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Assessing visibility and geomorphological biases in regional field surveys: The case of Roman Aesernia

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Abstract

Archaeological field survey data can be biased by many factors, such as ground visibility conditions (e.g. vegetation, plowing) and geomorphological processes (erosion, deposition). Both visibility and geomorphological factors need, therefore, to be assessed when patterns of settlement and location preferences are inferred from survey data. Although both factors have been taken into account in a variety of fieldwork projects and studies, their combined effects remain hard to predict. In this paper, we aim to address this issue by presenting a visualization method that helps in evaluating in combination the possible visibility and geomorphological effects in regional, site-oriented field surveys. Capitalizing on first-hand data on both archaeology and soil types produced by the recent Leiden University field survey project in the area of Isernia (Roman Aesernia, Central-Southern Italy), we propose a combined application of statistical tests and geopedological analysis to assess the extent and scale of the main biases possibly affecting the interpretation of the ancient settlement organization. Translating both sets of biases into GIS maps, we indicate the *likelihood* that negative field survey observations (absence of sites), in specific parts of the landscape, are genuine or rather distorted by biasing factors. The resulting “archaeological detectability” maps allow researchers to formally highlight critical surveyed zones where the recording of evidence is likely unreliable, and thus provide a filter through which archaeologists can calibrate their interpretations of field survey datasets.

KEYWORDS

deposition, detectability, erosion, field survey, site discovery, soil, surface visibility

1 | INTRODUCTION

Survey data are essentially fragmentary and biased by visibility factors and geomorphological processes. The impact of surface visibility on the recognizability of archaeological material at the surface has been a central debate in field survey archaeology in the last decades (e.g., Allen, 1991; De Guio, 1985; Francovich, Patterson, & Barker, 2000; Given, 2004; Terrenato, 2004; Terrenato & Ammerman, 1996; van Leusen, 2002; van Leusen, Pizziolo, & Sarti, 2011). At present, general agreement exists that our view of the past as offered by field survey data is critically distorted by many factors (Banning, 2002, pp. 39–79 for a summary of these factors) and that we should be very cautious using these data uncritically (Fentress, 2000). As a way to get around some of these biases, various correction methods have been proposed (e.g., Gilling & Sbonias, 1999; Nance, 1983; Shennan, Gar-

diner, & Oake, 1985; Terrenato, 2000; Verhoeven, 1991; van Leusen, 1996, 2001). Such studies, moreover, show that not only may surface visibility conditions impact heavily on-site recovery rates, but that it is also fundamental to take into account the role of Holocene erosional and depositional processes, before attempts are made to infer settlement patterns from field survey data (for a discussion on this theme for Mediterranean landscapes see Barker, 1995a; Bintliff, 1992; Bintliff, 2000; Brown, 1997; Feiken, 2014; Koopman, Kluiving, Holdaway, & Wendrich, 2016; Leonardi, 1992a; Potter, 1976; Sevink, 1985; Vita-Finzi, 1969: 237–248, 1999; Vermeulen & De Dapper, 2000; Walsh, 2014).

Through a systematic analysis of the most frequent methodological biases affecting the discovery of archaeological material during field survey, and using results from archaeological and soil research in the area of Isernia (Molise, Italy), we aim to assess the extent and scale of

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these biases in this region. Our test case regards the territory of the ancient settlement of Aesernia, where during the Roman conquest of Italy a colony was established by Rome in 263 B.C. Since 2011, a large-scale archaeological project has been carried out in the territory of this ancient town, mapping and (re-)considering both archaeological and soil characteristics of the area (Stek, Modrall, Kalkers, van Otterloo, & Sevink, 2015).

In the current debate on Roman colonization, there are divergent views about site densities and settlement organization in early Roman colonial territories (see Casarotto, Pelgrom, & Stek, 2016 with further references). The assessment of potential biases in the archaeological surface record, therefore, is becoming particularly pressing because it may eventually disclose which among these theories is the most plausible one. In the specific case of the territory of Aesernia, Stek et al. (2015) noted a variegated settlement arrangement in the distribution of Hellenistic and early colonial sites, characterized by long tracts of empty space in between localized concentrations of settlements, although a regularly dispersed settlement pattern was discerned in a portion of the western part of the survey sample area (see Fig. 1). If this variegated pattern of colonial sites reflected historical reality, it would differ considerably from conventional models of Roman colonial territorial organization. Considering the high impact that such an unexpected pattern of colonial settlement has for historical debates on Roman colonization, it becomes crucial to thoroughly assess the possibility that the recorded configuration is actually patterned by biasing factors. By combining archaeological survey data, field observations, and soil information, we develop a method to test whether the recorded early colonial site distribution in the territory of Aesernia is the result of visibility and geomorphological biases, and if so, to what extent.

2 | DATA

Our analysis capitalizes on the recently collected dataset of archaeological sites registered by the LERC team (Landscapes of Early Roman Colonization project, <http://www.universiteitleiden.nl/en/research/research-projects/archaeology/landscapes-of-early-roman-colonization>; <https://landscapesofearlyromancolonization.com/>) from 2011 to 2015 in the territory of the ancient colony of Aesernia (Stek et al., 2015). The project was first started with an EU Marie-Curie fellowship (FP7) granted to the second author and was based at Glasgow University, but in 2012 it moved to Leiden University and since then has been funded by the Netherlands Organization for Scientific Research (NWO) and the Royal Netherlands Institute in Rome (KNIR). The survey can be qualified as a regional, site-orientated survey: within a surveyed area of 1886.031 ha, all encountered scatters of archaeological material at the surface were mapped with a GPS, using a threshold for site detection of 5 sherds per square meter. Survey teams, consisting generally of five walkers spaced 10 m apart, investigated each accessible field unit (in total 6116 units, see Stek et al., 2015, pp. 255–257 for further details on the size of these units). In total, 99 archaeological sites were identified, of which 81 are interpreted as probable/possible Hellenistic settlements (Fig. 1).

The other primary dataset used in this analysis consists of information provided by two soil surveys of the area around Isernia (Koopmans, 1980; van Otterloo, 1981; van Otterloo & Sevink, 2016). This is used to assess the occurrence of possible recent gradational processes of erosion and deposition at a regional scale. The original soil surveys were carried out by the Laboratory for Physical Geography and Soil Science of the University of Amsterdam (Koopmans, 1980; van Otterloo, 1981) and a summary map was published later on (van Otterloo & Sevink, 1983). The soil map by Koopmans was originally at scale 1:50,000 and covers most of the territory surveyed by the LERC team around Isernia, whereas Van Otterloo's soil map is at scale 1:25,000 and part of it covers the extreme portion of the west survey transect (published in Stek et al., 2015, pp. 290–291). These maps were recently reviewed and checked in the field by van Otterloo and Sevink (2016) as part of the LERC project in order to produce a single, integrated map. This integrated map is at scale 1:25,000 and was obtained through a cross-check of the previously collected soil information and maps (i.e., Koopmans, 1980; van Otterloo, 1981) with newly available higher detail topographic maps (carta tecnica regionale (CTRs) maps, 1:5000). The part of this updated soil map covering the area under investigation in this paper is shown in Figure 3.

3 | METHODS

Survey visibility factors and geomorphological processes operate at different spatial and temporal levels, and can interrelate in intricate ways. Modeling their combined effects with respect to site detection in order to predict their potential impact on the survey record is therefore complex. For example, soil erosion peaks drastically on arable land, lacking a protective arboreal mantle (water erosion is induced) and seasonally disturbed by tillage activities (Torri et al., 2006), but a cleared or ploughed field usually offers better visibility for the survey (and, thus, a higher discovery expectancy) than a vegetated area. Because of these complex interrelationships, in this paper, we first discuss survey visibility factors and geomorphological processes separately and only in a final phase consider their combined effects on site distributions. To maintain a defined chronological focus, we only consider the early Roman or Hellenistic sites as attested by black gloss pottery (ca. 350–50 B.C.).

First, we assessed the role played by visibility conditions in favoring or preventing site discovery in the walked field units of the Aesernia survey. We focused on the physical characteristics of the modern landscape (e.g., vegetation cover, tillage status, or land use) and their correlations (if any) with site discovery. We considered whether the recording of sites by field walkers may have depended on physical constraints by means of statistical tests (i.e., chi-square, Kolmogorov–Smirnov, and Atwell–Fletcher tests). These tests highlight visibility categories where the number of recorded sites is significantly higher or lower, thus offering an indication of possibly biased samples.

As part of this analysis, a multicriteria evaluation (MCE) was implemented in IDRISI GIS (Selva edition; Eastman, 2012) in order to produce a map indicating favorable units for survey visibility. The MCE is a decision support tool frequently applied in archaeological

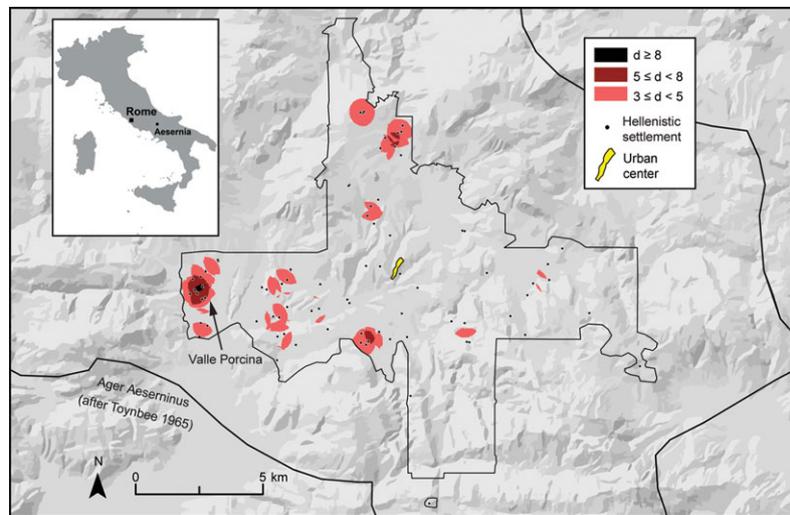


FIGURE 1 Distribution of the Hellenistic settlements registered by the LERC survey project in the survey sample area [Color figure can be viewed at wileyonlinelibrary.com]

Notes: The palette highlights areas of different site density (d): d indicates the number of sites found in a circle of 1 km^2 from each cell ($20 \times 20 \text{ m}$) of the study area. Base map: graphic elaboration of the shaded relief calculated from the 10-m resolution DEM named TINITALY/01 (Tarquini et al., 2007, 2012; Tarquini, & Nannipieri, 2017).

Source: Figure by Anita Casarotto.

predictive modeling for location preference analysis of past settlements (e.g., Casarotto, De Guio, Leonardi, & Ferrarese, 2011; Di Zio & Barnabei, 2009; Goodchild, 2007). It combines different criteria (predictors) and, depending on the problem at issue, shows the most suitable choice to be taken among many alternative solutions. Since most predictive models aim at identifying the most attractive landscape features for settlement in antiquity, this choice usually regards the most suitable locations for ancient settlements or past agricultural land use (see the discussion in De Guio, 2015). In our case, instead, we wanted to choose the most suitable units (choice) for survey visibility (problem) according to a set of visibility factors (criteria/predictors).

The most influential visibility factors for archaeological detection (which we previously established through quantitative tests) were used in this model as explanatory variables. This means that, according to their weight of importance, they proportionally contributed to the construction of a suitability map showing which surveyed units are expected to offer a high probability of encountering a site based on the favorable visibility conditions. Such a predictive map helps us to highlight where absence of evidence may indeed reflect a real evidence of absence of settlement in antiquity (but see next section on geomorphological biases), and conversely which units may have instead yielded unreliable information, and thus where absence of evidence can likely be explained by adverse visibility conditions.

The second approach aimed at investigating the extent to which Late Holocene erosional and depositional processes may have destroyed or obscured Hellenistic sites. If degraded or buried, such sites could not have been detected in the topsoil during field surveys, even though survey visibility conditions were optimal. The absence of recorded sites may not be reliable, and geomorphological filtering is necessary before attempts can be made to interpret the data in historical terms. This is a well-known issue that has attracted much attention of scholars working in the Mediterranean world, above all

ever since New Archaeology stimulated the analysis of depositional and post-depositional formative processes of the archaeological record (e.g., Clarke, 1968; Leonardi, 1992b; Schiffer, 1987).

Geo-pedological investigations are increasingly being carried out in Mediterranean archaeological studies, not only for land evaluation analyses of ancient agricultural practices (e.g., Barker, 1995b; Brown & Walsh 2017; Citter & Arnoldus-Huyzenveld, 2011; Finke, Harding, Sevink, Gewuster, & Stoddart, 1994; Goodchild, 2007; Kamermans, 2000; Kamermans & Sevink, 2009; Van Joolen, 2003), but also for assessing geomorphological biases in the survey results. As regards the latter, sophisticated computer-based simulation models have been recently developed in order to study and quantify long-term sedimentation and erosion rates possibly affecting the archaeology (e.g., Feiken, 2014; Zwertvaegher, 2012, pp. 125–162) or long-term soil degradation related to ancient agropastoral land uses (e.g., Barton, Ullah, & Bergin, 2010). However, the most widely applied methods for assessing archaeological preservation potential are those based on more general landscape classification procedures of geological and soil maps (e.g., Arnoldus-Huyzenveld, 2007, 2011; Ebert & Singer, 2004; Feiken, 2014; Leonardi, 1992a, pp. 57–122; see the discussion in Sevink, 1985). These methods are much more intuitive than the previous ones and more appropriate for a regional analysis that aims at testing sedimentation or erosion affecting large-scale settlement patterns. Here, we apply as well a particular landscape classification procedure of soil maps to assess the Late Holocene gradational effects on our Hellenistic settlement distribution.

More specifically, we analyzed the information provided by the soil map of the area (Koopmans, 1980; van Otterloo, 1981; van Otterloo & Sevink, 2016) to gain understanding of the most recent sedimentation or erosive processes that may have occurred after the Hellenistic period. On the basis of this evaluation, we established the *detectability* (i.e., the probability of recording sites, also known as preservation

potential) of Hellenistic period archaeology in each soil unit. We used the Attwell–Fletcher test of association (1985; 1987) for analyzing whether geomorphological biases may have affected the detection of Hellenistic sites, and to what extent.

As a last step, we combined the results of the visibility and geomorphological analyses in order to obtain a comprehensive detectability map of the walked survey units: to each unit, a pair of values was appointed indicating the probabilities that the site sample (or the vacuum) recorded in that unit is representative and, thus, reliable. This was done in IDRISI through a cross-tabulation that displays, for each surveyed unit, the different Hellenistic visibility and preservation potentials.

