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NEW APPROACHES TO OLD ISSUES: THE APPLICATION OF PREDICTIVE MAPS IN ARCHAEOLOGY

A case study: modelling the location the Grosseto salt works from 700 BC to AD 1200

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Introduction

The medieval town of Grosseto (central-western Italy) and its surrounding territory have been the focus of a long lasting research project since 1997. Archaeologists, historians and geoarchaeologists have debated the origin and the development of the city, the available resources and their exploitation. Though no Roman settlement has been found underneath the small early medieval village during excavations in the town centre, recent research suggests the crucial role played by salt revenues, at least during the Middle Ages. Salt is likely to have been a key factor in the village's growth between AD 800 and 1138 when it formally became a town, due to the shifting of the bishop's see from the former Etruscan and Roman town of *Rusellae*, which is located about 7 km to the north-east. The position of the salt works through time, and even their chronology, is still a matter of conjecture. Only excavations can aim at producing consistent data on this topic, but the general trend of funding in Italian archaeology and the vast area to investigate require a new strategy. We have therefore evaluated the whole data set with GIS-based spatial analysis (hydrology tools) in order to reduce the plain to smaller areas, no more than a few hectares each, that can be investigated by geophysics and trenches. In this paper, we introduce the data set, the evaluation process, and a brief discussion of the result, which is a predictive map of the most likely locations for the salt works in two different epochs.

Predictive models: how does this research relate to an old issue?

For more than thirty years archaeologists have debated whether we have tools to evaluate the unknown. Recently, Verhagen and Whitley (2012) have painted a detailed fresco of this fascinating topic, which deserves a careful reading. With the exception of Spanish scholars, this debate saw Mediterranean archaeologists little interested, though they would have much to say. The debate followed the rapid development of both hardware and software: evaluations that were very complicated only ten years ago can now easily be run with the available GIS software on an entry-level laptop. At the same time, the post-processual criticism of the theoretical bases of investigating past societies has hampered many attempts to develop this topic, though this obstacle seems to be partially removed in the last five years. The annual meeting of the CAA (*Computer Applications and Quantitative Methods in Archaeology*) never ceases to stimulate discussion and its proceedings are always a precious source of suggestions, applications and case studies.

Generally speaking, the discussion has focused on three issues. The first, and most debated, has been settlement location, which produced a vast literature (amongst others Lock 2000; Wescott and Brandon 2000; Wheatley and Gillings 2002; van Leusen 2002; Haining 2003). Can we forecast where a given type of site would be located in a given region, starting from known sites and a basic knowledge of the landscape's features? The post-processual criticism pointed out some weak points, mainly an overestimation of the available tools. However, it almost blocked any further development in that direction, which we think is, at least, ungenerous. Recently, this weak point has been partially removed by procedures of confidence evaluation, whose results are encouraging (Finke *et al.* 2008; Verhagen *et al.* 2011; Malpica *et al.* 2011). An interesting development in predictive modelling for the distribution of archaeological sites is the so called 'belief' mapping, which allows uncertainty to be accounted for, and has been applied for several areas and purposes (Lorup 1999; Eastman 2003; Ducke, Münch 2005; Ejstrud 2005; Canning 2005; De Vries 2007). As always, Dutch archaeologists are much engaged in mapping out these new roads, and we owe much to them (though see Kamermans 2010 for a critical evaluation of the methodology developed for the 'Indicative Map of Archaeological Values of the Netherlands'). Great efforts in this direction with long lasting results have been made by the French projects Archaeomedes and the following Archaedyn (Gandini and Favory 2012). Other key topics include the analysis of viewsheds and lines of sight (see amongst others Wheatley 2000; Fitz and Orengo 2008) and modelling least cost paths (De Silva and Pizziolo 2000; Bellavia 2002; Posluchsny 2010; Llobera *et al.* 2011).

How does our research relate to these debates? We have been studying the medieval town of Grosseto in central Italy and the surrounding plain since 1997. Multidisciplinary research on the region (whose steps we outline below) has reached the conclusion that salt works were one of the main reasons for the foundation and growth of Grosseto. Established as a small village around AD 700, it became a bishop's see (AD 1138) and

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later a *Comune* (13th century AD). The research also suggested that the development of the Etruscan town of *Rusellae* in the 6th century BC, very close to Grosseto on the hills to the north, could have some relationship to the exploitation of this precious resource. At present we have no more than generic indications from literary sources that there would have been salt-works before the 12th century AD somewhere in the region of Grosseto. The plain was reclaimed in the 19th and early 20th centuries by raising the topsoil of the lower-lying areas by around a metre, making it impossible to carry out fieldwalking with success. The size of the study area (c. 14,000 hectares) means that there are inevitably practical funding constraints, so we chose to evaluate the most promising location of the salt works from the Roman period, or even earlier, until the high Middle Ages, through spatial analysis using the hydrology tools in ArcGIS 9.3. The results can give us some indications about how this vast plain can be reduced to small areas – no more than a few hectares each – with the greatest potential for field evaluation. These can be surveyed with geophysics, trial trenches and, where successful, extended excavations.

To the best of our knowledge, there has only been one other attempt to evaluate the relationship between settlements and salt works (Weller *et al.* 2011); this study overlay buffer zones centred on settlements and the known position of salt springs, which relate to settlements quite differently to the salt work of our case study.

Predicting the location of the Grosseto salt works through time

Data

In this section we briefly outline the available data set. We refer to the most recent literature (Citter and Arnoldus-Huyzendveld 2011), discussing its value for producing an evaluation map, rather than its significance for a historical discussion.

