

Modelling Prehistoric Land Use Distribution in the Rio Aguas Valley (SE Spain)

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Abstract

The Rio Aguas Project has been aiming to better understand the long-term ecological consequences of different economic and social strategies in the lower Rio Aguas valley (province of Almería, SE Spain). The area has a long history of human occupation, during which several periods of strong pressure on the environment have occurred. This pressure has however not always been generated by the same economic or social structures. Part of the work for the project was undertaken as a GIS modelling of the agricultural production landscape. The purpose of this modelling was two-fold: firstly, to gain insight into the potential of the Rio Aguas valley for different agricultural strategies. And secondly, to start reconstructing the possible production zones in the past, using palaeo-ecological and archaeological evidence on diet and population. The paper will discuss the methodology applied and the implications for the interpretation of the prehistory of the Rio Aguas valley.

1 Introduction

The Rio Aguas Project is an international, interdisciplinary research project, funded by Directorate General XII of the Commission of the European Union. Its main goal has been the investigation of the long term evolution of human and natural systems in the Lower and Middle Rio Aguas Valley, an area covering approximately 16 by 10km in the Spanish province of Almería (Fig. 1a and 1b). This socio-natural evolution has been a crucial factor in the development of land degradation in the area, which was already studied within the larger context of the Vera Basin for the Archaeomedes Project (van der Leeuw 1994). The Rio Aguas Project has considerably expanded this knowledge through climatic, geomorphologic, hydrological, palaeo-ecological and archaeological investigations. One of the main questions to be addressed was the relationship between the potential resources in the area and the use that has been made of these resources during different (pre-)historical periods. Agricultural land use in particular has exerted a strong pressure on the environment during such diverse eras as the Bronze Age, the Roman period and the nineteenth century. In order to further investigate the environmental impact of agricultural subsistence strategies, a GIS based modelling of the possible production landscape in the past was undertaken. An outline of the procedure followed can be found in Figure 2.



Figure 1a. Location of the study area.

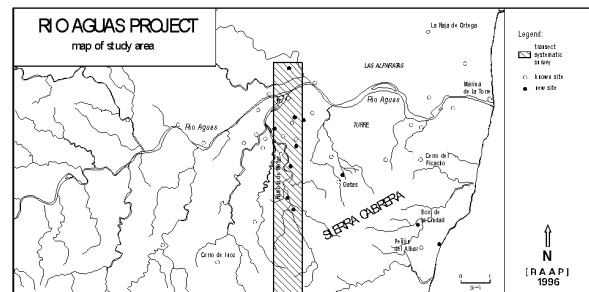


Figure 1b. Location of the study area.

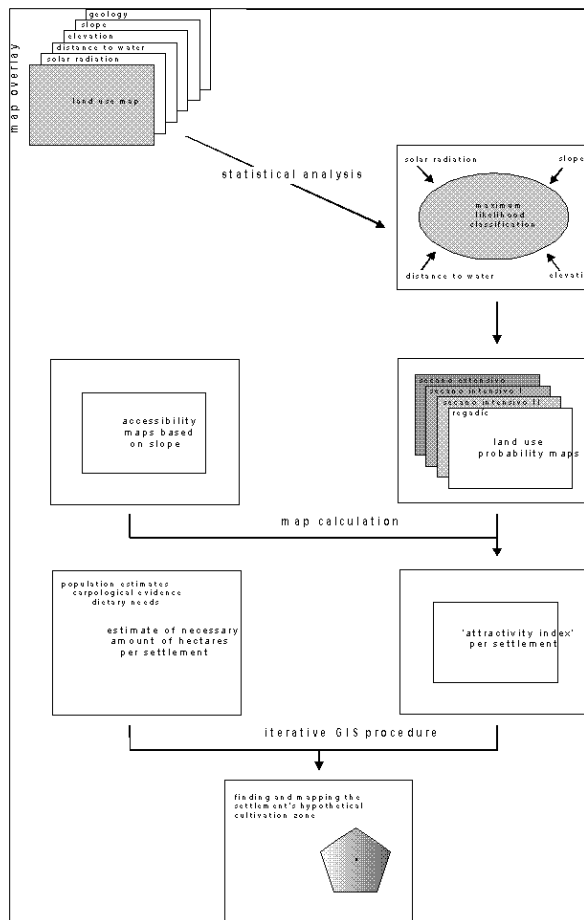


Figure 2. Outline of the modeling procedure followed.

2 Environmental context

The study area is located in one of the driest regions on the European continent, with rainfalls generally between 250 and 300mm per year. Annual figures may vary considerably because of the highly irregular nature of the rainfall. The area is dominated by the Sierra Cabrera mountains south of the Rio Aguas, which rise steeply from the valley floor to their summit at 934 meters. Geologically speaking, the sierra is composed of hard Palaeozoic metamorphic rocks, whereas the foothills consist of softer Miocene marls, sands and limestones. The Rio Aguas valley itself is characterised by a broad Quaternary plain with dispersed remnants of Pleistocene river terraces and glacia (Schulte 1996).

