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Testing settlement models in the early Roman colonial landscapes of Venusia (291 B.C.), Cosa (273 B.C.) and Aesernia (263 B.C.)

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This paper examines settlement density and settlement patterns in the Roman colonial territories of Venusia, Cosa and Aesernia, located in three different landscapes of central southern Italy (modern Basilicata, Tuscany and Molise). