

Interpreting Field Survey Results in the Light of Historic Relief Change: The Fogliano Beach Ridges (South Lazio, Italy)

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Abstract

This paper details the authors' feasibility study into the use of historic elevation data for the mapping and correction of biases in the archaeological record. Detailed elevation maps produced by the Italian Military Topographic Institute (IGM) in 1927/8, in preparation of large-scale land reclamation works (Bonificá) in the Agro Pontino, were digitised and compared with more recent commercially available DEMs produced by the IGM. After the removal of a number of extraneous causes of differences between the two DEMs, the remaining differences could be correlated both to the historic activity that took place during the Bonificá, and to the effects of intensive agricultural land use in the subsequent 70 years. A brief discussion of the results of field surveys conducted in the area in 1998/9 demonstrates the need to include historic relief change as a significant biasing factor in archaeological land use models.

1. Background

The Pontine region, a low-lying and partly marshy area along the coast of south Latium, was taken up into the Roman power sphere in a slow process completed only midway through the 4th century BC, which is why the preceding period 500 - 350 BC is named "post-Archaic" rather than "early Republican" (Attema 1993). Much of it appears to have been marginal to the major political and economic developments of the time, and this translates itself into the relatively low density of surface ceramics reported in field surveys (Attema et al. in press, Van Leusen 1998). Low finds densities present us with particular interpretation problems because of the relatively large influence of biases in the type and amount of research conducted, the visibility of the surface, statistical effects, and geopedological circumstances (Van Leusen in press). It is the effect of the latter factor that we have attempted to study in more detail, using the landscape of ancient beach ridges around the Fogliano lagoon as our study area (figure 1). However, a second area, below Sezze on the margins of the Lepine mountains, was also studied for the same purpose, but was later dropped from the analysis because of problems with the quality of the available data.

This feasibility study into the use of historic elevation data for the mapping and correction of biases in the archaeological record was conducted as part of the Regional Pathways to Complexity (RPC) project¹ in the Pontine region (south Lazio, Italy). The general aims of the RPC project are, first, to understand indigenous versus externally-induced growth in complexity (especially urbanisation), and second, to conduct detailed surveys in marginal areas to understand the scope and nature of dynamics that are mostly known from urbanised sites. Specifically, the case study presented here is part of the project's methodological focus on GIS approaches to the detection of spatial patterning in the archaeological record. One reason for concentrating on the Fogliano area is that it has been subject to two major surveys in the last two decades (Voorrips et al. 1991, Attema et al. in press), and the surface record is therefore relatively well known; the other reason is that the Pontine plain as a whole was subject to major restructuring in

the late 1920s and 1930s by the Italian government in a so-called *Bonificá*. These works have changed many parts of the landscape, and must therefore be taken into account if we are to interpret and understand our survey data. A detailed elevation survey of the Pontine plain was made in 1927 by the Italian Military Topographic Institute (IGM), allowing us to compare the post-World War II relief to the relief that was present before the *Bonificá*.

Before we proceed to describe the feasibility study itself, a brief overview of the settlement and land use history of the area is in order. The landscape of ancient beach ridges around the Lago di Fogliano must have attracted humans from earliest prehistory, and flint artefacts dating from the Middle Paleolithic onwards were found during the surveys. This material seems to concentrate mostly along the banks of the larger water courses and the lake itself, and one can imagine the water rich environment being very well suited for fishing and fowling. However, throughout this period and into the late 2nd millennium BC human presence would appear to have been quite rare and impermanent, the earliest indications for agricultural activity and the use of ceramics dating to the Bronze Age.² Figure 2 shows the probable settlement locations for the protohistoric period (running from the Bronze Age up to the beginnings of Roman influence in the Pontine region, around 500 BC) as derived from the finds densities of the RPC survey, on the background of the 1928 DEM. The absolute number of finds from this period tends to be very low for most of the area surveyed - on the order of 1 to 5 finds per hectare. Settlement in this period seems to be concentrated on relatively well-drained capes and banks along the larger streams, where access to natural resources would have been easiest and preconditions for paleotechnic agriculture were positive (Kamermans 1993: 100-4; see also Attema et al. in press). By the end of this period (6th century BC), the number of settlements begins to grow.

Figure 3 shows the post-Archaic, Roman Republican, and early Imperial sites identified by the RPC survey, again covering a period of approximately one thousand years (500 BC to AD 500). The number of settlements has greatly increased, but this occurs mostly between 200 BC and AD 200 - the late Republican and

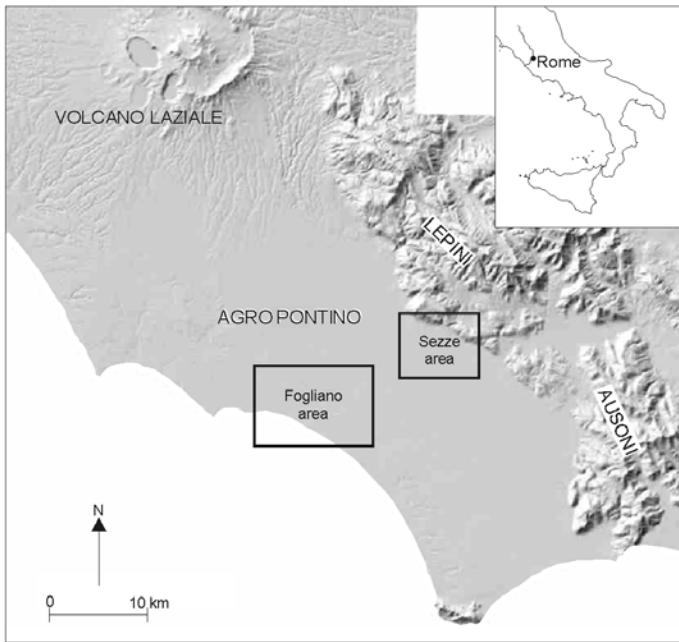


Figure 1: Location of the Fogliano study area within the Pontine region (Lazio, Italy).

early Imperial period. Settlement is concentrated on the relatively level and agriculturally usable area to the east of the Lago di Fogliano, where a late Republican village seems to have sprung up. We can tentatively relate this development to the inclusion of the area in the wider economy of Roman society. Roman agricultural technology (drainage of lower-lying areas, heavy ploughs) enables more land to be farmed; Roman hydrocultural technology (regulation of lake levels) enables commercial fisheries to be established in the lagoons; Roman roads and markets enable the commercial exploitation of the clay beds along the nearby Astura river; from the 1st century BC rich Romans even built their summer palaces along the banks of the coastal lagoons of south Lazio. All this activity makes it likely that the growing number of small farms became dependent on a few large specialised rural villae. However, this system collapses from the 2nd century AD onwards, as a wetter climate³ led to the return of marshy conditions and the expanding Roman empire found its supplies elsewhere.

2. Tracking Historic Relief Change

For the purposes of studying historic relief change in the Fogliano area, we have used historic maps of land use and land form. We know from historical research that the landscape was little changed since the Middle Ages, and historic maps dating to the 17th century show us an approximation of the landscape as it was in the late Roman period. Such maps may even be a better guide to interpreting the proto- and early historic archaeological record than the modern ones, which were made after major restructuring of the region during the Bonificá.

When we digitised and compared a very detailed digital elevation model (DEM) from the 1:5,000 scale maps prepared during the Bonificá (figure 4; IGM 1927) with a commercially available DEM of 1 arc second (~25 m) resolution (figure 5),⁴ some major differences became immediately apparent. Whilst obtaining a map of the differences between the two mappings was easy – all we needed to do was to subtract the two DEMs from each other – most of our study was concerned with the identification and removal of vari-

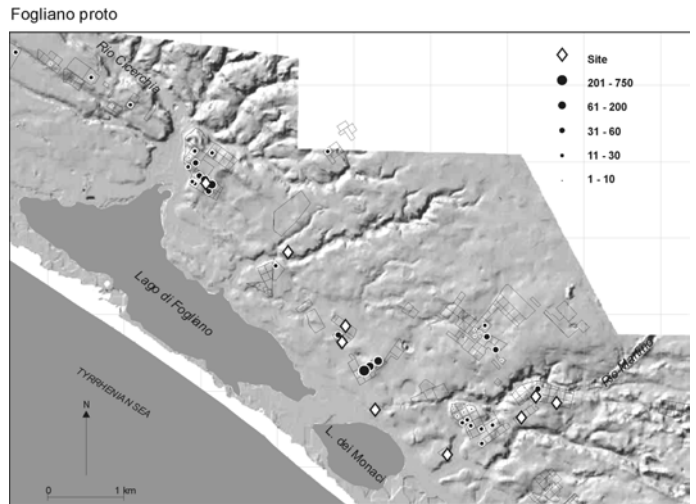


Figure 2: Results of the 1998/9 RPC survey in the Fogliano area, protohistoric period. Find densities per hectare corrected for surface visibility. Background: 1927 shaded relief map and km grid.

ous mapping errors obscuring the “real” relief changes that might have taken place during and following the Bonificá. Since it is usually one of the most important layers in a regional archaeological GIS, deficiencies in the DEM can cripple much analysis. These sources of error, and our attempts at removing them, are discussed in section 3; our interpretation of the archaeological evidence in the light of the “cleaned” elevation data follows in section 4.

3. Extraneous sources of differences between the two DEMs

The first point we need to make is that any DEM is a *model*, that is, a simplified version of reality. The type and amount of simplification that can be supported in any analysis depends on the questions asked, and any analysis relying on DEMs should be explicit about its limitations. Secondly, the *comparison* of two DEMs forces us to be even more precise in our description of the data. Differences between two DEMs may be due to real changes in the morphology of the terrain they represent, or to errors committed in the process of producing the digital elevation data, or to the precision with which the data were recorded, or to the use of different projection parameters and coordinate systems. The following list summarises seven distinct sources of differences we discovered between the two DEMs, which are NOT due to an actual (real) change in the land form.

Cause of difference/discussion

Scale:

The scales of the topographic map sheets, from which our two DEMs are derived, differ. The 1927 DEM derives from a 1:5,000 scale map; the more recent DEM derives from a 1:25,000 scale map. The reduced mapping scale implies that features are simplified and smaller features may even be lost. When comparing DEMs of different scales, such features will stand out as differences.

Resolution:

Both the horizontal (X and Y) and the vertical (Z) resolution of our two DEMs differ. (1) The horizontal resolution of the 1927

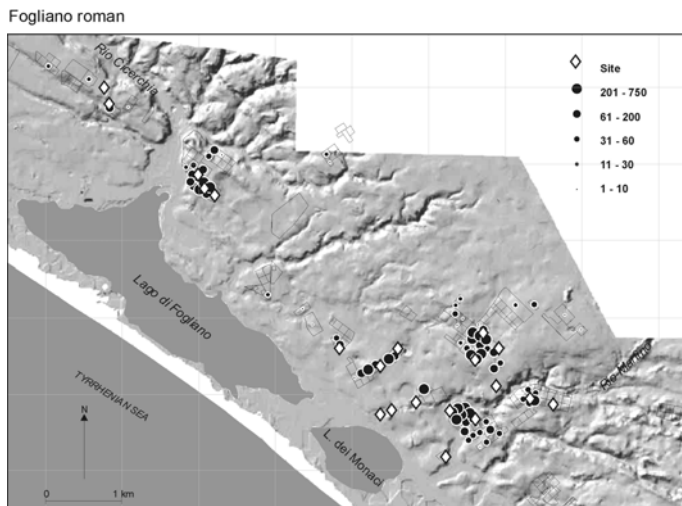


Figure 3: Results of the 1998/9 RPC survey in the Fogliano area, Roman period. Find densities per hectare corrected for surface visibility. Background: 1927 shaded relief map and km grid.

DEM is approximately 5 by 5 m; that of the more recent DEM is 1 arc second (approximately 25 by 31 m at the latitude of Italy). This means that an area represented in the latter by a single elevation value, is represented by approximately 30 (5 by 6) values in the former. Unless that area happens to be level, most of those values will be different from the single elevation value provided by the low resolution DEM – they will lower downslope, and higher upslope (see figure 6a), giving rise to the “banded” appearance in some areas of the raw differences map (figure 7a). The amplitude of the differences is related to the terrain slope and the difference in resolution of the DEMs: at any given percent of slope, the error is directly proportional to that difference. Because the error is systematic, we can devise a formula for deducing it: $E = \delta R * S / 2$ (where E = Error; δR = resolution difference; S = percent slope). (2) The vertical resolution of the 1927 DEM is 0.1 m; that of the more recent DEM is 1 m. Since the latter must round any values to the nearest whole meter this may lead to differences of up to 0.5 meters compared to the former.

Mapping errors:

Mapping errors may (and will) occur both during the original recording of elevation measurements, and during the subsequent cartographic process. Proper control procedures are needed to minimise the occurrence and effects of such errors. While we could not check the quality of the primary cartographic data, we were able to compare both DEMs with the elevation data in the original map sheets, and found some major mapping errors. One of these can be seen in figures 4 and 5 (area marked ‘A’) where a small valley that existed in the 1928 DEM had mysteriously changed into a hill by the 1950s. Whilst such obvious errors can be found and corrected fairly easily, there certainly remain many less obvious mapping errors in our DEMs - a very worrying situation...

Interpolation:

Our two DEMs were created by interpolation from digitised contour lines and elevation points, and this has led to the introduction of three different kinds of errors in the data. Since many properties of the resulting DEM are determined by the interpolation method (e.g., inverse distance weighting or thin plate splining; see Hageman and Bennett 2000), it is important to study its ef-

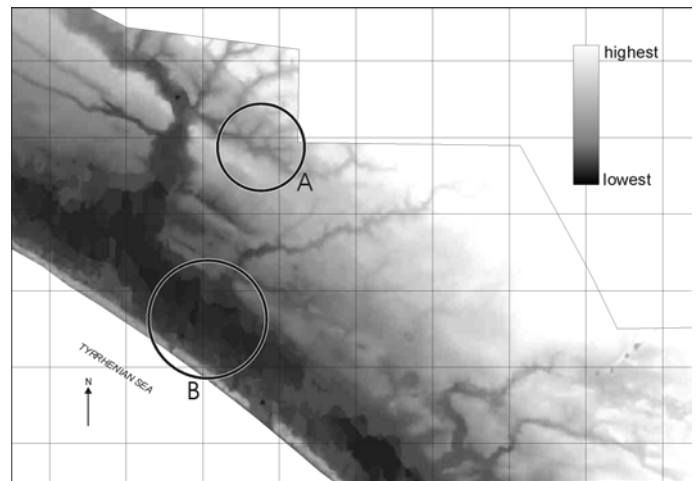


Figure 4: Digital Elevation Models of the Fogliano area, derived from the 1927 1:5,000 IGM maps.

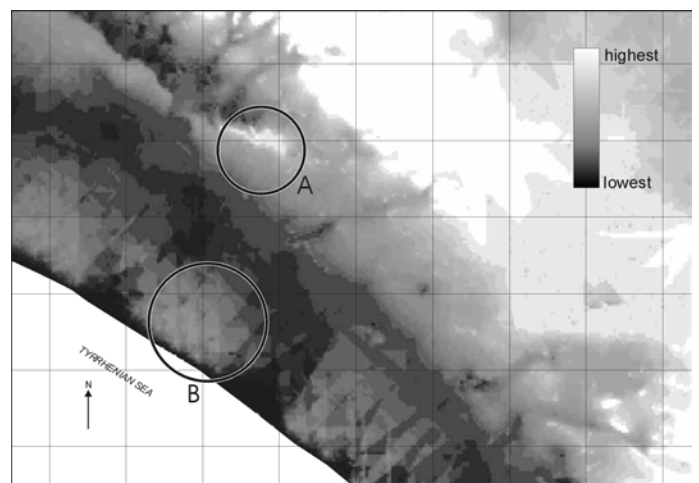


Figure 5: Digital Elevation Models of the Fogliano area, from 1" numeric cartography derived from the 1:25,000 IGM topographic map series (permission IGM 26/05/98, no. 4805). A: digitising error; B: interpolation error.