Agricultural land use nowadays is mainly found along the Rio Aguas, with irrigated farming of barley, vegetables and fruit trees. On the river terraces irrigation is less frequent, and the main crops here are barley, wheat, almonds and olives. The shallow soil

profiles on the northern flanks of the Sierra Cabrera are less used for agriculture, as they are very dry and vulnerable to erosion. Where slope is more gentle, cultivation of almonds, olives and sometimes barley can be found. The ubiquitous terracing found on the intermediate altitudes in the Sierra Cabrera is a remnant of the subsistence practices that existed until very recently in this area and date back as far as the Andalusian period. The terraces were constructed to catch the water and fine sediment that comes down through the dry river beds during rain storms. These terraces have been used to grow olives, almonds and barley, but most of them have now been abandoned. The central sierra area, covered by garrigue, was until recently used as grazing land for goats, but this practice has almost come to an end.

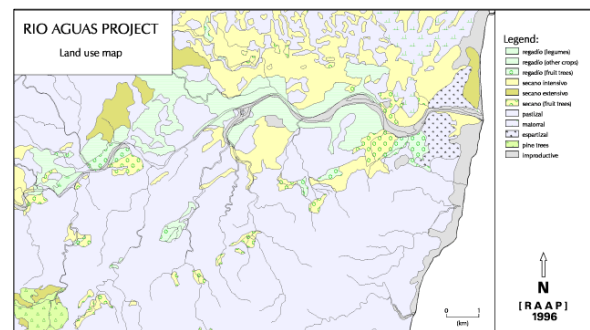


Figure 3. Land use map of the area (situation in 1978).

3 Archaeological context

The Vera Basin, where the Rio Aguas valley is located, presents one of the most complete archaeological records of the western Mediterranean, especially for the later prehistoric periods (Lull 1983; Chapman 1991; Castro *et al* 1994; Castro *et al* 1997). Human occupation started in the Neolithic around 5000/4500 BC. This first occupation phase was characterized by a subsistence strategy of low intensity and high diversity. Only few settlements have been reported, and they seem to be short-lived. There is no sign of environmental perturbations in this period, either as a consequence of the diversified land management or as a function of the low population density.

The ensuing Chalcolithic period (3000-2250 BC) shows a steady increase in the number, size and duration of the settlements. Subsistence production is still based on diversified exploitation. The larger and longer-lived settlements are involved in specialised production of metal, stone and bone tools, and

exchange networks develop in order to distribute the goods.

Around 2250 BC a new socio-economic and political system emerges, known as the El Argar culture. The steadily increasing population is concentrated in fewer and permanent settlements, that are located on higher ground. The agricultural production obtained in the plains is concentrated, processed and redistributed in these settlements. However, only a new political class, that also controls the production of metal goods, is benefiting from this system, evidence for which is found in the rich grave goods and higher life expectancies of this group. Towards the Late Argaric period (1750-1550 BC) the system develops into what has been referred to as the first state society in the western Mediterranean. Extensive barley cultivation ensures the basic subsistence needs of the population, but only at the cost of deforestation of the lowlands and decreasing health of part of the population. This form of socio-economic organisation, possibly coupled to aridification and geomorphic instability, eventually leads to the sudden collapse of the Argaric society around 1550 BC.

After the Argaric period, a long lasting process of depopulation starts. Nevertheless, the lowlands do not seem to recover from the deforestation and intensive exploitation suffered during the Argaric period. A new diversified subsistence system develops, introducing the cultivation of olives and grapes, and possibly of small-scale terracing and irrigation infrastructure as well. The establishment of the large settlement of Villaricos in the northeast of the Vera Basin around 800 BC to exploit the lead and silver ores there does not lead to a demographic recovery in the Rio Aguas valley, presumably because of the absence of these ores in the Sierra Cabrera.

Only with the integration of the area into the Roman Empire (0-400 AD) does a new phase of economic and social development start. The plains and valleys are exploited through several villae, two of which are located along the Rio Aguas. Alongside these vast estates, small rural settlements develop, both in the flood plains as well as on the mountainsides, and population increases until the fifth century AD. Agricultural production consists mainly of extensive cultivation of cereals and olives. This period also witnesses the introduction of irrigation systems in order to increase agricultural production in the river valleys. During the Late Roman and Byzantine period (400-650 AD), this situation is largely continued.

After the political and economic crisis of the seventh century AD, a demographic decline and the abandonment of many small settlements is observed, a situation that continues well into the first century of the Andalusian period (711-1492 AD). The establishment of the Omayyad state leads to a new phase of socio-economic development. Extensive crop production, development of irrigation and terracing systems, mining and iron smelting form the economic basis for a growing population that settles in the lowlands as well as in the mountains close to mining and water resources.