The geomorphological data

The plain of Grosseto, surrounded by low hills, is the surface of a delta extending along the west coast of central Italy. It is characterized by a rather flat marine platform, slight subsidence and a small tidal excursion (Bellotti 2000). The plain is composed of a now reclaimed lagoon, which is more or less isolated from the sea by sandy coastal barriers. Its main river is the strongly meandering Ombrone, the second largest river of Tuscany. A second, much smaller river, is the Bruna, located in the north-western part of the plain.

During the Holocene, due to the post-glacial sea level rising, the plain has been subject to intensive changes, like the gradual infill and restriction of the lagoon by river sediments and the seawards expansion of the dune belt (Bellotti *et al.* 2004). The city of Grosseto is located upon a slightly higher Pleistocene terrace, which has remained free of natural and artificial infill. The terrace morphology is rather flat, but it becomes slightly undulating to the north through dissection by a network of minor water courses, a configuration that over time may have caused local erosion and accumulation. However, that must have been a process on a much smaller scale than the overall infill of the plain through late-Holocene floodings.

More recent changes include the artificial infill of the lower areas of the plain during 20th century land reclamation (Randone 1995), which further reduced the remaining lagoon; and, moreover, a marked retreat of the coastline (Bellotti *et al.* 1999).

The area of Grosseto is well covered by maps of physical land characteristics. Apart from the geological maps of the National Geological Service, there exist good soil maps on a more detailed scale (Van Berghem *et al.* 1991, Sevink *et al.* 1986). The 1:50,000 map of the Landscape Units (Fig. 1), which provides useful information for the integration with archaeological data (Citter and Arnoldus-Huyzendveld 2011) was derived from the latter two.

A detailed reconstruction of Holocene landscape development is given by Arnoldus-Huyzendveld (2007). For the present purpose, the following aspects of the local historical landscape changes are particularly relevant:

- the River Ombrone closely followed the border of the terrace near Grosseto until the adjacent meander was naturally cut off during a flood in the late 13th or early 14th century, which completely changed the relationship between the town and the river (Arnoldus-Huyzendveld 2005);
- it seems that the lagoon has always been divided into sub-basins by radially extending slightly elevated areas. This morphology must have determined the selection of the areas suitable for salt winning and for the creation of a channel connecting the salt pans to the sea;
- apart from the reduction of its outline and its depth, in historical times the lagoon waters underwent a change from salt to slightly brackish; this must have been an additional motive for the stepwise shifting of the known salt works in the direction of the sea after the 14th century.

The archaeological data (Fig. 2)

As yet, we have no archaeological data about the salt works in the region of Grosseto. Almost all the known sites in the plain of Grosseto and in the surrounding hills date to c. 100 BC–AD 200. We have some relevant information for the Bronze and Iron Age, as well as the whole time span of the Middle Ages, though we still lack Etruscan farms and villages. One major Roman settlement has been investigated through geophysics – Aiali (Campana *et al.* 2009). Only a handful of sites have been excavated apart from the two towns of *Rusellae* and Grosseto. These include the prehistoric and protohistoric sites of Scoglietto, Spaccasasso (Leonini *et al.* 2007), La Fabbrica (Lo Vetro 2007), and Fontino (Volante 2007), the Roman temple at Scoglietto (Cygielmann *et al.* 2009), the Roman productive and storage site at Lo Spolverino (Chirico *et al.* 2011), and the early Roman villa at Nomadelfia and the late Roman villa at Le Paduline (Cygielman ed. 2004 and Cygielman 2005), the early and high medieval hilltop site at Poggio Cavolo (Salvadori *et al.* 2006; Citter, Vaccaro 2008). Thus, the greatest amount of knowledge comes from survey (Citter 2007a; Vaccaro 2008; Citter,

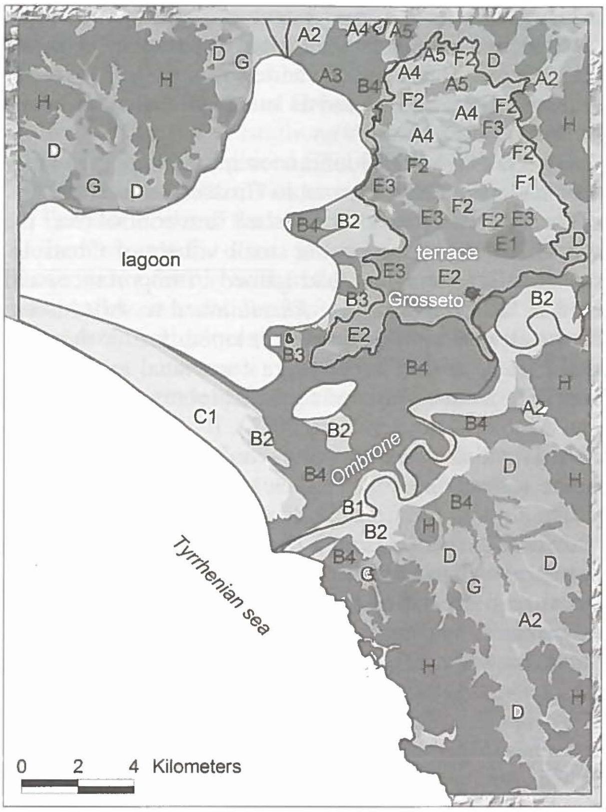

Figure 1 Part of the Landscape map of the Grosseto area, with the lagoon outline reconstructed for about c. 1300 AD; the Ombrone still runs close to the city; in black the outline of the Grosseto terrace; the black square indicates the first known position of the saltworks, located at Squartapaglia until 1386. Legend: Legend: D, recent and older alluvial fans; G, recent and older colluvium; H, conglomerates, limestone, marly rocks, clays, sandstones, shales; A2, recent flood plain with moderate drainage; A3, recent flood plain with slow drainage; A4, river terraces with good drainage; A5, river terraces with slow drainage; B1, reclaimed plain with well-drained soils; B2, reclaimed plain with good drainage; B3, reclaimed plain with moderate drainage; B4, reclaimed plain with slow drainage; C1, dunes with very dry soils ; C2, ancient dunes with moderate drainage; E1, Grosseto terrace, flat, slowly drained; E2, Grosseto terrace, undulating, moderately drained; E3, Grosseto terrace, undulating, slowly drained; F1, travertine plain with good drainage; F2, travertine plain with moderate drainage; F3, travertine plain with slow drainage.

Arnoldus-Huyzendveld 2011), which confers to the data an additional degree of uncertainty. Moreover, during the land reclamation (Citter and Arnoldus-Huyzendveld 2011: 100–104) the crucial area of the lagoon border west of Grosseto has been covered by a consistent amount of artificial infill, which makes traditional survey, and most geophysical techniques, useless. On the other hand, the settlements in the eastern portion of the plain are located upon a terrace with a moderately deep – 70 to 100 cm – ploughed soil, which makes traditional excavation predictably unsuccessful.

Figure 2 Main sites mentioned in the text.

The historical and administrative context
The plain of Grosseto could have belonged to two jurisdictions in the Etruscan and Roman periods: the northern, smaller, portion ruled by *Vetulonia*, and the remainder by *Rusellae*. We probably have an echo of this in an early medieval privilege (Citter 2007b; Fig.3a). Torelli (1987) hypothesised that the powerful Etruscan town of Chiusi aimed to have access to the sea and so gained a kind of protectorate over the nearby *Rusellae*. This would explain the anomalous case of both towns being ascribed to the *tribus Arnensis* after the Roman conquest, as if they were a single administrative area. One can imagine that Chiusi had also always had an interest in gaining *Rusellae*'s salt revenues. The end of the Roman empire seems to be a turning point, because it is likely that the whole plain finished under the rule of the bishop of *Rusellae* and, later, its Carolingian earl (we have no trace of a Lombard *gastaldus* for the 7th and 8th centuries). By that time, *Vetulonia* had been eclipsed and replaced by new foci of power: an enclave of the town of Chiusi at Castiglione della Pescaia (not surprisingly, a place along the sea shore close to potentially good locations for salt works), and the abbeys of *S. Pancratius* and *Sestinga*, which both shifted later to new locations (Fig. 2). We know that in 772 an *exercitalis* of Chiusi (part of the town's elite) used to obtain each summer 10 *modii* of salt from the *dominico* of the *curtis* of *Iuncarico*, which should be a rather large estate positioned in the northern portion of the lagoon. If it was the Roman *modium*, this would correspond to140 kg per summer (see Citter 2005: 78 and Moinier 2011: 138). Of course,

this is only the proprietor's part of the revenue, and we can guess that there could have been more saltworks in the area. It is noteworthy that both the above mentioned monasteries of *S. Pancratius* and *Sestinga* lie at the end of the lower Bruna valley, a small river flowing into the northern portion of the early medieval lagoon, as drawn by Antonia Arnoldus-Huyzendveld (2007). Also remarkable is the interest of the papacy (Citter 2007c), whose set of properties encircled the lagoon in the early 8th century (and possibly since the 5th century) (Fig. 3b). The privilege of 814 to the abbey of S. Antimo (which survives in a later document based upon more ancient sources) defines a portion of territory around the lagoon which is very close to the presumed extension of the southern portion of the territory of *Vetulonia* in Etruscan times. Among the toponyms are *mostaria et angularia*, perhaps salt basins and fishponds, which are often connected to each other (Citter 2007c: 218, Farinelli 2007: 36, 68, 78, 86–87). In the same way another charter produced by the powerful bishop of Lucca mentions the tradition of collecting salt and crops from his properties along the coast of southern Tuscany (Citter 2005: 80). Moreover, the boatmen involved in this commerce used to do the same for the *Dux* of Lucca. Thus, we know that there were salt works along the southern Tuscan coast in the early middle ages, though we lack any precise geographical indications. The last early medieval incidental mention of salt works is in a charter of AD 973, which cites for the first time Grosseto as a *castrum* (at the time meaning more than a simple village), and salt works dependent on one or more of the 45 sites mentioned in the charter, though only five can realistically be considered as such, and Grosseto is one of them (Citter 2005: 84).

By AD 1050 the Aldobrandeschi, a Lombard family who had moved from Lucca to Grosseto around the end of the 8th century, had established firm control over the whole region. However, the small village of Grosseto, one of their properties, had gained in importance, and by AD 1138 the bishop of *Rusellae* had to shift his see to the new town. Grosseto developed during the 12th and 13th centuries, becoming a communal town which was only formally related to the Aldobrandeschi (Citter and Arnoldus-Huyzendveld 2011). By that time it ruled directly a district covering the whole plain and a portion of the surrounding hills (Fig. 3c).

The first unquestionable mention of salt works in the district of Grosseto is in a charter of 1152 (*terraticum salinarum* – Farinelli 2009: 109, note 107), which shows the strong interest of both the Aldobrandeschi and the powerful monastery of S. Salvatore al Monte Amiata. However, the main document is the debated *charta libertatis* of 1204, where the Aldobrandeschi are forced to grant the community of Grosseto half of all the salt revenues (Mordini 1995).