fects: (1) While the interpolation method used in creating the 1927 DEM is known (a “flood fill” algorithm provided by GRASS GIS), no such information was available for the more recent DEM. However, it appears from the data that some sort of inverse distance weighting using a low number of data points was used, and this has led to a large number of visible artefacts in the latter. Since the two DEMs were created using different interpolation algorithms, the interpolated values will also differ; (2) Some softwares are unable to handle ‘0’ (zero) as a real elevation value, in which case such values are ignored during interpolation. The method used to create the more recent DEM apparently suffers from this error which, for example, has caused the present dunes to “smear out” across the lagoons because the water’s edge was digitised as a zero contour (see figures 4 and 5, area marked ‘B’). The elevations here are clearly in error, and the area cannot be used in any further analysis; (3) Many interpolation algorithms that start from an input of digitised contour lines (including the ones used to create both our DEMs) do not resample the input values. Since contour lines always represent cardinal elevations, these end up being overrepresented in the resulting DEMs - the map histogram has a “saw tooth” appearance, with the distance between “teeth” depending on the vertical resolution of the original map. While

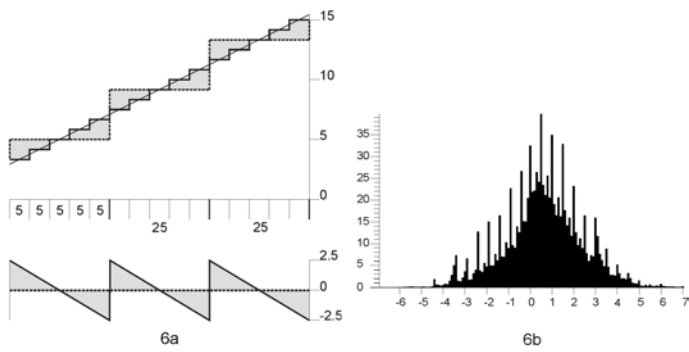


Figure 6: (a) On a slope represented by the thin continuous line, the differences between two DEMs of differing horizontal resolution (here, 5 and 25 m) alternate between positive and negative (shaded areas). The maximum difference depends on the terrain slope and the difference between the resolutions of the two DEMs. All units in m. (b) The histogram of a typical DEM shows the systematic “saw tooth” shape caused by overrepresentation of cardinal values. Horizontal axis: elevation in m; vertical axis: number of cells x 1000.

the 1927 DEM used contour lines every 0.5 m, the more recent DEM used contour lines every 5 m. In terms of accuracy, this means that values are only accurate to half the distance between contours, i.e. to 2.5 m in the case of the more recent DEM (see figure 6b).

Datum shift:

One of the parameters of the coordinate system used by both DEMs is its datum (origin). The horizontal datum of Italian topographic maps was moved by 2.53” (about 70 m) on one occasion; we could not obtain any information regarding changes in the vertical datum used in either DEM. We attempted to compensate for this by comparing the recorded elevations of relatively stable landscape features (e.g., buildings) in both DEMs. No vertical datum shift could be deduced from these. Left uncorrected, comparison of the two DEMs using different datums would have led to measurement errors especially in areas of steep slope; in this case, we were able to correct the horizontal datum shift.