4 | EVALUATING SURFACE VISIBILITY BIASES

In this first section, we focus on the physical obstacles at the surface that can affect the results of field surveys, such as vegetation cover or modern land use. During the field surveys carried out in Isernia, the visibility conditions of each walked field unit were registered systematically. Precise indications about tillage status, soil humidity, shadow conditions, stoniness, presence of recent material at the surface, vegetation cover, and land use were recorded on a scale from 1 (low) to 5 (high) in a database and reproduced in GIS as georeferenced vector files. Such indications are particularly precious for the purpose of the present analysis, since they allowed us to highlight possible significant correlations between site recovery rates and survey visibility conditions.

Using predictive modeling techniques, we modeled the aptitude for discovery of archaeological sites by modern field walkers in relation to more or less favorable visibility conditions. This analysis helped us to point out those surveyed units where, despite the optimal visibility, site discovery did not happen. The emptiness attested there may be due to either past constraints against settlement (thus people chose to avoid those locations) or to a possible geomorphological bias affecting the preservation of sites, which we will address separately in the next section of this paper.

Before proceeding, however, we needed to take into account that different types of sites are variably visible in the survey record according to the periods and regions (Sbonias, 1999). It is usually assumed that small and diffuse artifact concentrations escape detection more easily than large and dense scatters of material (Barker, 1995a; Cherry, 1983; Flannery, 1976). To balance this effect, in this study small sites such as Hellenistic farms were treated separately from the other settlement categories (e.g., sites interpreted as villages or villas). Site categories were formulated for each site by the LERC survey team. Therefore, we could easily make a selection of small Hellenistic sites (farms). In this analysis, we considered both the totality of sites recorded (independently from period and category) (99), the Hellenistic settlements (81), and the small Hellenistic farms (62). More precisely, in order to assess the role played by ground visibility in site discovery, we controlled the surface conditions characterizing those units where the actual discovery of sites took place. If a site extended over more units,

only the visibility conditions of the first unit walked were considered in this analysis since this is where the discovery, in the first place, happened.

4.1 | Procedure

Technically speaking, significant associations (if any) between the proportions of discovered sites and survey visibility conditions are evaluated through nonparametric one-sample tests (for a good overview of one- and two-sample tests see Conolly & Lake, 2006, pp. 112–148; Kvamme, 1990; Siegel, 1956, pp. 35–156; Shennan, 1988, pp. 57, 104–126; Wheatley & Gillings, 2002, pp. 123–132). These tests are of the goodness-of-fit type (Siegel, 1956, p. 35): they compare the observed sample with a theoretical distribution in order to single out unexpected anomalies in the frequency of the phenomenon under consideration (in our case, site discovery).

For the visibility factors that are nominal in type (i.e., composed of different categories, e.g., land use), we applied the chi-square test to see whether a significant difference existed between the observed and the expected proportions of sites. For testing the influence of the ordinal variables (i.e., variables for which values can be ordered on a ranking scale such as vegetation cover rate, stoniness, etc.), we preferred instead the Kolmogorov–Smirnov test, which measured the strength of the divergence between the observed and the expected cumulative frequency distributions (Siegel, 1956, pp. 47–52; Shennan, 1988, pp. 53–61).

In addition to these approaches, we also used the analytical technique devised by Attwell and Fletcher (1985, 1987) to overcome some intrinsic limitations of the previous two tests. This test of association, unlike the other two, has the advantage of indicating both the magnitude and the direction (positive or negative) of the association in each category and can be used on small samples or categories. We relied especially on the results of the Attwell–Fletcher technique because it is more sensitive and powerful than the other two tests (Attwell & Fletcher, 1985, 1987; see also the discussion in Siegel, 1956, pp. 46–52).

As we will see, the Attwell–Fletcher test indicated a significant association only with the tillage variable. However, because other factors, such as the presence of overgrown vegetation, are known to prevent the surveyors from properly seeing the ground while surveying (e.g., Terrenato & Ammerman, 1996; Terrenato, 2000), we also considered the other factors in the following MCE. It is worth remembering that our aim here was to visualize those landscape locations where visibility conditions were optimal for site discovery independently of whether or not a site was actually found. This allowed us to pinpoint reliable settlement vacuums in the Hellenistic pattern (but see the discussion below on geomorphological biases).

Before proceeding with the MCE, we wanted to assess a possible linear relationship (collinearity) among the explanatory variables (visibility factors; Langston, 2013; Shennan, 1988, pp. 177–179; Vaughn & Crawford 2009, pp. 62; 112). Collinear variables are dependent variables, which mean that they depend on each other and are related to the very same phenomenon. These factors are redundant predictors and thus some can be excluded from the model. For instance, it is very

likely that the degree of shadow could be highly correlated with other factors that contribute to the shading of the field, such as the vegetation cover rate (which is directly proportional to the shadow) or the soil humidity (which, like the shadow factor, depends on the time of survey and on the weather conditions).

The visibility factors were therefore tested for collinearity by means of the Band collection statistic tool of ArcGIS 10.2.2 (Esri, 2014). The threshold of 0.6 was chosen for the exclusion (Langston, 2013, p. 116). Tillage and land use did not exhibit collinearity and were selected as suitable independent predictors. On the other hand, stoniness, soil humidity, shadow condition, recent material, and vegetation cover rate exhibited high collinearity (index of correlation > 0.8). As mentioned earlier, using them simultaneously would have entailed redundancy in the model. Therefore, only one of them was selected as candidate predictor for the calculation of the predictive map of visibility. We opted for the vegetation cover factor for two main reasons: among these collinear factors, it is the most tangible and the most objectively definable by surveyors in the field.

These three independent visibility factors were then reclassified in visibility scores according to experts' judgments in order to obtain criterion maps for the MCE tool. The procedure of using experts' judgments for assigning scores and weights of importance is a common practice in predictive modeling (Judge & Sebastian, 1988; Van Leusen & Kamermans, 2005; Verhagen, 2007). The team leaders that had been working in the various LERC campaigns in Isernia gained quite some experience in surveying this landscape and thus were the most appropriate persons for assigning visibility scores from 1 (low) to 3 (high) to the categories of the three selected visibility factors (tillage, land use, vegetation cover rate; Table I).

Afterwards, weights of importance were appointed to these three variables according to the statistical results (see Tables II–IV) and the experts' personal judgments. These weights numerically represent the different influence each factor theoretically would play in site discovery. According to the survey team leaders and the statistics, tillage plays the most significant role in influencing the discovery of sites, followed by land use and then by vegetation cover rate. The Pairwise technique of IDRISI GIS—Selva edition (Eastman, 2012, pp. 133–134) was applied to carry out this weight calculation and the following rank of weights was established (consistency 0.03, the sum of the weights must be 1):

1. Tillage: 0.7514.
2. Land use: 0.1782.
3. Vegetation cover rate: 0.0704.

Once the visibility factors were reclassified in criterion maps, they could be merged through the MCE tool to finally obtain a predictive map of the suitability for site discovery based on survey visibility conditions (regardless of ancient settlement strategies or recent geomorphological erosive or depositional biases). The three criterion maps representing, respectively, tillage, land use, and vegetation rate were combined in a weighted linear combination (WLC) according to the following formula (Eastman, 2012, p. 132):

$$S = \sum w_i x_i$$

where S is suitability for site discovery based on visibility factors, w_i is the weight of visibility factor i , and x_i is the criterion score of visibility factor i .

4.2 | Results

The Atwell–Fletcher results showed that at a 95% level of probability, the finely ploughed units (tillage factor) seem to be favorable for the discovery of all sites, Hellenistic settlements, and small Hellenistic farms (Tables II–IV). In spite of the fact that only 3.3% of the area surveyed by the LERC team was finely ploughed, the number of archaeological sites recorded there is significant (more sites than expected from a random distribution). The Atwell–Fletcher test did not identify any other significant association for site discovery with the other visibility factors, neither for the totality of sites nor for the Hellenistic settlements and small farms.

As a last step of this first analysis, a value of suitability for site discovery was assigned through the MCE to each surveyed unit, which is the result of the sum of the visibility factor scores (i.e., the scores for tillage, land use, and vegetation cover rate indicated in Table I), characterizing that unit, multiplied by their respective factor weights (see before). Such a predictive map (Fig. 2) highlights effectively reliable empty spaces in the recorded settlement pattern or, in reverse, possibly unreliable vacuums where there is the risk of missing some archaeological evidences due to the critical survey visibility conditions.

As has been demonstrated, visibility factors may favor or prevent the discovery of sites (e.g., Terrenato & Ammerman, 1996). However, in our case, considering the widely scattered configuration of the few surveyed units characterized by finely ploughed surfaces, the previously detected association with the tillage factor is insufficient for explaining the entire regional pattern recorded. Other factors may have affected the overall pattern much more significantly, such as large-scale gradational processes of erosion and deposition. We turn our attention now precisely to these processes.

5 | EVALUATING GEOMORPHOLOGICAL BIASES

The aim of our next analysis is to assess the extent to which recent erosion and deposition may affect the preservation of the Hellenistic-period archaeological record in the Isernia basin (Coltorti, 1983; Stek et al., 2015; Van Otterloo & Sevink, 1983). Post-depositional geomorphological processes that have been occurring over the late Pleistocene and Holocene may be a source of bias for the distribution of Prehistoric and later sites. For the period of interest to us (i.e., the Hellenistic period), we focused on the most recent late Holocene features and gradational processes (i.e., 2500 B.C.–present) in order to point out critical zones where deposition or erosion may have covered or deleted Hellenistic sites after their abandonment.

Gradational processes comprise both degradational and aggradational processes (Bos & Sevink, 1975). The former stand for erosive forces acting in a landscape to destroy, remove, and occasionally also uncover (Ebert & Singer, 2004) the archaeological remains after the

TABLE I Experts' visibility scores for the variables used in the MCE analysis

Tillage	Visibility Score: From 1 (Low) to 3 (High)
None	1
Rolled	3
Harrowed	3
Finely ploughed	3
Medium ploughed	2
Heavily ploughed	2
Land use	
Arable/arable cleared	3
Arable completely cultivated	1
Horticulture	1
Olives/fruit trees	1
Viticulture	2
Fallow	2
Fallow clean/burnt	2
Fallow with stubs	2
Wood/ <i>macchia</i> / fallow overgrown/pasture	1
Vegetation cover rate	
0	3
1	3
2	2
3	2
4	1
5	1

TABLE II Attwell–Fletcher test for the tillage variable

Tillage Class	Area (ha)	Number of Sites	Expected Proportion of Sites	Observed Proportion of Sites	Category Weight	Positive Association	Negative Association
None	1426.880	47	0.757	0.47	0.06	No	No
Rolled	22.054	1	0.012	0.01	0.08	No	No
Harrowed	51.488	5	0.027	0.05	0.17	No	No
Finely ploughed	62.601	18	0.033	0.18	0.50	Yes	No
Medium ploughed	276.398	27	0.147	0.27	0.17	No	No
Heavily ploughed	46.609	1	0.025	0.01	0.04	No	No

Sample: totality of sites (99). Surveyed area 1886.031 ha. Number of simulations: 200. Critical values: 95th percentile = 0.43 ± 0.016 ; 5th percentile = 0.00 ± 0.000 .

Notes. The Kolmogorov–Smirnov test indicates a maximum difference of 0.283 between the observed and the expected cumulative frequency distributions (critical value to reject the null hypothesis of no association is 0.137, with $\alpha = 0.05$).

primary deposition (i.e., in our case the Hellenistic period). The latter indicate the processes leading to sedimentary accumulative *facies* (alluvium and colluvium) and may result in the burial of sites (see the discussion in Cremaschi & Nicosia, 2012).

Soil formation requires landscape stability in order to let the rate of pedogenesis exceed that of erosion or deposition (Bos & Sevink, 1975, p. 223). In other words, when erosion or accumulation on previous unstable surfaces stops, pedogenesis can start and, eventually, a soil is formed on these now stable land surfaces, whether in the sediment accumulated (following aggradation) or the truncated land sur-

face (following degradation), with eventually remainders of the former soil. A given soil thus represents the record of the gradational history of the land surface concerned, allowing for making inferences about its pedogenesis and formative history.

5.1 | Procedure

We used the information provided by the descriptions of the soil types by Stek et al. (2015), van Otterloo (1981, p. 291), and Koopmans (1980) to assign, within the survey sample area, gradational scores to each

TABLE III Attwell–Fletcher test for the tillage variable

Tillage Class	Area (ha)	Number of Hellenistic Settlements	Expected Proportion of Settlements	Observed Proportion of Settlements	Category Weight	Positive Association	Negative Association
None	1426.880	42	0.757	0.52	0.06	No	No
Rolled	22.054	1	0.012	0.01	0.09	No	No
Harrowed	51.488	5	0.027	0.06	0.20	No	No
Finely ploughed	62.601	15	0.033	0.19	0.49	Yes	No
Medium ploughed	276.398	17	0.147	0.21	0.12	No	No
Heavily ploughed	46.609	1	0.025	0.01	0.04	No	No

Sample: Hellenistic settlements (81). Surveyed area 1886.031 ha. Number of simulations: 200. Critical values: 95th percentile = 0.46 ± 0.022 ; 5th percentile = 0.00 ± 0.000 .

Notes. The Kolmogorov–Smirnov test indicates a maximum difference of 0.238 between the observed and the expected cumulative frequency distributions (critical value to reject the null hypothesis of no association is 0.151, with $\alpha = 0.05$).

TABLE IV Attwell–Fletcher test for the tillage variable

Tillage Class	Area (ha)	Number of Hellenistic Farms	Expected Proportion of Farms	Observed Proportion of Farms	Category Weight	Positive Association	Negative Association
None	1426.880	28	0.757	0.45	0.04	No	No
Rolled	22.054	1	0.012	0.02	0.10	No	No
Harrowed	51.488	4	0.027	0.06	0.18	No	No
Finely ploughed	62.601	14	0.033	0.23	0.51	Yes	No
Medium ploughed	276.398	14	0.147	0.23	0.12	No	No
Heavily ploughed	46.609	1	0.025	0.02	0.05	No	No

Sample: Hellenistic farms (62). Surveyed area 1886.031 ha. Number of simulations: 200. Critical values: 95th percentile = 0.47 ± 0.021 ; 5th percentile = 0.00 ± 0.000 .

Notes. The Kolmogorov–Smirnov test indicates a maximum difference of 0.305 between the observed and the expected cumulative frequency distributions of (critical value to reject the null hypothesis of no association is 0.172, with $\alpha = 0.05$).

of the individual mapping units of the integrated soil map (1:25,000) produced by van Otterloo and Sevink (2016). Scores range from 0 (recent gradational processes almost absent) to 3 (recent gradational processes very prominent). In this way, the landscape stability of each soil map unit was classified. On the basis of this evaluation, we then established the detectability of Hellenistic sites, that is, the probability of finding such sites during field survey, regardless of the influence of ancient location preferences. However, the scale and the temporal resolution of the soil map allowed us to make an evaluation of the depositional and erosive processes only at a regional scale (1:25,000), and we did not reach more detailed assessments. For instance, due to the relatively large scale of the soil map, we could not evaluate the effect of possible smaller scale geomorphological phenomena observable only at a finer spatiotemporal resolution such as at the unit-scale resolution represented by modern farming fields (see the discussion in Butzer, 2008, pp. 403–404). For example, it is not possible to assess through this soil map the occurrence of potential local transport of top-soil related to modern mechanized agricultural activities performed within the field, such as plowing or land-leveling for field clearance and preparation.

