its quantity in the soil. In fact, the agricultural limitations deriving from poor soil drainage are well known. To obtain this factor map, the Topographic Wetness Index of area was calculated by applying the TWI formula (where is the water accumulation and the slope) within the "Raster Calculator" tool. The obtained raster file was then reclassified considering the value of 10 as the threshold beyond which a land is to be considered a wet area. Finally, for the last factor considered, that is the effect of the erosive phenomenon, the risk classes proposed by Davidson *et al.* 1994 have been identified using exclusively the criterion of their slope. Starting from the DEM file, the slopes of the areas have been calculated and through the "Reclassify" tool, they have been grouped into the four classes in Fig. 2.

Clearly, erosion has a negative effect on agriculture since it basically subtracts or alters the land useful for cultivation. In cases of more intense erosion, the removal of portions of land has a faster speed than the sedimentation of the new soil, revealing the underlying bare rock. Starting from the value of 10 for class I, two points have been subtracted from each class as the effect of erosion increased. Once all the factorial maps were completed, they were superimposed, thus considering together all the variables involved in the definition of the most suitable soils for the cultivation. However, since some factors, such as soil type, are more important than others, such as Aspect, a technique was used to weigh each individual factor value: the Analytical Hierarchy Process, as it has already been done in many works on contemporary agriculture (Akinci *et al.* 2013; Ahmed *et al.* 2016).

This technique, developed within the communication sciences, allows to identify the specific weight of each factor within a choice, using comparison scales (like the one by Saaty 1980) between single variables as fully described in Sotgia 2020 and 2021. Through the Analytic Hierarchy Process (AHP), it was possible to obtain the percentage of incidence of the individual factors to use the ArcGIS function of "Weighted Overlay" and obtain the final map through a weighed overlay of the individual factors. Once the most suitable soils for the cultivation of each species were identified, the AHP was applied again, overlapping the factors according to the following scheme: the weight assigned to wheat is 38%, to legumes 29%, to vines 19% and to olive trees 14%. These numbers refer to the attested frequency of each plant species within the archaeobotanical and palynological record (Minniti 2012).

The definitive model is therefore a raster file in which the cells contain the convenience value from 1 to 10 for their exploitation for agricultural purposes. All the cells with a value from one to five are considered unsuitable for agro-pastoral exploitation, the cells with a value of six can be used for woods or as pastures, while the cells from seven to 10 are suitable for agricultural exploitation.

In accordance with the palynological and archaeobotanical data of Southern Etruria, the model can be interpreted as follows: 60% of the class six land was occupied by woods and 40% by pastures.

The agricultural land, on the other hand, housed the following crops: olive groves (14%), vineyards (19%) and fields of wheat and legumes in the remaining 67%. The latter group was further internally subdivided as a rudimentary form of crop rotation was applied. Therefore, of the 67% of the land, 50% was devoted to the cultivation of wheat, 30% to legumes and the remaining 20% was set aside.

4. Model use

Once in possession of the agro-pastoral exploitation model of a territory, it can be used to carry out a whole series of important analyses for the historical reconstruction of ancient communities. The agro-pastoral landscape exploited by a settlement can be reconstructed through techniques such as the Bubble Method (Alessandri 2015) or Thiessen Polygons. The extension in hectares of fields and pastures can be individuated and the agro-pastoral system of an inhabited area can be modelled. It is also possible to infer the animal and vegetable production and consequently both the maximum sustainable demography of the settlement and the possible specialization of the site, following one of the many ancient production estimates proposed in the literature[1].

The following paragraph shows the application of this type of analysis to all the settlements present in the Late Bronze Age in the *Ager Tarquiniorum* (Fig. 4). The most important data that can be obtained through the model are the demographic ones, and the graph shows the trend of the population in the area and the number of inhabitants per village during the analysed period (Fig. 5a). Thanks to these data it is possible to characterize historical phenomena – such as the passage from the villages to the early cities ("Protourban Turn", Pacciarelli 2016) – from the point of view of the population involved. Furthermore, it is also possible to reconstruct the communities in detail through the quantification of the primary economy of each settlement, also identifying the existence of specialized sites in certain production.

In this way it will be possible to hypothesize the existence of groupings between sites, such as microsystems or other socio-political typologies, and at the same time any surplus produced (Fig. 5b). In the study area a general phenomenon of concentration of the settlements is attested, with the decrease in the number of sites and the increase of the inhabitants. However, with the passage between FBA1-2 and FB3A there is no massive increase of population, and even falls at the end of the FBA3B. In other words, there was a coherent and organic development of the communities throughout this period with a

[1] In the presented case study the considered vegetable yield is an annual production of 3 quintals of wheat against a *per capita* consumption of 1,82 q. In the total of quintals produced, one sixth was subtracted for sowing the following year and considered a loss of 25% of the product during transformation into flour. Animal yields, on the other hand, were obtained by considering the number of pastures exploited, the different meat production and the percentages of animals slaughtered for each species, in accordance with Minniti 2012,102. The considered annual *per capita* consumption of meat is 18,2 kg.

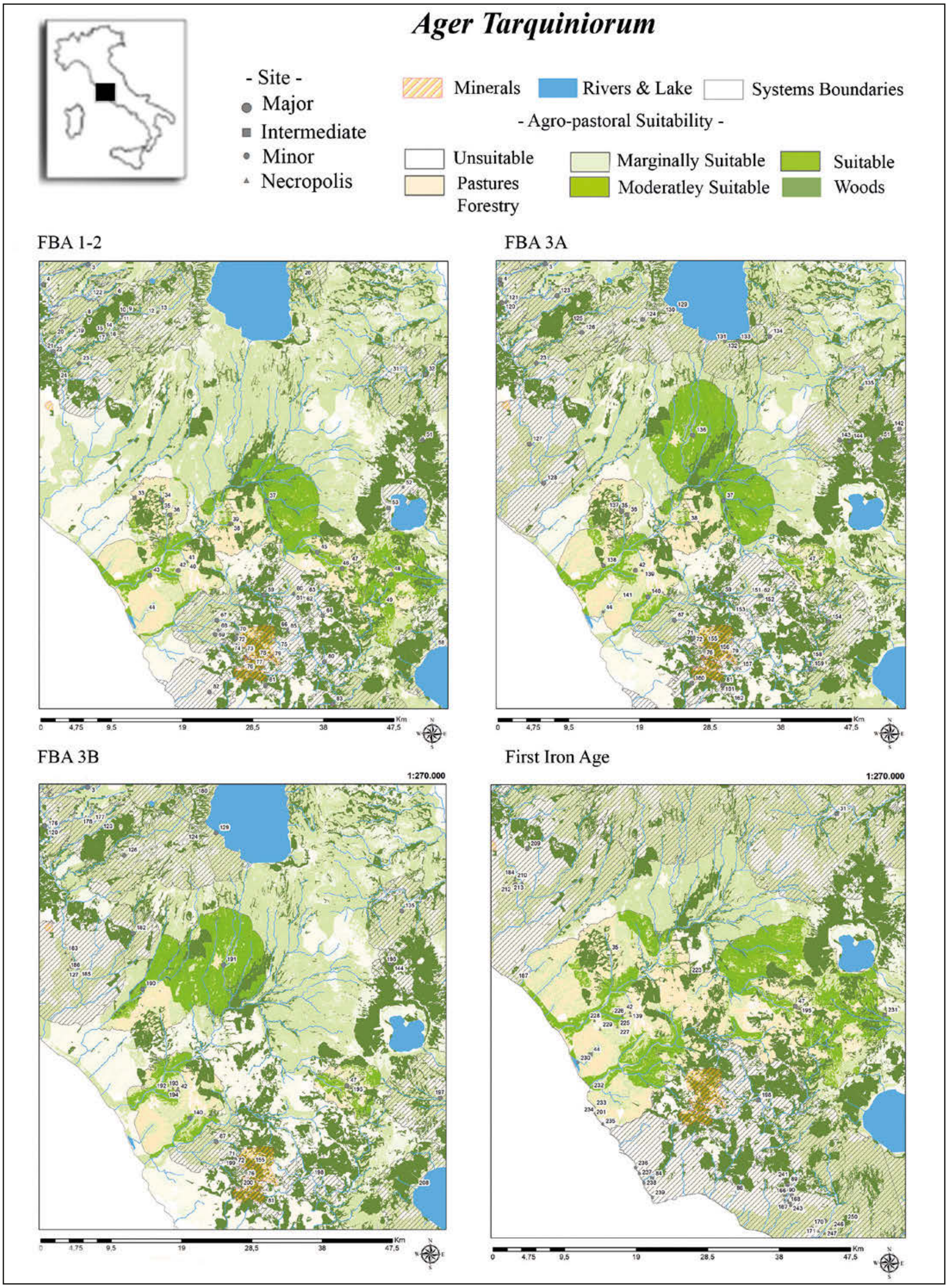
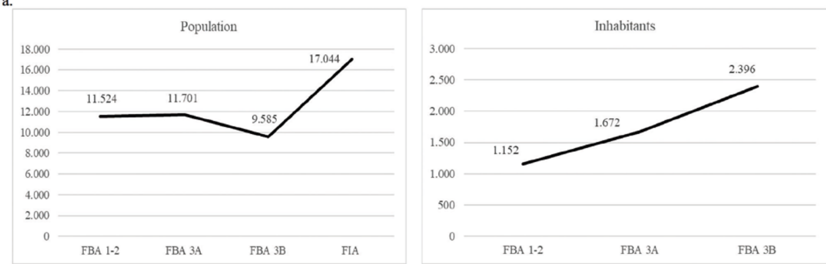


Fig. 4 – The case study of the *Ager Tarquiniorum*.

a.



b.

specialization — Surplus — Not Self-Sufficient

Final Bronze Age 1-2

ID - Site		Territory (hectares)	Land Use (hectares and %)						People supported			Surplus %	Total population	Inhabitants (average)
			Woods	%	Pastures	%	Crops	%	Tot.	Veg. yields	An. yields			
33	Poggio Martino	5.332	2.710	51	539	10	1.722	32	835	684	151	-	11.524	1.152
34	C. Roccaccia													
35	Ferleta													
36	Casale Saetto													
37	Norchia	10.717	3.151	29	334	3	6.198	58	2.700	2.463	236	57 %		
38	Torrionaccio	4.045	2.001	49	515	13	1.180	29	599	469	130	-		
42	Tarquinia	5.107	1.690	33	356	7	2.381	47	1.079	946	132	-		
43	C. Corneto	9.739	2.904	30	1.155	12	4.670	48	2.192	1.856	336	47 %		
44	F. delle Serpi													
45	Blera	4.658	1.617	35	301	6	1.959	42	890	779	111	-		
46	il Pontone	2.107	1.051	50	225	11	574	27	287	228	59	-		
47	San Giuliano	1.628	702	43	117	7	574	35	267	228	39	-		
48	Monte Sant'Elia	8.099	2.743	34	211	3	4.333	54	1.888	1.722	166	39 %		
49	Valle Nobile	3.471	1.150	33	151	4	1.788	52	789	710	79	-		

Final Bronze Age 3A

ID - Site		Territory (hectares)	Land Use (hectares and %)						People supported			Surplus %	Total population	Inhabitants (average)
			Woods	%	Pastures	%	Crops	%	Tot.	Veg. yields	An. yields			
136	R. Respampani	12.004	1.910	16	48	0	8.693	72	3.703	3.455	248	55 %	11.701	1.672
35	Ferleta	4.518	2.424	54	442	10	1.369	30	668	544	123	-		
36	Casale Saetto													
138	Montarana	7.658	2.340	31	860	11	3.621	47	1.694	1.439	255	1 %		
44	F. delle Serpi													
42	Tarquinia	8.025	2.111	26	600	7	4.336	54	1.951	1.723	228	14 %		
140	Pisciarello													
141	Casale Pacini													
38	Torrionaccio	3.737	1.849	49	476	13	1.086	29	550	431	119	-		
37	Norchia	9.598	2.659	28	317	3	5.671	59	2.471	2.254	217	32 %		
47	San Giuliano	3.458	1.303	38	242	7	1.455	42	665	578	86	-		

Final Bronze Age 3B

ID - Site		Territory (hectares)	Land Use (hectares and %)						People supported			Surplus %	Total population	Inhabitants (average)
			Woods	%	Pastures	%	Crops	%	Tot.	Veg. yields	An. yields			
191	Tuscania	12.162	2.398	18	63	1	8.570	70	3.655	3.406	249	34 %	9.585	2.396
190	C. Formiconcino	8.617	2.197	28	611	7	4.754	55	2.132	1.890	242	-		
42	Tarquinia	12.251	3.395	28	986	8	6.430	52	2.911	2.556	356	18 %		
140	Pisciarello													
47	S. Giuliano	4.847	1.934	40	326	7	1.940	40	887	771	116	-		

First Iron Age

ID - Site		Territory (hectares)	Land Use (hectares and %)						People supported		
			Woods	%	Pastures	%	Crops	%	Tot.	Veg. yields	An. yields
42	Tarquinia	81.364	29.051	36	6.098	7	37.414	46	17.044	14.869	2.174

Fig. 5 – a) The trend of the population in the area and the number of inhabitants per village during the analysed period; b) quantitative analysis of the different territorial systems of the *Ager Tarquniorum*.

territorial system becoming more and more extensive through the reasoned occupation of the most fertile areas. However, it is interesting to note that the increase in the agricultural vocation of the territorial systems does not affect all the main sites: Tarquinia even seems to maintain an articulated productive exploitation of the territory.

Finally, observing the self-sufficiency/surplus indices, the existence of a supra-village mutualistic dimension is emphasized, aimed at avoiding internal competition and guaranteeing the control of this fertile territory. However, with the development in the full phase of the FBA of Tarquinia, this dimension is put into crisis, and competition between systems for controlling the coastal area increases exponentially. The outcome of this competition will lead – in the end – to the affirmation of the protourban city of Tarquinia and to the concentration in it, in the Iron Age, of the communities of the area.

5. Final notes

This methodology can also be applied to other cultural and chronological contexts with very few modifications such as the mapping of additional plant and animal species or the addition of further factors (the presence of roads, the distance from market areas, etc.). The operations described have also been automated within a tool for ArcGIS under development (Sotgia 2022). The goal is to make this tool available to allow various scholars to use it in their research contexts. In the end, obviously, like all theoretical models, also the one presented here have a certain rigidity, which can only be smoothed out with a "field check". Pending systematic surveys of the territory to expand the available data and acquire precise geological and environmental information, a preliminary investigation tool has been developed, which is added to our archaeological toolbox, thus allowing more and more complete and detailed historical reconstructions.

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ABSTRACT

Thanks to the reconstruction of agro-pastoral land use of a territory, it is possible to obtain much information, both of an ecological nature, and about the populations. By the reconstruction of these dimensions of a community it is possible to understand not only the aspects linked to the exploitation of a territory, the subsistence and demography of a given group, but also more generally the group's social organization itself. With a series of GIS tools, capable of applying the FAO's land evaluation techniques, it has been possible to generate a predictive raster model of the landscape with the degree of agro-pastoral suitability inside each cell. Thanks to this model, the agro-pastoral exploitation of a territory can be simulated, calculating the food production of each settlement, as well as the consequent demography maximum sustainability. Thanks to the identification of specialized productions sites and of settlements capable of producing a 'surplus', or vice versa 'not-self-sufficient', it will be possible to articulate socio-political models, hypothesizing exchange networks or relationships between the different sites. The text illustrates in detail the structure and functioning of the developed model, as well as its applications in the archaeological context of the *Ager Tarquiniorum* during the Final Bronze Age.