This document informs us that 840 tons of salt were produced in 1203. The 13th century seems a crucial period of intensive production. The salt of Grosseto was

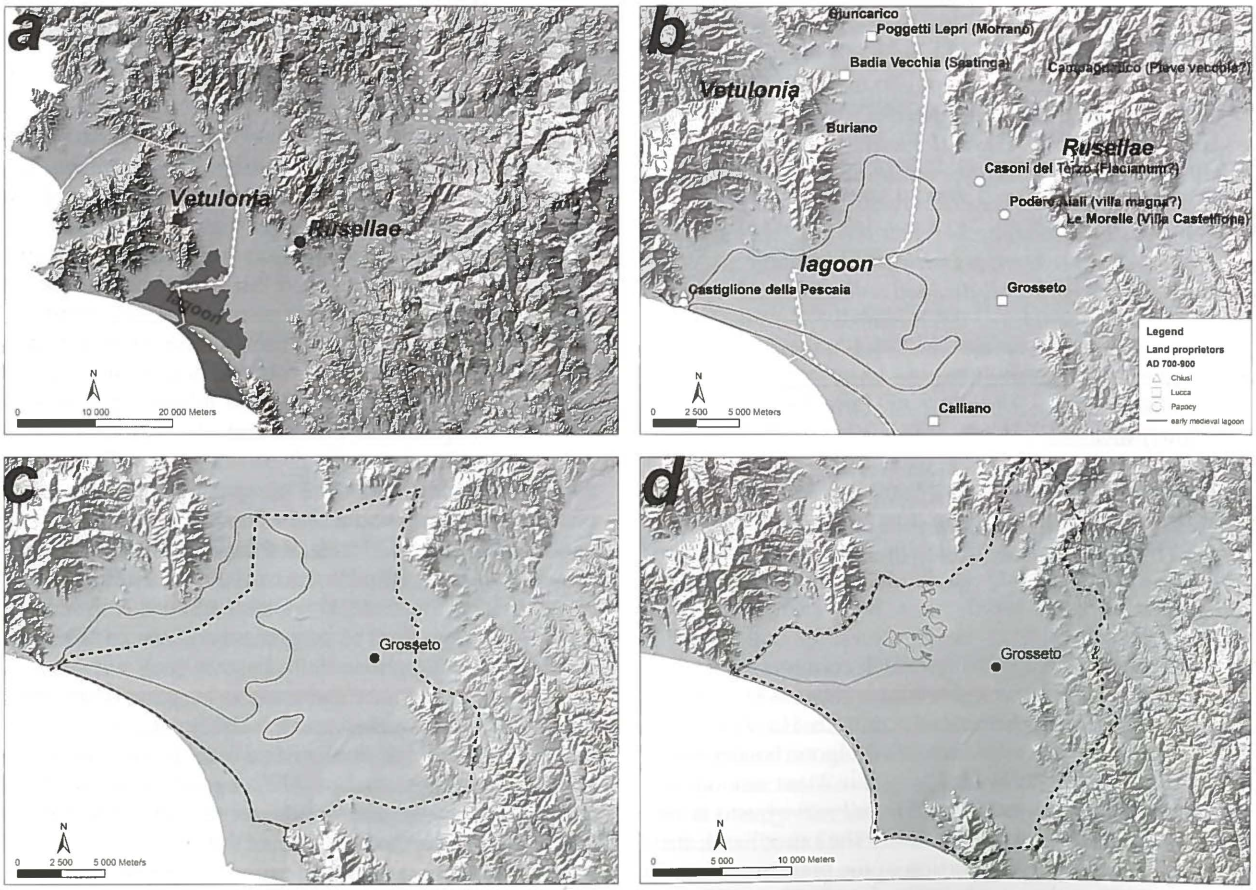

Figure 3 The administrative structure of the area respectively in the Etruscan and Roman periods (a), during the early Middle Ages (b), in the 13th century (c) and in the 19th century (d).

sold in Siena, Florence and Genoa, and it was famous enough to deserve a literary mention by medieval poets (Farinelli 2009: 107). The interest of Pisa in the salt revenues of the lagoon of Grosseto is well known and in particular those at Castiglione della Pescaia in the 13th century. Pisa thus replaced Chiusi until it was conquered by Florence in 1406 (Wickham 2001: 463).

The salt works of the northern side of the lagoon have shifted towards the coast, following a process similar to those we are dealing with in the southern portion. In fact, salt works are mentioned in 1285 close to the *Abbatia de al fango*, which is the new position of the former *S. Pancratius* on a small island in the deeper part of the lagoon, very close to Castiglione della Pescaia (Farinelli 2009: 112).

The administrative situation did not change the situation substantially until the 18th century, when the network of communities, the predecessors of the present-day *Comuni*, took form (Fig.3d). Meanwhile, the salt masters of Siena declared in 1386 that the former salt works near Grosseto could not be used anymore, because the lagoon environment had changed to freshwater. From the 15th century on, the new salt works were shifted south-west of Grosseto, along the Ombrone river, in a place very close to *La Trappola* (Zagli 2007: 89–90). We have no mention of salt winning by other techniques than evaporation, as seems appropriate for the regional climatic conditions.

Interpolations and forecasts

The ArcGis model, step by step (Fig. 4)

The first step is to select the input data set. Our starting data consisted of a point shapefile of the elevations of the plain and its surroundings, provided by the Tuscan regional map service. We removed all points located on roofs, channel ditches and quarries, which would have misled the interpolation. Next, we had to provide a simulation of the early Roman elevations. We have some, but not many, helpful indications: the 5th century AD level at Spolverino lies some 2.2 m below the present level (Citter and Arnoldus-Huyzendveld 2011: 32). This site is located near the lagoon, and its depth is compatible with a 3rd century BC datum from geoarchaeological coing (Biserni and Van Geel 2005), which has yielded a depth for the Roman level of c. 3.5 m (including the land reclamation layers) below the present surface. On the terrace of Grosseto, not influenced by the late Holocene fills, altitudes must have remained substantially unchanged over historical times. In fact, according to geophysical survey, the pavement of the Roman villa of Aiali lies at a depth of less than 100 cm (Goodman and Piro 2009: 298). This shallow burial depth may be due to local minor erosion and accumulation processes. On the basis of these, and other data, we derived a hypothetical lagoon coastline for the Roman period (Arnoldus-Huyzendveld 2007) by subtracting 3.5 m from the present altitudes in the eastern area of the hypothetical Roman age lagoon, 2.5 m in the western area (presuming a minor degree of natural infill related to the major distance from the Ombrone), and zero on the terrace. At the time (in 2007) we did not take into account a lower sea level for the Roman period, but in the present paper we balance this datum by selecting a pour point at –80/90 cm for the calculation of the potential salt working basin.

A similar process was repeated for the Middle Ages, when the lagoon had been partially filled in and was completely isolated from the sea.

Once the data set was completed, we started to build the model using ArcGis' *model builder*. The first step was to create a DEM of the selected area, in which a crucial point is the setting of the cell size (Fig. 4.1). The optimal value depends on the data set; we calculated the nearest neighbour of the elevation points and the result was 108 m. A 50 m cell size therefore seemed to be a good compromise between the data consistency and a sufficiently detailed output map.

We chose to add to the calculation a correction for the Ombrone river incision, in order to create a more realistic model of the hydrology of the plain (Fig. 4.2). However, this seems not to affect much the stream modelling in the crucial area of the lagoon. For that purpose we applied four buffers of 50, 100, 150, 200 m upon the Ombrone course as reconstructed for the Roman period (Arnoldus-Huyzendveld 2007), in order to simulate the river valley incision and so to force the stream network to take account of the presence of the river. This shapefile was transformed into a raster file, whose cell values represent the depth of the incision, increasing towards the centre of the river.

Next, in the model we subtracted the values of the Ombrone valley cells from the DEM of the plain (Fig. 4.3). The result is the best approximation available of the morphology of the plain in the Roman period. We continued with the calculation of the flow direction and flow accumulation (Fig. 4.4). These operations provided the base for the stream network builder (Fig. 4.5), because they calculate where the water flows to and where it concentrates, according to the elevation value of each cell. In other words, this calculation determines the theoretical stream pattern over a given surface.

In order to model the location of salt works it was necessary to select a pour point, i.e. a point where a specific basin has its final water outflow. We know that the sea in the Roman imperial times was around 1 m, or somewhat less, below the present level (Schmiedt 1972, Leoni, Dai Pra 1997, Goiran *et al.* 2009). We therefore selected a pour point snapping on one of the streams at ca –90 cm with respect to the present sea level (Fig. 4.6). Apart from altitude, a second condition for the selection of the pour point is its position right upon the border area of the lagoon (the only possible location for a salt works; Agricola's 16th century recommendations for the creation of salt works in a flat coastal plain provide the same instructions). A third condition is the feasibility of creating a channel from that point to the sea, since salt water must flow into the area.

The model allows us to calculate the extension of the basin in relation to the selected pour point. The height of a hypothetical dam barring this depression was set at 70 cm, by analogy with the Roman imperial salt works excavated in the coastal plain of Rome (Arnoldus-Huyzendveld *et al.* 2009). We simulated this by creating a new raster set within that of the specific watershed, whose cells are all above a given elevation. We applied values of 40 cm above the pour point for the bottom