While it is demonstrated that such small-scale processes could affect the distribution of artifacts in the plough soil (e.g., Given,

2004, pp. 18–19), it remains unclear to what extent these local processes affect large-scale patterns such as regional distributions of archaeological sites (but see the case-study in Diez-Martín, 2010). With regard to the Aesernia case-study, the difference in scale between the mapping of the field units (1:1) and the soil units (1:25,000) might have influenced in certain zones of the landscape our analysis of the reliability of the regional pattern of sites. As long as higher resolution soil maps are not available, the only way to assess the potential impact of small-scale geomorphological processes on the position and/or extension of sites detected at the surface would be through small-scale targeted excavations or probing. Such ground truthing campaigns aimed at testing our predictions on the date and character of colluvial and erosive processes, and their effects on site presence and position, are scheduled for the future.

In this analyses, however, we concentrate only on the effects that recent large-scale erosive or accumulative phenomena may have had on the visibility and connected discovery of archaeological sites. The diagnostic indicators we used can help disentangle degradation (erosion) and aggradation (accumulation) processes. Degradation was evaluated through judgment of the soil profile development, particularly the soil horizon differentiation, and eventual extent of truncation of the soil concerned. For instance, well-developed and well-drained soils

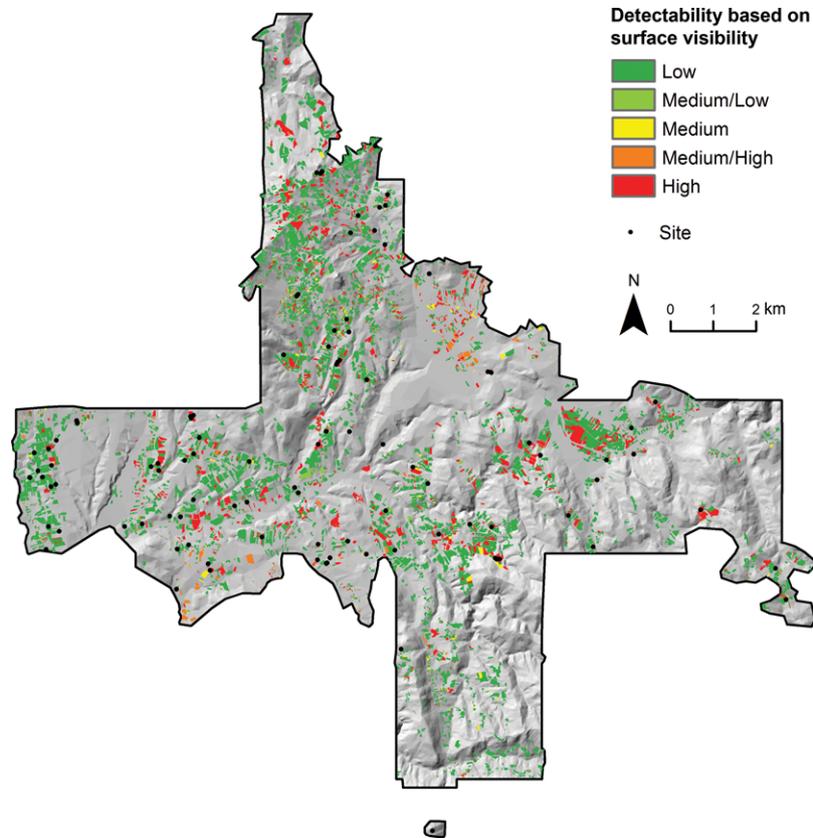


FIGURE 2 Predictive map of the suitability for site discovery in the surveyed units based on surface visibility conditions (i.e., detectability map based on surface visibility) [Color figure can be viewed at wileyonlinelibrary.com]

Notes: The probability for site discovery (detectability) based on surface visibility goes from low to high and is indicated in each unit by the different colors of the palette. Raster base map: shaded relief calculated from the 10-m resolution DEM named TINITALY/01 (Tarquini et al., 2007, 2012; Tarquini, & Nannipieri, 2017).

Source: Figure by Anita Casarotto.

on old stable surfaces, exhibiting all the characteristics of a nontruncated and well-preserved soil, notably a well-developed A horizon and eventually E horizon, indicate that natural or anthropogenic erosion (plough erosion) and colluviation did not occur over a very prolonged period of time. On the contrary, soils that exhibit a pronounced argic horizon, but lack an eluvial horizon and have a poorly developed Ah horizon, evidently have been recently truncated, losing their topsoil.

An example of a unit with well-preserved soil is unit 10 (see Figs. 3 and 4 and Supplementary Table S1). The Eutric Nitosol (FAO/UNESCO, 1974) on fluvio-lacustrine deposits is a well-developed polygenetic soil of old, stable, and subhorizontal surfaces where only minor recent erosion occurred, evidenced by the presence of well-developed A and E horizons. For these reasons, we established that the detectability of Hellenistic sites at this unit was high.

Evidently, land surfaces may also be so recent that they postdate the Hellenistic period and in that case chances for finding Hellenistic sites do not exist or are very low. This is the case when serious degradation took place after that period, and may be the situation on truly unstable land surfaces, for example, steep, unstable slopes. Chances for such subrecent strong degradation can be judged by evaluation of the extent of soil formation. An example is units 32–34 (see Figs. 3 and 4 and Supplementary Table S1), in which Rendzinas and Regosols domi-

nate on relatively unstable and steep marls and shales, with prominent active erosion. The limited extent of soil formation and currently active erosion strongly suggested that the current land surface is of a younger age and thus the detectability of Hellenistic sites was low.

As regards the evaluation of land surfaces that exhibit aggradation, criteria very much resemble those described above: crucial is the extent of soil formation and soil horizon differentiation, which provides a clear indicator for the time elapsed since the deposition of the sediment in which the soil has formed. In fact, this approach forms the basis for all studies on soil chronosequences and has led to considerable insight into the rate of soil formation as dependent on climate and parent material (see, e.g., Sauer et al., 2012; Sevink, Vos, Westerhoff, Stierman, & Kamermans, 1982). Evidently, also other criteria were used by van Otterloo and Koopmans in their assessment of the age of sediments encountered, in particular the presence of archaeological material in these sediments. Such a criterion has been extensively used in soil studies, paying attention to the age and origin of anthropogenic colluvial topsoils in the Mediterranean (e.g., Lang & Bork, 2006; Rimmelzwaal, 1978).

There is another, very region-specific, diagnostic indicator in the evaluation of these soil map units. Throughout the Isernia area, the latest major Holocene tephra layers, called the Avellino pumice layer

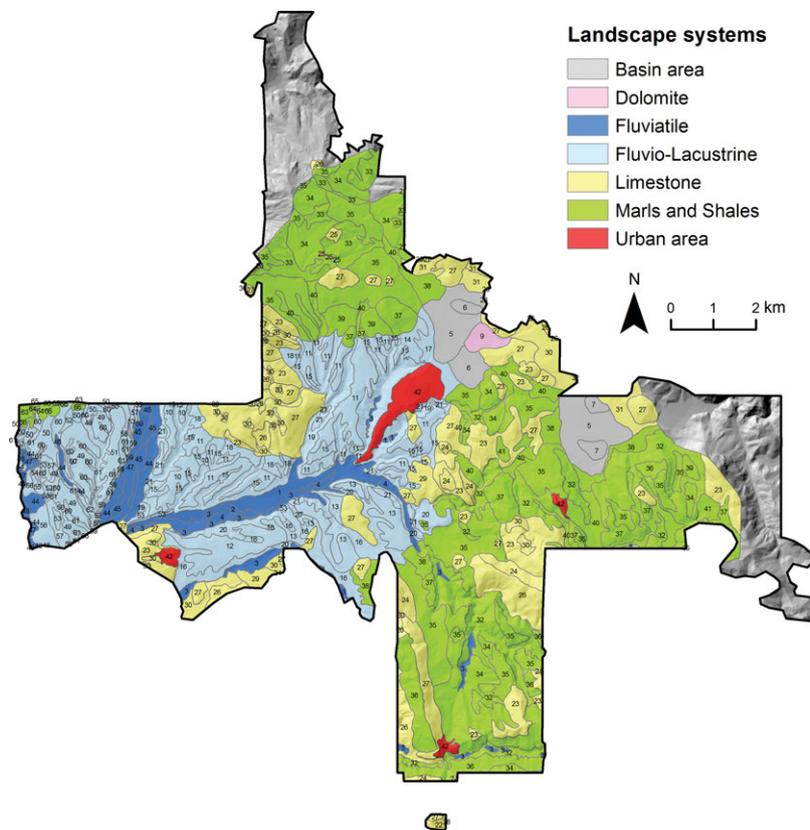


FIGURE 3 Soil map, 1:25,000 by van Otterloo and Sevink (2016). The numeric labels indicate the soil units (see Supplementary Table S1). Raster base map: shaded relief calculated from the 10-m resolution DEM named TINITALY/01 (Tarquini et al., 2007, 2012; Tarquini, & Nannipieri, 2017) [Color figure can be viewed at wileyonlinelibrary.com] Source: Figure by Anita Casarotto.

(near 2000 B.C.) and the Vesuvius Pompeii ash layer (79 A.D.), have been deposited and thus should be present in “stable” soils. They were easily identified through the dark color of the topsoil, because rather than distinct layers the volcanic material often appeared as abundant fine angular pyroclastic particles. Therefore, the presence in the topsoil of pyroclastic material was a proxy in aid of the evaluation whether a soil has been recently truncated or “aggraded” after the last eruptions (for a discussion on ash fall as an excellent temporal marker for studying gradational processes in the Mediterranean; see Brown, 1997; Judson, 1963; Lefèvre, Raynal, Vernet, Kieffer, & Piperno, 2010; Vita-Finzi & Judson, 1964, pp. 239–242). If not present, we could conclude that soils were formed on late Roman or younger deposits, or on strongly truncated, more recent land surfaces and thus are devoid of Hellenistic and earlier sites. For an extensive review of the late Pleistocene and Holocene ash falls in the Isernia area, reference is made to Stek et al. (2015, pp. 241–276).

In areas where such unique ash falls did not occur, the dating of soils, their truncation, and the age of the deposits in which they were formed in case of relatively young soils, is more problematic to establish and often far less reliable, having to be based on rather tentatively established rates of soil genesis during early soil formation, for example, decalcification and accumulation of organic matter (e.g., Cremaschi, 1987). Both processes are very much climate and parent material dependent, and do not allow for more than broad statements on soil age. Processes like clay translocation and weathering were not

discriminative at the time scales concerned, and were thus unsuited for our purposes (see, e.g., Cremaschi & Sevink, 1987; Sauer, 2010; Sevink et al., 1982).

An example is provided by the Le Piane karst basin located north-east of Isernia (unit 5, see Figs. 3 and 4 and Supplementary Table S1). Here, post-Roman colluvial fill deposits, devoid of pyroclastic material, cover any previous archaeological remains. These colluvia probably originated through strong erosion impacting on the unstable surfaces of the surrounding mountains, and subsequent deposition of the eroded soil material in this basin, which may be related to intensive anthropogenic deforestation and agricultural activities especially in Roman times (see the discussion in Burri, Castiglioni, & Sauro, 1999).

5.2 | Results

Through the evaluation of the soil maps, we could identify and delineate zones where erosion and sedimentation likely took place recently to various extents (Fig. 4). In archaeological surveys, these critical units (in dark gray in Fig. 4) can be expected to more likely exhibit a biased archaeological record: the higher risk of late Holocene erosion and deposition at these units must be taken into account when evaluating the reliability of the recorded Hellenistic archaeological evidence.

On the basis of Figure 4, a potential bias possibly hampering the detection of sites seems strong in the south transect, and to a lesser extent in the central, east, and north parts of the survey sample area,

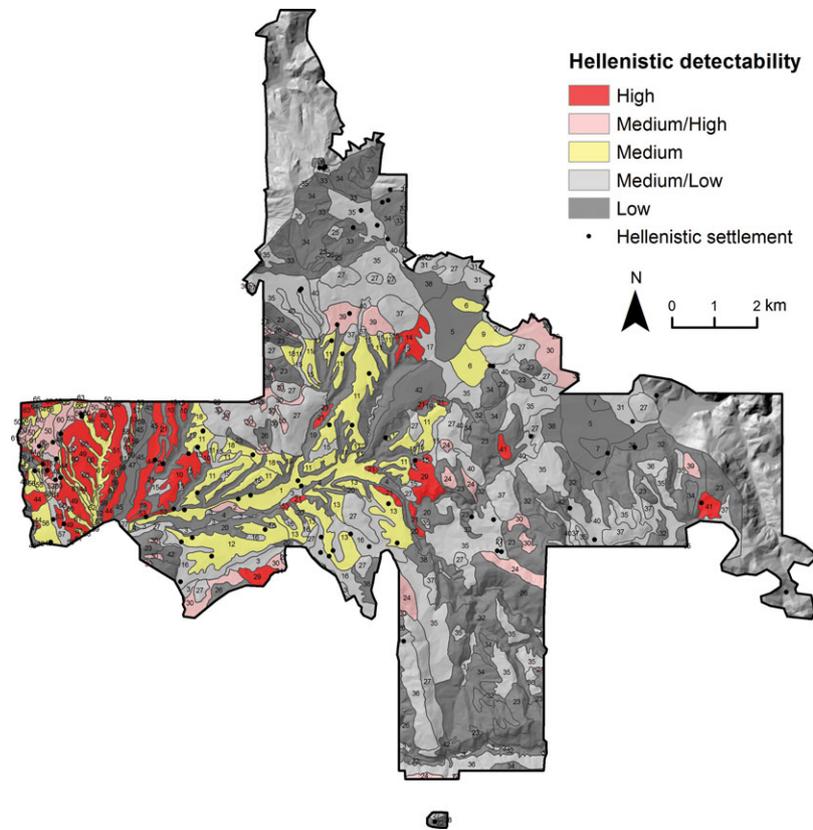


FIGURE 4 Detectability map for the Hellenistic period based on geomorphological processes (i.e., geomorphological detectability map) [Color figure can be viewed at wileyonlinelibrary.com]

Notes: Raster base map: shaded relief calculated from the 10-m resolution DEM named TINITALY/01 (Tarquini et al., 2007, 2012; Tarquini, & Nannipieri, 2017).

Source: Figure by Anita Casarotto.

whereas in the west transect its effect should be minimal in light of the predominantly highly stable surfaces (see Fig. 4). We used a statistical test to assess the probability that the archaeological pattern is indeed influenced by this factor.