The aim of identifying all these errors is, of course, to be able to correct them. Mapping errors (at least those that were discovered by us) were corrected by re-digitising and interpolating from contour lines on the original map sheets, and replacing the incorrect sections with these new data. Other areas of faulty data could only be “corrected” by removing them entirely from the analysis (using “masking” functions in the GIS). But the most interesting type of error was the one that could be estimated or calculated, because these errors could be corrected by first mapping them and then using them as “noise filters” when interpreting the differences between the two DEMs. Thus, the error formula referred to under “Resolution” in the list given above was used to calculate a map layer of the estimated amplitude and sign of the error, given the known slope and resolution of the more recent DEM. We then applied the correction by subtracting this calculated error from the observed difference between the two DEMs.

Figure 7 shows the differences between the 1928 and 1950s DEMs, both (a) before and (b) after the corrections were applied. The general effect is one of producing a much less extravagant map, whose values do not exceed 5 meters. We were now ready to evalu-

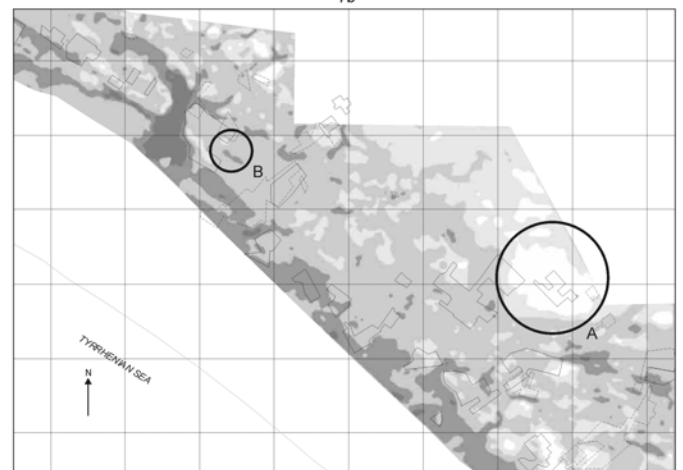
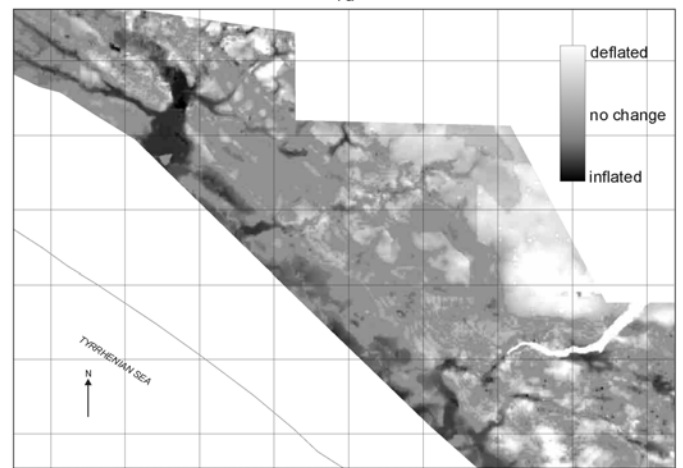
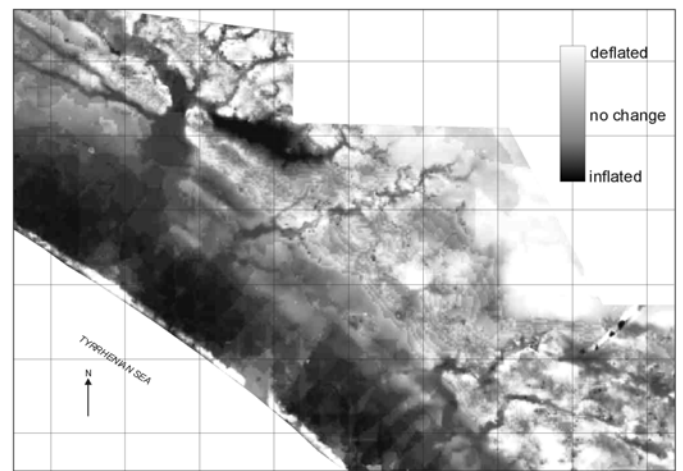


Figure 7: Interpreting the differences between the two DEMs. (a) uncorrected; (b) corrected; (c) simplified corrected differences between the two DEMs, with the RPC (continuous lines) and APP fieldwork areas (dashed lines) overlaid. A: area where large-scale sand removal may have taken place; B: area where farmer has levelled his field.

ate these differences in terms of natural and human processes that occurred in the area, rather than in terms of data error.

4. Interpreting the evidence

Any real differences between the two DEMs might be the result of either natural or human causes, or to a combination of both. In

the simplified corrected map of differences between the two DEMs (figure 7c), light zones have become up to 7 meters lower, dark zones up to 6 meters higher since 1927, and these zones may therefore betray works carried out during the Bonificá. However, we must also consider other processes such as plough-induced erosion and settling of zones with a clayey subsoil.

With the help of a soil scientist familiar with the region we began by evaluating the potential size of the effects of natural causes. We could see that the lower-lying areas (especially the small valleys) had all gotten considerably higher since the late 1920s, whereas some areas to the north-east had been reduced by 3 meters or more. The former is probably due both to intentional dumping of material into marshy places and to the effects of ploughing the slopes of the adjacent ancient beach ridges. The latter may well be partly caused by soil settling after the construction of the canal system during the Bonificá,⁵ but it is unlikely that a difference of more than one meter could be explained that way. We have some historic evidence that a top layer of aeolian sands may have been removed from some terrains in order to provide material for the founding of the new capital of the area, at Latina, and sand and gravel pits were still in use in the northwestern part of the study area in the early 1980s and recently (Sevink et al. 1984:28); archive research may reveal further evidence as to which terrains were historically involved in such activities.

Certainly many parts of the study area were levelled in order to facilitate access and workability for modern farming equipment, but such works were not often recorded (with the exception of the local, often marshy, hollows which were mapped on the 1920s land cover maps), so we have to rely on the recollections of the local farmers and on the occasional evidence from soil cores. Raised terrains also occur along the banks of the coastal lagoons, and we know from historical sources that these were deepened and the material used to raise the surrounding land enough to prevent the formation of marshes. In fact, this was one of the major aims of the Bonificá – to reclaim the Pontine marshes for agriculture by destroying the habitat of the malaria mosquito.

Figure 7c shows that some of the fields surveyed in 1998/1999 by the RPC project (and in the 1980s by the Agro Pontino Project) lie in zones affected by serious deflation or inflation. For the fields surveyed by the RPC project, the relation between the average amount of change in the elevation and the average density of ceramics found (see figure 8) gives rise to the suspicion that limited deflation (of ca. 0.5 m) is helpful in bringing archaeological material to the surface, while strong deflation (more than 0.8 m) destroys the record altogether. Conversely, even weak inflation tends to hide any archaeological material that might be present on the surface. A closer look at the observations made in the field confirms the general picture, and suggests ways in which our archaeological interpretations may be improved:

- Areas with strong deflation (over 1.5 m) were observed during the survey to have no soil profile at all and to be archaeologically sterile (area marked 'A'); Sevink et al., in their account of the soils of the area (1984:30), suggest that subsoil was brought from elsewhere, but this is flatly contradicted by the evidence for deflation from our study. It is therefore quite possible that the top layer of soil, including any archaeological remains, was removed from this area and used elsewhere in construction work.⁶ The late Republican village mentioned in the introduction may