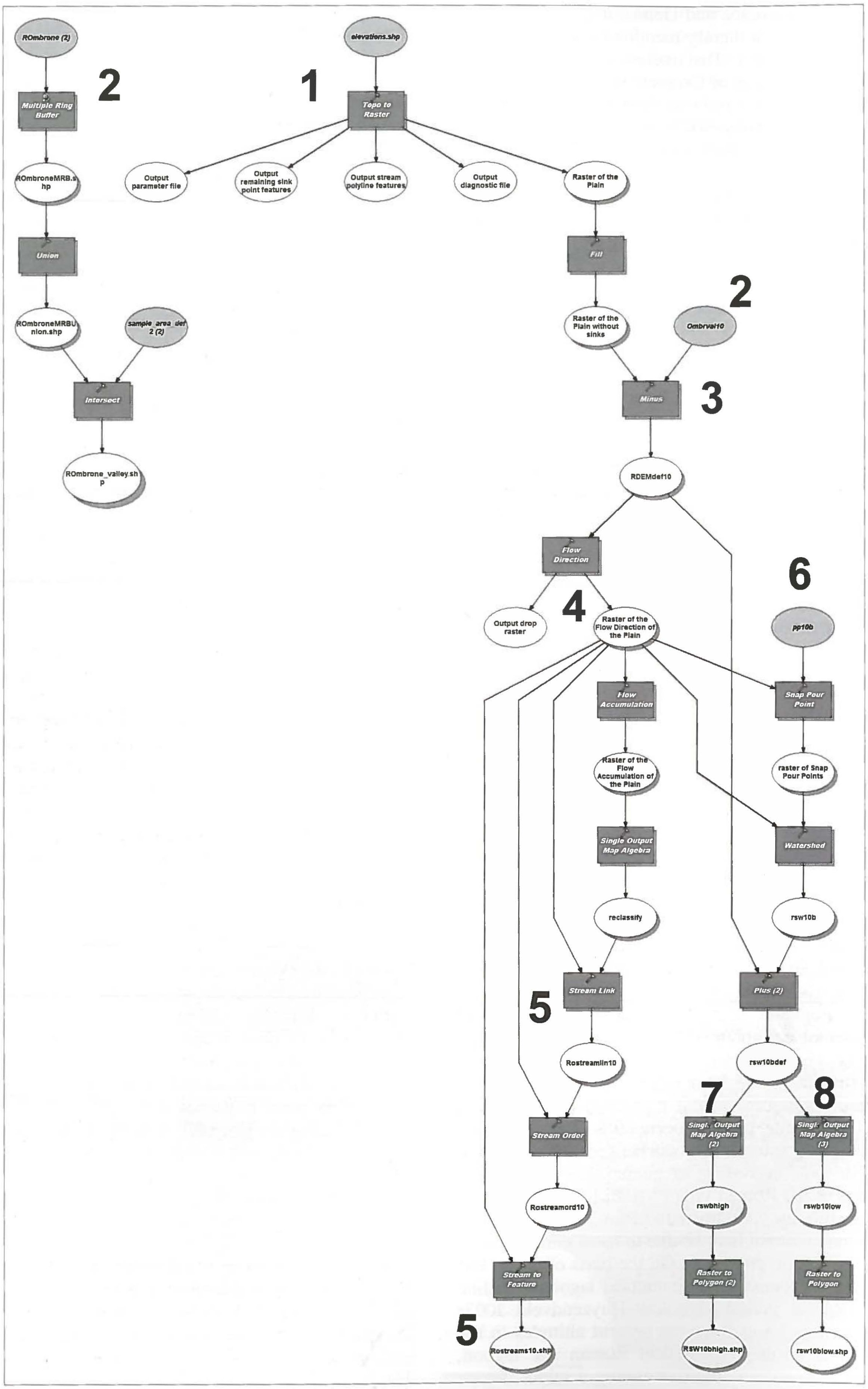

Figure 4 The ArcGis model. Dark grey: calculations, light grey: input data, white: results. The numbers from 1 to 8 refer to the steps of the process discussed in the text.

of the basin (Fig. 4.7), and 70 cm for the top (Fig. 4.8 – we avoided assigning 0 to the first parameter, since we presumed that the deeper parts of the basin did not fully contribute to the salt production by evaporation). The two rasters of the bottom and of the top level of the presumed basin were subtracted, which yields the extension of the basin from which salt could be extracted effectively.

We repeated the procedure for the late Middle Ages (around AD 1300), presuming a salt winning technique based upon the isolation of a bay from the main lagoon body as in the Roman epoch. We know that in the Grosseto area this technique was substituted, at least after the 14th century, by the creation of a series of artificial basins (the *La Trappola* salt works). We have almost no indications for setting the terrain elevations for the end of the Middle Ages. However, the lagoon was declared isolated from the sea by AD 1386 (Arnoldus-Huyzendveld 2007: 56). The definitive abandonment of Lo Spolverino by the second half of the 5th century was followed by the progressive covering of the ruins up to the present with more than 2 m of sediment. We used this datum for both the early Roman period and the late Middle Ages as a comparative elevation. The early to high medieval site of Rachalete (Campana *et al.* 2009: 320), which lies close to the Roman villa of Aiali, shows the same environmental and morphological conditions as the latter, suggesting that upon the terrace almost no ground level change had occurred over a thousand years.

We created a new elevation data set by comparison with the lagoon outline as hypothesized for about AD 1300 by Arnoldus-Huyzendveld (2007: 57), which was based upon independent data. The surface growth level applied was set at about half of the Roman values: 1.5 m in the eastern part of the plain and 1 m in the western part. Starting from this new elevations data set, it is clear that the stream network and, consequently, the pour point was different. The optimal location for salt exploitation shifted to the west with respect to the Roman period. We wanted to check whether the literary references (though not precisely georeferenced) and the very unusual crop mark visible in all aerial phorographs (Caprasecca 2011) could fit in with the general environmental conditions for a salt work. It is important to note that 'island' of the Grosseto terrace is located in this area.

The final results for the Roman and late medieval periods are shown in figs 5, 6 and 7. For the Roman period the potential extension for salt winning is around 22.2 hectares, whereas for the Middle Ages it is 3.6 hectares. However, the majority of these areas lie far from the pour points, which would make salt winning very difficult. Thus, the areas closest to the barriers amount to 5.1 hectares for the Roman period, and 2.7 for the Middle Ages.

Based upon a presumed effective water height of 30 cm, use of a basin delimited by a dam, and the full extraction of the sodium chloride present in seawater (30 gr/l), the revenue of these salt works would amount to 90 tons of pure salt per hectare per cycle; unfortunately we do not know how many production cycles there were each summer with the application of this technique, though it was probably much less than in the more refined system with small sequential basins. Thus 5.1 hectares of salt works implies a maximum production of about 460 tons per production cycle, and 2.7 hectares of about 240 tons per production cycle.

Recently, Moinier (2011) reviewed the literary sources for salt production in the Roman period, pointing out that any mathematical formula should be verified in each regional context, because of the variation of key factors. For the case we are discussing, however, we have two relevant data. The modern *salinae* at La Trappola produced 2,527,200 *librae* (pounds) of salt in 1745 (http://www.storia. unisi.it/uploads/media/saline_trappola_1752_01.pdf), with normal production of 2,400,000, that is c. 840 tons, which is, surprisingly, the same amount as the charter of 1204. These salt works were organized in three parallel rows of basins (*lagacci-*