Statistical tests of association can systematically compare the proportion of the total sites found by the LERC team in a certain detectability class to the proportion of the total survey coverage at that detectability class (i.e., the proportion represented by the area walked in that class, see Fig. 5), and tell us whether or not this association is statistically significant. In order to assess whether a significant association exists between detectability class and site discovery the Attwell–Fletcher statistical test of association was performed within the surveyed units (Attwell & Fletcher, 1985, 1987). This test indicated, for the surveyed units in each detectability class, whether there were significantly more, or significantly fewer sites than expected vis-à-vis random distributions. These random distributions theoretically represent site distributions whose configurations are independent from the variable under consideration (i.e., geomorphological detectability): according to the extent of the area surveyed in each detectability class, sites were thus proportionally allocated by means of several simulations (in our case 200 simulations were run). This means that the site proportions of these simulated random distributions that were allocated in the various detectability classes (i.e., expected proportions of sites) corresponded to the proportions of the total surveyed area at the

detectability classes. If a significant negative association existed (i.e., in that class, there were fewer observed sites than expected from distributions unaffected by geomorphological processes), the category weight of the detectability class under consideration resulted lower than the critical value for the fifth percentile. Conversely, if there was a significant positive association (i.e., more recorded sites than expected), the category weight exceeded the critical value for the 95th percentile (see Tables V and VI).

As shown in Tables V and VI, there seems to be a positive association with the medium/high detectability class (covering 7.1% of the total surveyed area, i.e., a proportion of 0.071:1) and the presence of Hellenistic settlements and farms. This may be explained by the relatively stable surfaces characterizing this land class, which are favorable for the preservation of Hellenistic settlement sites (see for instance the Valle Porcina in the West transect, Fig. 1). However, this does not completely exclude the possibility that, rather than more preserving landscape units, ancient location preferences instead caused sites to cluster in certain zones. This hypothesis is supported by the fact that we did not discern any other significant correlation between detectability classes and site numbers: indeed, site numbers in the theoretically low and medium/low detectability zones were actually not significantly lower than expected. More importantly perhaps, there was also no positive correlation between site numbers and the high detectability zones. Despite the highly stable surfaces associated with

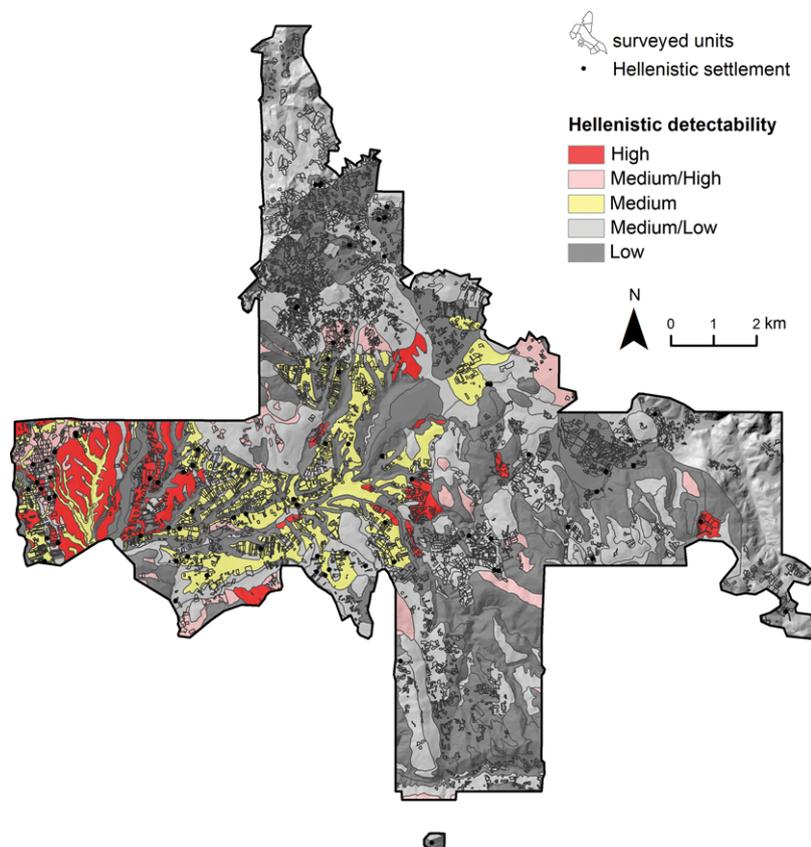


FIGURE 5 Geomorphological detectability map for the Hellenistic period showing the surveyed units within each detectability unit [Color figure can be viewed at wileyonlinelibrary.com]

Notes: Raster base map: shaded relief calculated from the 10-m resolution DEM named TINITALY/01 (Tarquini et al., 2007, 2012; Tarquini, & Nannipieri, 2017).

Source: Figure by Anita Casarotto.

TABLE V Attwell–Fletcher test of association on the Hellenistic settlements

Geomorphological Detectability Class	Area (ha)	Number of Hellenistic Settlements	Expected Proportion of Settlements	Observed Proportion of Settlements	Category Weight	Positive Association	Negative Association
High	110.382	6	0.065	0.08	0.19	No	No
Medium/High	119.928	12	0.071	0.16	0.36	Yes	No
Medium	375.959	25	0.223	0.32	0.24	No	No
Medium/Low	578.492	26	0.343	0.34	0.16	No	No
Low	504.172	8	0.299	0.10	0.06	No	No

Total number of Hellenistic settlements within the geomorphological detectability map: 77. Surveyed area within the geomorphological detectability map: 1688.93 ha. Number of simulations: 200. Critical values: 95th percentile = 0.34 ± 0.012 ; 5th percentile = 0.04 ± 0.022 .

these zones, they did not show significantly higher percentages of sites.

Therefore, the overall picture that emerged from this analysis is that there is not always a clear correlation between site recovery rates and detectability classes in the investigated territory of Isernia. As a matter of fact, if geomorphological detectability was responsible to a significant degree for the discerned regional settlement pattern, we would have expected to find positive correlations with the high and medium/high classes and also negative correlations with the medium/low and low classes.

Consequently, the low site density areas recorded in several large portions of this territory, and the few localized higher density zones widely scattered (Fig. 1), could plausibly be the result of genuine Hellenistic settlement patterns. This hypothesis is supported especially by the low site numbers recorded for the high detectability units. Considering the minimal susceptibility to post-Hellenistic period erosion and deposition, in these units, it seems implausible to assume that the recorded pattern of thinly populated zones in the Hellenistic period is entirely the result of geomorphological biases.

TABLE VI Attwell–Fletcher test of association on the Hellenistic farms

Geomorphological detectability class	Area (ha)	Number of Hellenistic farms	Expected proportion of farms	Observed proportion of farms	Category weight	Positive association	Negative association
High	110.382	5	0.065	0.09	0.21	No	No
Medium/High	119.928	10	0.071	0.17	0.38	Yes	No
Medium	375.959	15	0.223	0.26	0.18	No	No
Medium/Low	578.492	22	0.343	0.38	0.17	No	No
Low	504.172	6	0.299	0.10	0.05	No	No

Total number of Hellenistic farms within the geomorphological detectability map: 58. Surveyed area within the geomorphological detectability map: 1688.93 ha. Number of simulations: 200. Critical values: 95th percentile = 0.37 ± 0.013 ; 5th percentile = 0.00 ± 0.025 .