In the thirteenth century, the Vera Basin becomes a border region of the Nazari state, the last Islamic state in Spain. This may have led to the establishment of new settlements on better defensible sites in the mountains. A sophisticated terracing and water storage systems allows for high agricultural yields, so each settlement can provide for its own subsistence needs. From an environmental point of view, this agricultural system was very efficient for the prevention of further degradation of the area.

4 Agricultural potential of the Rio Aguas valley

One of the aims of the modelling was to come up with a classification of the landscape in terms of agricultural potential which could be used as the basis for land use distribution mapping. The traditional land management system in the area consists of two types of agriculture: *regadío* or irrigated farming, and *secano* or dry farming. Evidently, *regadío* is a more productive land use type than *secano*. However, the area suited for low technology *regadío* is relatively small: it is restricted to the flood plain of the Rio Aguas, where irregular flooding provides the high groundwater table necessary for higher yields. This strategy was possibly used since Neolithic times. Two different strategies (that can be used complementary) have been applied in the past to increase the area suitable for *regadío*: the construction of hydraulic structures like canals and water conduits to transport the water to the fields, and the application of terracing to catch the water before it runs off into the valley. The application of irrigation by means of canals started in the Roman period, whereas the use of terraced agriculture is the trademark of the Andalusian Nazari period. When we look at the land use map of the area based on the situation of 1978 (Ministerio de Agricultura, Pesca y Alimentación 1982; Fig. 3), we can see that the basic subdivision in *regadío* and *secano* is still valid. It is assumed that the location of the *regadío* and *secano*

areas will depend on the suitability of the terrain for either type of agriculture. By comparing the 1978 land use distribution with the environmental variables available in the Rio Aguas GIS (geology, elevation, slope, solar radiation received, distance to streams) it was possible to arrive at the following scheme of four land use types:

1. *regadio* in the Rio Aguas flood plain (no artificial irrigation applied) - the basic form of *regadio*, available in all (pre)historical periods
2. *secano intensivo I* at larger distances from the river in the Rio Aguas flood plain - these areas can be irrigated by means of canals
3. *secano intensivo II* on the river terraces of Rio Aguas and in the foothills of the Sierra Cabrera - these areas will need a more complex hydraulic infrastructure for irrigation
4. *secano extensivo* at intermediate altitudes - a low productivity type of *secano* that has not been very important in prehistory, as the yields are extremely low; this land use type was predominantly applied during the nineteenth century, when demographic pressure forced farmers to take marginal land into production

In order to find out where these land use types are most probable, a maximum likelihood classification (Schowengerdt 1983) was performed. Each of the land use types was compared with the available continuous variables (elevation, slope, solar radiation and distance to streams) in order to construct the 'signature files' that describe the characteristics of the land use types with regard to the variables used. The resulting classification yielded probability maps for each land use (see Figure 4 for an example). By comparing these maps, it can be concluded which land use is the most probable at a certain location, and whether it is probable at all. The results at the 80% probability limit show that approximately 3000 hectares of agricultural land are available (900 ha *regadio*, 750 ha *secano intensivo I*, 500 ha *secano intensivo II* and 750 ha *secano extensivo*). The resulting map is of course only a tentative approximation of the actual land use potential, but is nevertheless useful as a basic model to define the relation between potential land use and exploitation in different periods. A surprising conclusion is that there is still a considerable amount of relatively high potential *regadio* and *secano intensivo I* land that is currently not being used.

5 Land suitability: a function of potential and accessibility

The land use potential map in itself is not sufficient to interpret the attractiveness of the land for agriculture. For the modelling, the basic assumption was made that people preferred high potential land at a short distance from the settlement. In order to reconcile these demands, a map was constructed for each single settlement that combined the land use probability map with an accessibility map. The accessibility map is based on the slope of terrain, as this will have been the major constraint to transport by foot in the area (the river beds are dry most of the year). According to Gorenflo and Gale (1990) the effect of slope on travelling speed by foot can be specified as:

$$v = 6 e^{-3.5|s + 0.05|}$$

where:

v = walking speed in km/h

s = slope of terrain, calculated as vertical change divided by horizontal change, and

e = the base for natural logarithms.

This function is symmetric but slightly offset from a slope of zero, so the estimated velocity will be greatest when walking down a slight incline. As we are interested in the time needed to go from a settlement to the fields and back, we add the estimate for going down and going up to find the total amount of time spent. In this particular case an exact estimate is not required, as we will be comparing the relative accessibility of areas, not their absolute values. Using the equation above, a cost surface has been constructed that specifies the amount of time needed to traverse each grid cell and go back again. This cost surface has been used to calculate a cumulative cost surface for each single settlement in order to arrive at a measure of accessibility of the terrain as perceived from the settlement.

The maps of land use probability and accessibility were then combined in a map of 'attractivity indices', which are defined as follows:

$$A = p(L) (1 - D/D_{max})^2$$

where:

A = attractivity index

$p(L)$ = land use type probability, measured on a scale from 0 to 1

D = distance, measured in hours walking, and

D_{\max} = maximum possible distance.

In this particular case, the distance decay is assumed to be a square function of the actual distance, an assumption commonly used for gravity models, as the travelling time will become increasingly constraining at larger distances from the settlement. For ease of calculation, D_{\max} is set to two hours, which means that areas that require more than four hours walking a day in order to be exploited will not be available for cultivation.

The index will range from values near 1 on locations near the settlement with optimum land use potential, to 0 on locations that are either wholly unsuited for agriculture, or that are too far away from the settlement.

6 Estimation of land surface needed for agriculture

Having a map of land attractivity for each settlement, the next question to be addressed is the amount of hectares that each settlement needs for its agricultural production. For the modelling, it was assumed that during all periods the settlements will have tried to adopt a strategy of self-sufficiency. Although this is not true for each period, it serves a clear purpose: if we can model the amount of land needed for self-sufficiency and compare this to the actual land available, it is possible to see if there is potential for surplus production, or inversely, if there is insufficient space to grow crops for the whole population. The real uncertainty we are dealing with is the size of the population. The population estimate applied here is following Renfrew (1972):

$$P = 200 A$$

where:

P = estimated population of the settlement, and

A = the size of the settlement, measured as the extent of the archaeological remains visible on the surface.

Where additional information was available from excavations, this information was used to adapt the

population estimates. It is however acknowledged that this method of population estimation cannot lay a claim to extreme accuracy.

The population estimates were then used for the calculation of the number of hectares that needed to be cultivated in order to feed the population. This was done by taking into account the nutritional value of the five most important crops that have been identified by analysis of the seeds found on the archaeological sites. Two types of cereals (barley and wheat) and three types of legumes (beans, peas and lentils) seem to have been important elements of the diet, be it in changing proportions over time (Clapham *et al* 1997). Using the nutritional value of each species and its relative importance in the diet as inferred from carpological analysis, it was possible for each period to calculate the amount of each species needed to feed a person, taking an average nutritional need of 2600 Kcal per person per day. From this amount it was possible to calculate the number of hectares needed for the whole population, taking into account the following conditions:

1. grinding of cereals implies a loss of 30% of the original seed weight
2. a certain amount of seed must be stored in order to have a crop next year; the volume of stored seed is different for cereals and legumes, and is also different for *secano* and *regadio*; figures from the literature have been applied to calculate the stored seed volume
3. for *secano*, each year of cultivation is followed by two years of fallow in order to recover soil fertility; this implies a multiplication by three of the land needed for *secano*
4. productivity indices are different for *secano* and *regadio*; productivity indices from present day traditional agriculture have been applied; it is unlikely that these figures overestimate the productivity in the past

In order to make the final calculation, it was necessary to specify the relative importance of *regadio* and *secano* for each time period considered.

1. from the Neolithic until the Roman Republican period, the evidence suggests that legumes were cultivated on the more humid Rio Aguas flood plain, whereas cereals seem to have been cultivated under dry farming
2. from the Roman Imperial period onwards it seems that legumes and wheat were cultivated using irrigation systems, whereas barley continued to be a dry farming crop

3. from the Nazari period until modern times historical data provide detailed information on the cultivation practices in the area

For a more detailed description of the method followed and the empirical evidence that supports it, see Castro *et al* (1996, 1997).

7 Finding the land

Using the hectare calculations and the maps of attractivity indices it is possible to map the hypothetical cultivation zone of each settlement. In the simplest case, this mapping assumes that each settlement has free access to all the land in the study area, and can therefore choose the best land available for its agricultural production. The model was run for three different cases, the number of options increasing with each run: firstly with just the land use potential map for *regadio*, secondly using the land use potential map for both *regadio* and *secano intensivo I*, and thirdly also including *secano intensivo II*. The *secano extensivo* case has not been considered here, as there is no conclusive evidence that this land use type was applied before the nineteenth century. Generally speaking, large cultivation zones will result in lower mean attractivity indices. Sites that were relying on *regadio* alone will not exhibit large differences in mean attractivity between the three runs, whereas settlements that relied on one of the *secano* strategies will show significantly higher attractivity indices when these options are included. So the comparison of the attractivities will tell us if the settlements were in a favourable position for agriculture, and if they could improve their options by including land that is more suitable for *secano* than for *regadio*.

The final step in the modelling was the cartographic representation of the modelled cultivation zones. In order to present a hypothetical land use distribution map for each period, an additional condition had to be fulfilled: the cultivation zones of the settlements should not overlap with the land of neighbouring sites. Basically, two theoretical models can be applied: one that favours the larger sites over the smaller ones (i.e. a form of social exploitation), and a second model that allows the smaller settlements to have their own land, leaving the less attractive bits to the larger ones. This second approach was chosen for the mapping, as it is assumed that social exploitation was the exception and not the rule.