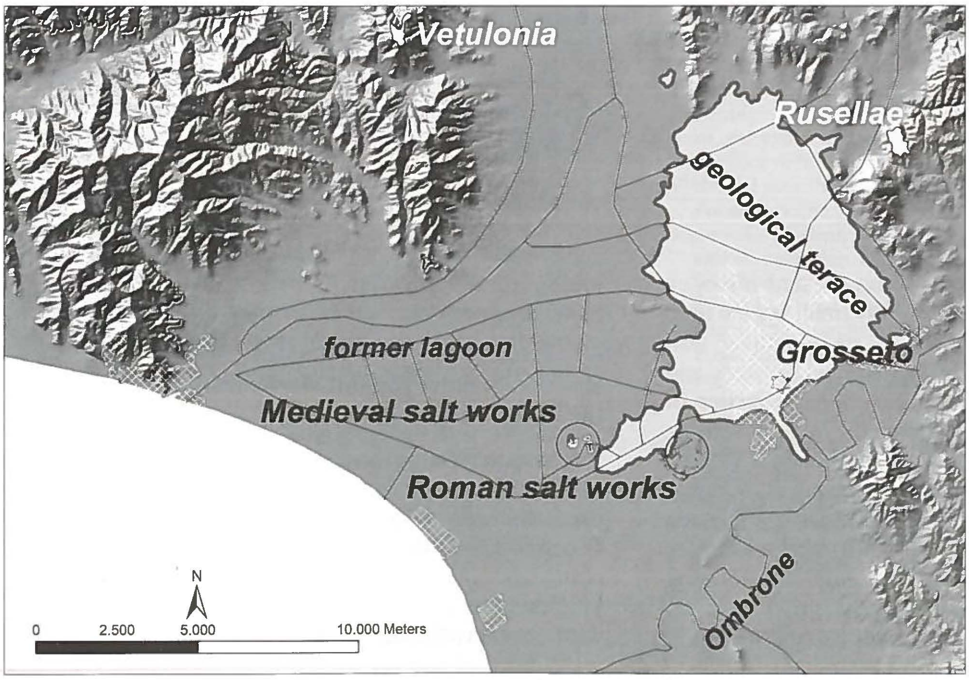

Figure 5 The position of the presumed area of the Roman and late medieval salt works, according to our evaluations, in the contemporary landscape. The dashed areas are the urban centres.

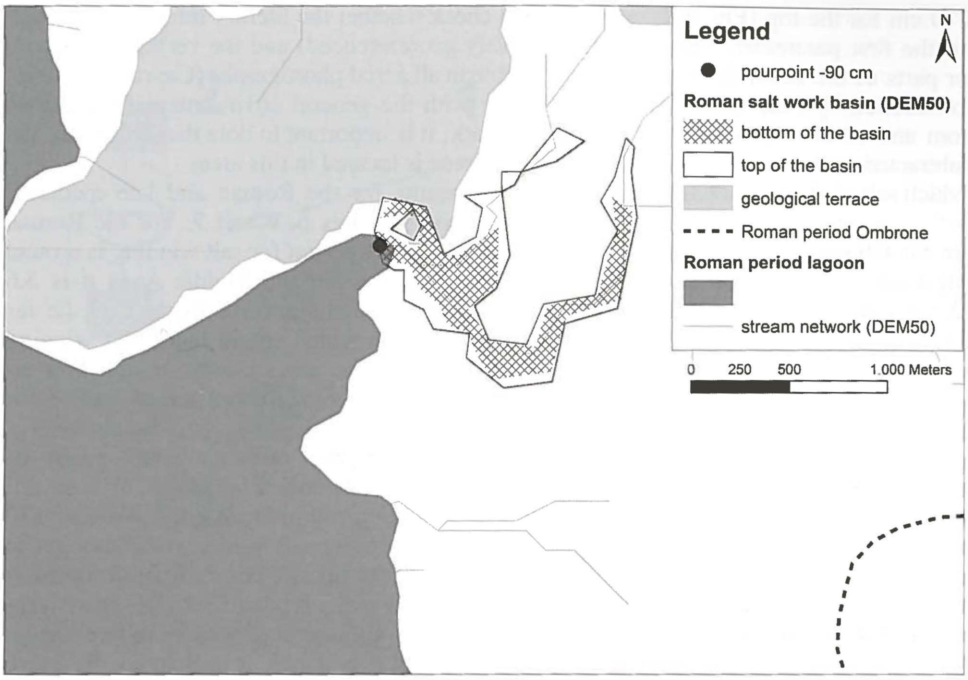

Figure 6 The evaluated most potential basin for the Roman period, according to a 50 m cell size DEM and a pour point close to the presumed lagoon coastline. The most profitable salt winning area is the blank strip between the top (hollow) and the bottom (cross-hatched) of the basin.