The fact that there were not significantly fewer sites than expected in the low detectability conditions may possibly be related to the large sample of surveyed units in the medium/low and low detectability zones affected by high erosion (erosion score 2 or 3, see Supplementary Table S1). It is important to underline that erosive agents can destroy sites, but they can also uncover otherwise buried and thus previously invisible archaeological material (see Ebert & Singer, 2004). Field walkers often find sites at places where erosion is active, and this may be also the case for some of the sites found in our study area. For example, where late Holocene degradational processes are prominent and still active (e.g., low detectability units 32–34), sites might have been occasionally exposed at the surface by forces of erosion (e.g., local slope movements, plowing).

Overall, if we accept the validity of the principle used here to predict the effect of large-scale geomorphological biases (in other words, strong recent deposition may cover Hellenistic sites, and strong recent erosion may destroy or occasionally uncover Hellenistic sites) on the basis of our tests, we may therefore conclude that this analysis underscores the value of the Aesernia survey data for studying past settlement behavior at a regional scale of analysis.

6 | COMBINING RESULTS

By means of a cross-tabulation, the previous two detectability maps, based on surface visibility and geomorphology, respectively, were combined in order to assign to each surveyed unit a pair of detectability scores that aid archaeologists to evaluate the combined effect of these two sets of biasing factors.

As shown in Table VII and in Figure 6, the combination of these two types of information allows the archaeologist to assess for each surveyed unit whether the density and pattern of sites recorded may correlate with either, or both, types of bias. The complexity of the interrelationships between surface visibility and geomorphology can be better elucidated with two examples. First, a unit may display optimal surface visibility conditions, but despite a maximum visibility score Hellenistic evidence will hardly be found if covered under post-Hellenistic deposition. Second, stable-old surfaces may have a high detectability score, but thick vegetation may still prevent archaeologists from detecting a site.

Surface visibility and geomorphological biases are intricately interwoven, and their complex relationships are difficult to predict without

a suitable support for systematic consultation: if we aim to visualize the potential implications of these relationships for the survey record, we need to find a means to calculate them and then represent them simultaneously on a map. A combined detectability map as the one displayed in Figure 6 may fulfill this task. Archaeologists may use this map as a filter to be superimposed on a site distribution map compiled during field survey. In this way, they may eventually be able to filter out potential distortions provoked by visibility and geomorphological processes on site numbers and pattern, calibrate the pattern, and possibly correct it through the simulation of the potentially missing evidence and then, finally, assess differences in the historical interpretations they will put forward before and after such a calibration.

7 | CONCLUSIONS

By definition, survey data are fragmentary. Nonetheless, archaeologists by necessity have to base their reconstructions on here-and-there surfaces where preserved and uncovered archaeological material can be observed. When investigating regional settlement patterns and site numbers as reflected by field survey data, it is thus crucial to understand the formative processes leading to the creation of the field survey record. Assessing the constraints that may affect the preservation and the recording of sites in different portions of the landscape should be a first step to take before inferring ancient location preferences, land-use strategies, and, more broadly, historical processes. Detectability maps can help in achieving this goal.

Not only are detectability maps useful to test for biases in survey data, they can also help in designing a targeted sampling strategy for future surveys. In this way, detectability maps can increase the efficiency and reliability of survey methods and data: stable and well-visible surfaces, of course, are more likely to return a more representative settlement density and pattern than those where erosion and sedimentation are, or have been recently, occurring.

Detectability maps are by no means a new tool. However, the innovative aspect of our method is that it offers a formal, and widely applicable, procedure for combining a systematic statistical analysis of visibility biases with a straightforward assessment of regional geomorphological biases based on soil characteristics. The resulting maps that highlight the position of visible and less visible, stable, and unstable surveyed surfaces provide a filter through which archaeologists can calibrate or reevaluate interpretations of recorded site

TABLE VII Cross-tabulation between surface visibility classes (columns) of the predictive surface visibility map (see Fig. 2) and geomorphological detectability classes (rows) of the geomorphological detectability map (see Fig. 5)

Geomorphological Detectability	Detectability Based on Surface Visibility					Total
	Low	Medium/Low	Medium	Medium/High	High	
Outside soil maps	8.18	0.03	0.12	0.04	2.25	10.62
Low	20.16	0.29	0.33	0.33	5.62	26.74
Medium/low	22.98	0.19	0.89	0.48	6.15	30.7
Medium	14.25	0.38	0.36	0.72	3.96	19.67
Medium/high	5.07	0.06	0.23	0.3	0.71	6.37
High	4.05	0.08	0.13	0.06	1.58	5.9
Total	74.69	1.04	2.06	1.94	20.27	100

The numbers indicate the percentage (%) of the surveyed territory (1886.031 ha) for each combination of classes.

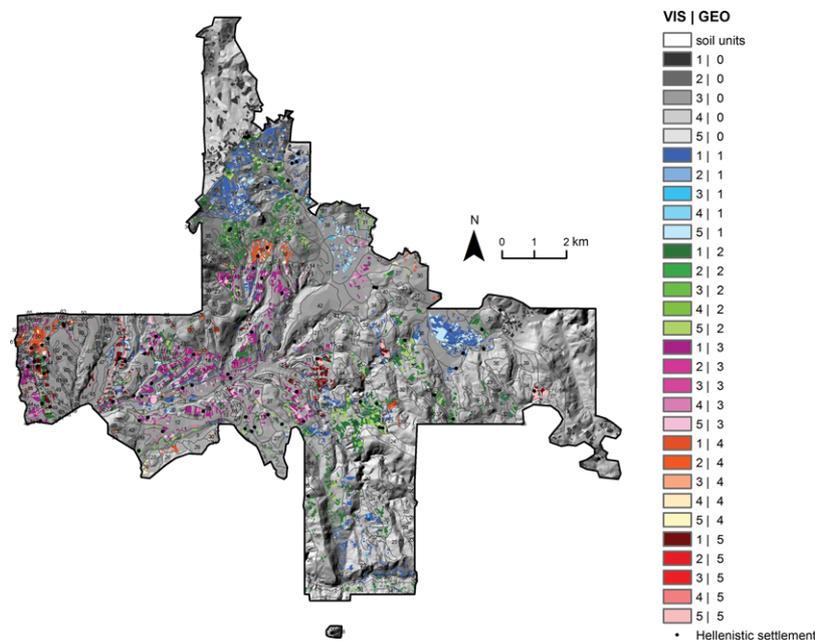


FIGURE 6 Cross-tabulation between the detectability map based on surface visibility and the geomorphological detectability map [Color figure can be viewed at wileyonlinelibrary.com]

Notes: Each surveyed unit receives a combination of detectability scores (the first score refers to the detectability based on surface visibility, the second score refers to the Hellenistic detectability based on the geomorphological evaluation): 0, outside soil map coverage; 1, low; 2, medium/low; 3, medium; 4, medium/high; 5, high. Raster base map: shaded relief calculated from the 10-m resolution DEM named TINITALY/01 (Tarquini et al., 2007, 2012; Tarquini, & Nannipieri, 2017).

Source: Figure by Anita Casarotto.

distributions. With its formal character, the method proposed here may also contribute to overcoming current challenges in the comparison and integration of large-scale survey data at the supraregional level.

As regards the case of the colony of Aesernia, we used the detectability maps to assess whether the few localized high-site densities and the large tracks of empty zones in between them may be the result of visibility and geomorphological biases, or rather the result of settlement location preferences of ancient communities. We observed that low site density and blank areas are also frequently present in areas characterized by good surface visibility and high geomorphological detectability. This conclusion strengthens the reliability of the recorded empty units in between clusters of sites and,

thus, further supports the clustered early colonial settlement hypothesis recently proposed for this Apennine landscape in the Hellenistic period.

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