The model should be able to check for each single settlement whether it is trying to claim land that is

also desirable to other settlements. As the mapping is performed using an iterative procedure, it is possible to check on each iteration if there is a potential land use conflict, and let the smallest settlement 'win'. In practice however, this is not the most straightforward procedure, as it requires some fairly complex programming and a considerable amount of computation. Therefore it was decided to start calculating the cultivation zones for each settlement separately, starting with the smallest one and moving up to the largest settlement. A comparison of the two technical solutions showed very little difference in the configuration of the cultivation zones.

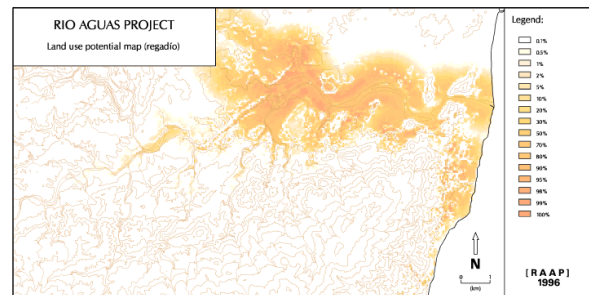


Figure 4. Land use probability map for *regadio*.

8 Results

8.1 Neolithic period (5000/4500 - 3000 BC; Fig. 5)

The small settlement sizes in this period lead to small cultivation zones with relatively high attractivity indices. It is nonetheless obvious from the mapping that some sites are trying to use the same land. The explanation for this is simple: not all sites existed simultaneously; the settlements were short-lived, and the same area could be colonised more than once. Most settlements can find sufficient land in the Rio Aguas flood plain, where large areas are still left uncultivated. Dry farming may have been important for settlements that were placed in more remote locations. The placement of the settlement of La Raja de Ortega at a distance of approximately 2.5km north of the Rio Aguas is unlike the location of any other settlement. The land use potential of this area between the Rio Aguas and Rio Antas is very low because of the absence of surface water. As the palaeo-climatic evidence indicates a more humid phase during the early Holocene, this area may have become less attractive in later periods than it was during the Neolithic.

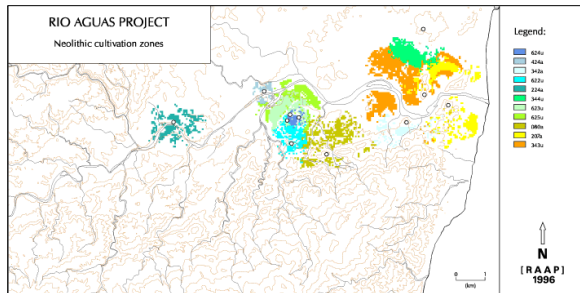


Figure 5. Hypothetical cultivation zones for the Neolithic period.

8.2 Chalcolithic period (3000 - 2250 BC; Fig. 6)

Increasing settlement size leads to larger cultivation zones, which cover almost the entire Rio Aguas valley. As in the Neolithic, not all settlements existed at the same time, which may explain the land use distribution pattern around the Rambla de Mofar. The land that is taken into cultivation is located at larger distances from the site than during the Neolithic, and dry farming seems to have become more important.

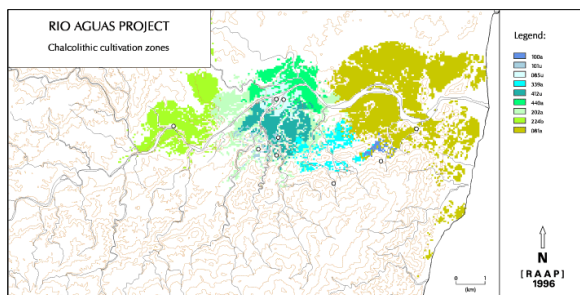


Figure 6. Hypothetical cultivation zones for the Chalcolithic period.

8.3 Argaric period (2250 - 1550 BC; Fig. 7, 8, 9)

At the transition of the Chalcolithic to the Bronze Age we witness a drastic change: the number of settlements is reduced to four. These are much larger, and are located at greater distances from the Rio Aguas flood plain. The archaeological evidence indicates that barley monoculture becomes the dominant cultivation strategy. This implies the need for large cultivation zones for dry farming, which can not be found close to the settlements. This is clear from the mapping for the first phase of the Argaric period (2300 - 1900 BC): the coastal zone south of the Rio Aguas is taken into cultivation for lack of any better alternative close to the settlements of Barranco de la Ciudad and Peñón del Albar. It is highly

improbable that this configuration reflects the actual situation during the Argaric period; a system of exchange will have developed with other settlements in the Vera Basin. During the second Argaric phase (1900 - 1750 BC) an attempt is made to increase the production of legumes, which could only take place by means of *regadio*. This decreases the size of the cultivation zones, although they are still located at large distances from the settlements. However, in the last Argaric phase (1750 - 1550 BC) a return is observed to barley monocropping. The settlement of Gatas, which has a growing importance during the Argaric, now becomes the centre of barley storage, processing and redistribution. The disastrous consequences of this development are well illustrated by the cultivation zone mapping for this period: even with the coastal zone in use for agricultural production, almost the complete Rio Aguas valley is used for cultivation, including unattractive areas that were not considered in the Neolithic and Chalcolithic. It is highly probable that food production could not keep up with the population growth, which eventually led to the collapse of the Argaric socio-economic system.