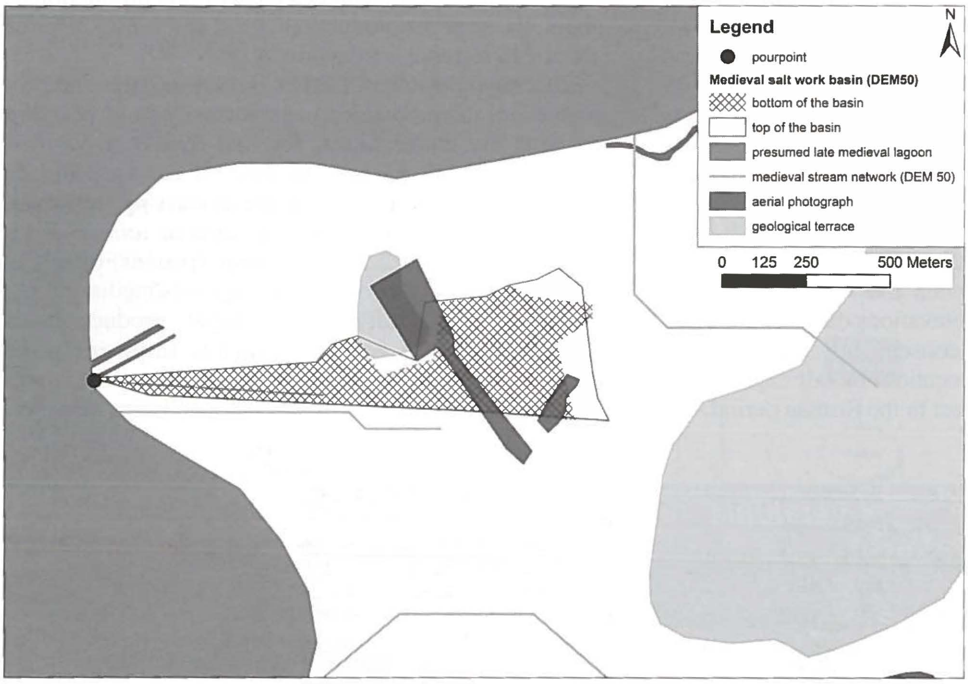

Figure 7 The evaluated most potential basin for the late Middle Ages, based upon a 50 m cell size DEM and a pour point close to the presumed lagoon coastline. The most profitable salt winning area is the blank strip between the top (hollow) and the bottom (cross-hatched) of the basin.

income basins, *cottoi*-evaporation pools, and *aie*-open stock areas). The first consisted of 98 small basins of c. 97 m^2 each, i.e. nearly 1 hectare, 25 cm deep (see also Caprasecca 2011). According to these parameters and descriptions we could guess that the effective portion of the presumed basins used for late medieval salt winning should be more or less 1 hectare. The main unsolved problem is that using the rows of basins is a rather different technique to a simple basin with a barrier. However, archaeological proof is not only necessary for earlier periods; other standard calculations, different types of salt, and different saltworks provide lower values (see e.g. Citter 2012: 195). Moirier (2011: 1430 assumes a salt production for the whole of Etruria in Roman times (i.e. from Rome to Pisa) of about 3,000–5,000 tons per year.

Discussing data: the salt works from the Iron Age to the Middle Ages

Salt production is one of the most elusive human activities for an archaeologist to find. The first presumed salt works along the Thyrrenian shore near Grosseto seems that of the Late Bronze–Early Iron Age permanent site at Punta degli Stretti inside the lagoon of Orbetello (30 km southward – see Poesini 2012 with previous literature). This settlement has produced many pots of the *ad impasto rossiccio* type (literally 'reddish fabric'), whose function is still debated: the two main hypotheses are salt or stock-fish production. A Bronze age settlement with salt works has been found at Isola di Coltano, south of Pisa, along the Thyrrenian coast (Pasquinucci, Menchelli 2002). The *briquetage* technique is highly debated, though traces can be found from Normandy (Carpentier et al. 2006: 34) to Andalusia (Morère 2002: 184). Roman salt works are recorded both north and south of Grosseto, especially in Vada (north, near Livorno), Cosa, Tarquinia (Carusi 2008: 133–135), and Maccarese near Rome (Arnoldus-Huyzendveld *et al.* 2009). Up to now, Medieval salt works have not been investigated (as noted out by D'Arienzo 2011). However, recent literature points out that both dams and rows of basins are in evidence from the Roman period up to the modern age.

What might we expect to find in the plain of Grosseto? From the Roman period (or even earlier) to the present day, we could find a dam to separate the lagoon from the saltworking basin, one or more channels connecting the system with the sea, buildings for the workers and the temporary storage of salt (though in the early Middle Ages these are likely to have been wooden structures). Otherwise, we might find a more complex system of rows of basins that might leave sharper traces. All of them have been buried for centuries by alluvial sediments and land reclamation infill. The 'traditional' strategies of surveying or applying extensive geophysics would be too expensive. For these reasons, we think that the evaluations we have made are useful in as much as they reduce to a few hectares the areas to investigate with geophysics and trial trenches.

For the Roman period we also applied other cell sizes and different pour point positions in the model, but the results showed that there is an intersection area which seems the most likely location for salt working, despite differences in the procedure. It is encouraging that this area is very close to two 7th or 6th century BC tombs, whose meaning has always been questioned (Mazzolai 1960: 23; these sites were erroneously dated a century earlier in Citter 2012). The proximity to the presumed salt works of the early Roman period suggests that this could be the position at least from the period of *Rusellae*'s rapid growth (7th to 6th century BC), possibly until the end of the antiquity. The second half of the 6th century AD is now commonly regarded as a crucial turning point, because of climatic and environmental changes, with intensive flooding (Arnoldus-Huyzendveld 2007). This seems to be a good point in time for the closure of the antique salt works and the opening of the new ones, witnessed by 12th century AD literary sources, 18th century maps and aerial photographs. If the inferred model fits, we have a strip of land where the medieval road from Grosseto to the *saline* used to run, which separated two distinct basins of the lagoon (Fig. 5). The position of Grosseto between these two locations helps explain why a rather small village was founded and promoted here from Lombard to Carolingian times. Thus the model seems to fit in both with the evolution of the natural landscape and with the historical sequence.

How reliable are these hypotheses? Different choices in the shaping of the lagoon's shore affect the output, but do not seem to change radically the salt works' locations. Before we applied these tools, we hardly had any idea of where the salt works might be, apart from a generic statement that there should have been salt works inside the lagoon and that they could be even more ancient than literary sources suggested. The present analyses indicate two, distinct, small areas where, respectively, there could have been Roman (or even Etruscan or late Iron Age) and medieval salt works. These areas are small enough to be investigated by intensive geophysics and trenches, without the considerable funding that would otherwise be necessary to investigate a larger portion of the plain.

This approach fits in with the current sharp reduction of funds for archaeological research in Italy. It is crucial that we rethink our methods and strategies without resigning our right to investigate the past.

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