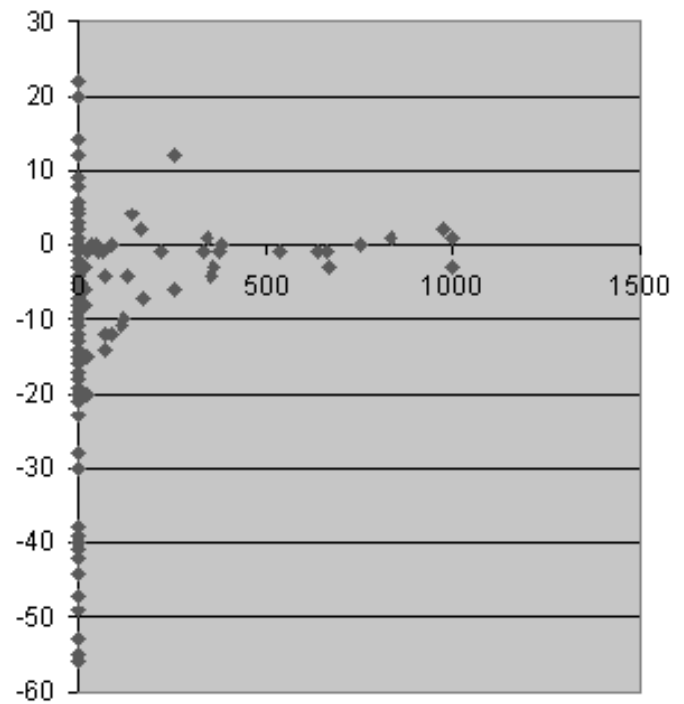


Figure 8: Scatterplot of average deflation/inflation (in dm) (vertical axis) versus average find density per surveyed unit (horizontal axis) of the Fogliano survey (Attema et al. in press).

therefore have extended further to the northwest than the results of our survey suggested.

- The reduction of local relief through ploughing or levelling can be traced in many fields:
 1. Areas that were observed during the survey to have an unusual soil colour or material often correlate with small hollows and valleys mapped in 1927/8 and afterwards levelled;
 2. The raised banks of canals dug during the Bonificá on occasion also contain archaeological material, which must presumably have come from the immediately adjoining stretch of the canal;
 3. We have several examples where our study confirms that sites located on hillocks were, along with the soil, “smeared out” across the surrounding fields by tillage;
 4. One hollow, which the owner informed us he had filled in using soil (containing Roman ceramics and building materials) from elsewhere in the same field, coincides exactly with a patch of inflated soil (area marked ‘B’).

These observations confirm the importance of landscape history as a factor biasing the results of field surveys, and the need for a structured “source criticism” so that we can trace and correct such biases.

5. Conclusions

This case study has demonstrated the feasibility of employing GIS to extract and interpret land form changes from historic elevation and land cover data. Although it is generally recognised that the interpretation of survey results requires knowledge of local geopedology and landscape history, workers have not yet gone very far with this approach. The present case study shows that,

provided certain requirements regarding data quality are met, historic elevation data can be used to track one of the most important factors biasing the results of field surveys today – changes in land form caused by human agricultural and construction activity. By comparing historic to recent elevation data, using GIS, maps can be made of the location and approximate amount of deflation/inflation influencing the presence and visibility of the archaeological record. Such maps can be used both to target future surveys to areas that are likely to have survived undisturbed, and to re-interpret the results of older surveys.

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Notes

- ¹ The RPC project was conducted jointly from 1997 to 2001 by the Groningen Institute of Archaeology and the Archaeological Institute of the Free University of Amsterdam. It studies protohistoric landscape and settlement dynamics in three Italian regions - the Pontine region, the Salento Isthmus, and the Sibaritide. Processes of centralisation, early urbanisation and colonisation are its main themes (Attema et al. 1998).
- ² The evidence for this comes from an unpublished pollen core from Fogliano (pers. comm. E. van Joolen), and from the unpublished finds database of the Agro Pontino Project (Voorrips et al. 1991).
- ³ As deduced from pollen cores analysed by Haagsma - cited by Attema (1993:253) and Veenman (1996:59).
- ⁴ A matrix of numeric data, containing one value for each 1" by 1" square, and based on the digitised contour lines and elevation points of the 25 and 25V map series produced in the 1940s and 1950s at a scale of 1:25,000 (IGM 1996:13 and Table 42).
- ⁵ Evidence of such soil settling is plentiful in the Pontine region. The approaches to many of the small bridges built in the late 1920s have had to be lengthened, and the concrete bottom of the channel below them broken through, because the surrounding land had sunk 70 cm or more.
- ⁶ It is known from historical records that large amounts of soil were brought in to found the new capital of the Agro Pontino at Latina.