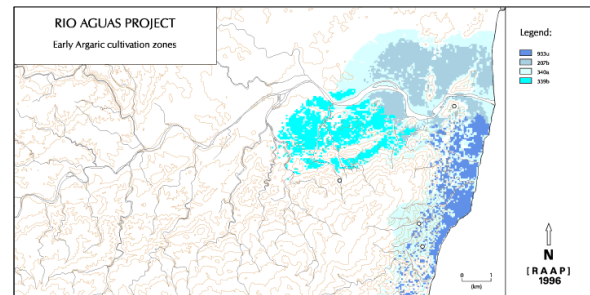


Figure 7. Hypothetical cultivation zones for the Early Argaric period.

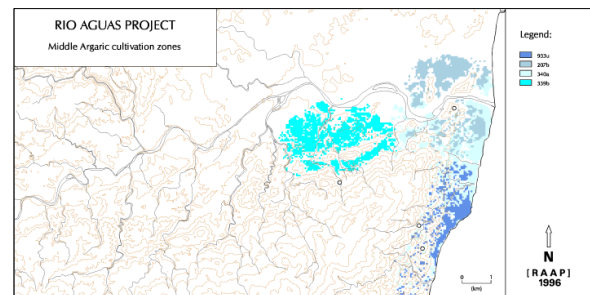


Figure 8. Hypothetical cultivation zones for the Middle Argaric period.

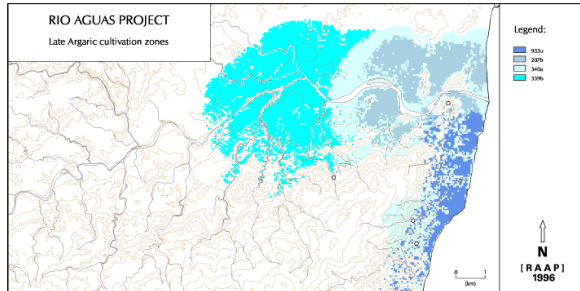


Figure 9. Hypothetical cultivation zones for the Late Argaric period.

8.4 Late and Final Bronze Age (1550 - 600 BC; Fig. 10)

A drastic population decline coupled to a change in subsistence strategy toward combined *regadío* and *secano* leads to smaller cultivation zones, which are limited to areas relatively close to the Rio Aguas and to the coastal zone. It is again questionable if the coastal zone was actually cultivated during this period given its generally low land use potential. From the Argaric period, only the sites of Gatas and Barranco de la Ciudad survive, while some new and smaller settlements are observed closer to the Rio Aguas. From the archaeological evidence it is clear that the population continued to decline during this period; until the Roman Imperial period, other areas of southern Spain seem to have been more attractive for settlement, as is shown by the archaeological record (Chapman 1991).

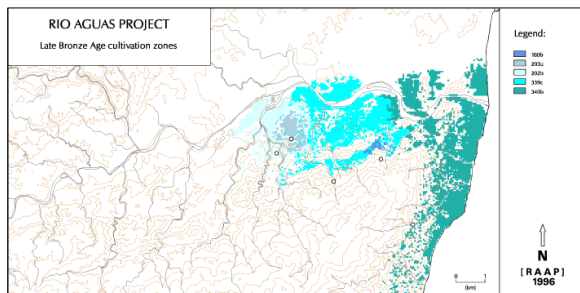


Figure 10. Hypothetical cultivation zones for the Late and Final Bronze Age.

8.5 Phoenician and Roman Republican period (600 BC - AD 0; Fig. 11, 12)

Population reaches its lowest point during this period. During the Phoenician period (600-100 BC), only one settlement is found. This site is placed in an area very well suited for dry farming. In the Roman Republican period, two settlements are found, one near the Rio

Aguas where *regadío* could be applied, and one at the coast where *secano* will have been the best option.

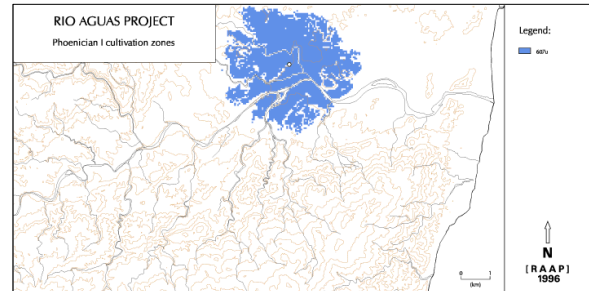


Figure 11. Hypothetical cultivation zones for the Phoenician period.

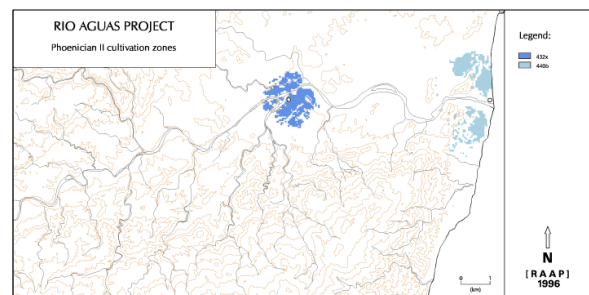


Figure 12. Hypothetical cultivation zones for the Roman Republican period.

8.6 Roman Imperial period (AD 0 - 400; Fig. 13)

In the Roman Imperial period, a drastic increase in population is observed. The introduction of the *Villa* system leads to a very intensive agricultural exploitation of the Rio Aguas valley. Most settlements seem to have been relying on dry farming rather than *regadío*, which confirms the evidence from the archaeological record. Out of the eleven settlements, only two are found at somewhat more remote locations: Marina de la Torre in the mouth of the Rio Aguas and Cerro del Picacho, which seems to have been chosen for its strategic position. No settlements are found that have extremely low attractivity indices, which is no surprise given the Roman policy of generating surplus food production. It is however clear from the modelling that this surplus production can not have been achieved with dry farming, as the complete Rio Aguas valley should be taken into cultivation to feed the population of the settlements alone. This explains the suggested shift in this period towards *regadío*, made possible by the introduction of the first irrigation systems along the Rio Aguas.

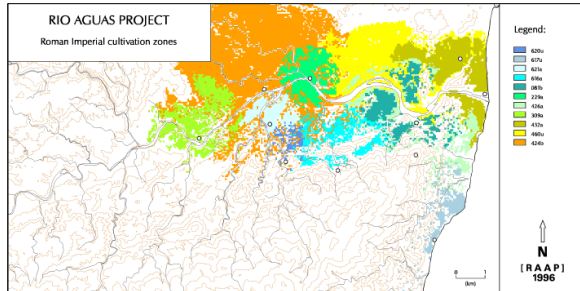


Figure 13. Hypothetical cultivation zones for the Roman Imperial period.

8.7 Late Roman / Visigothic / Byzantine period (AD 400 - 700; Fig. 14)

During this period the population shows no drastic change, and many settlements continue their existence from the Roman Imperial period. The more decentralised occupation pattern is coupled to a further development of hydraulic infrastructure and irrigation in the valleys, as is also suggested by the dominance of wheat in the subsistence production. Surplus production was no longer maintained because of a lack of external demand, and the population may have reduced its agricultural activities to the most productive ones for its own subsistence needs. This is reflected in the cultivation zone mapping for this period: the area cultivated is limited and mainly found in areas with high land use potential.

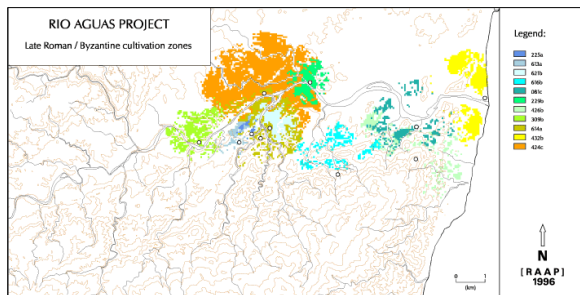


Figure 14. Hypothetical cultivation zones for the Late Roman / Visigothic / Byzantine period.

8.8 Omeya - Califal period (AD 700 - 1200; Fig. 15)

After the Arab conquest of Spain, a new settlement pattern emerges in the area. While maintaining the application of *regadío*, dry farming is re-introduced in the area, probably as a consequence of external demand. The location of the settlements reflects this focus on dry farming. Only one exception is found: the site of Cerro de Inox is an Andalusian castle built high in the Sierra Cabrera. A beginning is made with

the introduction of the complex hydraulic and terracing systems on the slopes of the Sierra Cabrera, which can still be observed today. This is however not reflected in the mapping of the cultivation zones, which are based on a strategy of predominantly dry farming. It is clear that most of the Rio Aguas valley will have been cultivated during this period.

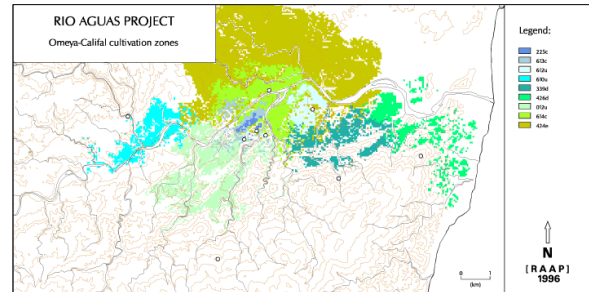


Figure 15. Hypothetical cultivation zones for the Omeya - Califal period.

8.9 Nazari period (AD 1200 - 1500; Fig. 16)

During this last phase of the Andalusian period, the settlement pattern has changed considerably. Two types of settlements can be observed: those located in the Rio Aguas flood plain with good access to agricultural land, and those located on the slopes of the Sierra Cabrera, relying on the now fully developed terracing system for their agricultural production. Surplus production of cereals was reduced in favour of mulberry plantations (related to silk production) and olive trees. The mapping of the cultivation zones shows that in fact very small areas were necessary for subsistence production, and that the largest sites are found in the Rio Aguas flood plain. Because of the independence of the settlements from high potential land, the mapping is not providing a very realistic picture of the possible cultivation zones.

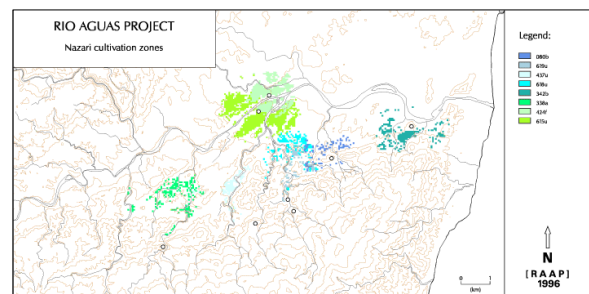


Figure 16. Hypothetical cultivation zones for the Nazari period.

9 Conclusions

The model discussed above provides a considerable amount of information on the possible development of the agricultural production pattern in the area in prehistory. At the regional level, it shows the possible impact of agriculture on the landscape for each time frame considered. The cultivation zone maps indicate which locations are the most probable production areas. The model assumptions do however not always conform to the actual situation. This is especially evident for the Neolithic period, when settlements did not exist simultaneously, and for the Nazari period, when the technological innovation of terracing made it possible to grow crops almost regardless of the land use potential, so for these periods the cultivation zone mapping may not be reflecting the real situation. On the other hand, the model strongly supports the hypothesis of over-exploitation during the Late Argaric period, and points to the necessity of irrigation in order to obtain surplus production during the Roman period.

At the settlement level, the model indicates which sites may not have been relying on agriculture for their subsistence needs, and whether *regadio* or *secano* may have been the most probable option. The model also points to situations where land use conflicts between settlements may have arisen.

Finally, from the point of view of long term land degradation, a measure of the degree of exploitation of the landscape can be obtained by adding all the land use distribution maps into one single map (Fig. 17). From this exploitation intensity map, it can be concluded that the area around the mouth of the Rambla de Mofar will have been the most frequently used for agriculture. This is a 'high potential' area that is not very susceptible to land degradation. The area north of the Rio Aguas around Las Alparatas however is not very frequently included in the cultivation zones, in spite of its relatively high potential. This may point to a lack of archaeological knowledge of this area located close to the town of Turre. Most other areas that show infrequent exploitation are classified as low potential land, with

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associated high degradation risks. The modelling therefore suggests that there is an upper threshold of available land that can be exploited without running into problems of land degradation. It is within these limits of possible exploitation that different solutions have been adopted through time to the question of agricultural subsistence production.

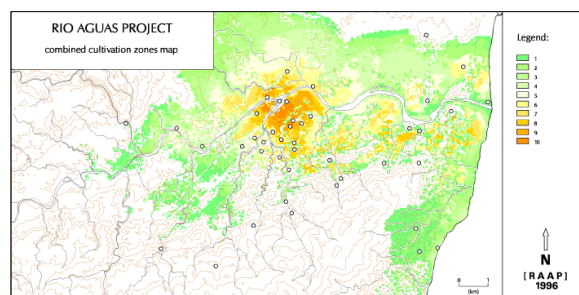


Figure 17. Combined cultivation zone map for all periods.

As a concluding remark, we may state that the GIS has proved to be an indispensable instrument for the modelling discussed here. It is however evident that the model will only serve its purpose if it provokes a dialogue with the archaeological and palaeo-environmental hypotheses and evidence involved. In this sense, the modelling presented here provides a working example of how GIS can be incorporated into a broader archaeological research framework.

Acknowledgements

This study was done in the framework of the Rio Aguas Project, funded by the Directorate General XII of the Commission of the European Union under contract EV5V-CT94-0487, the *Dirección General de Investigación Científica y Técnica del Ministerio de Educación y Ciencia*, and the *Comissionat per Universitats i Recerca de la Generalitat de Catalunya*.. The authors would also like to acknowledge the co-operation of the colleagues involved in the Rio Aguas Project, especially Pedro V. Castro and M^a Encarna Sanahuja (Universitat Autònoma de Barcelona).

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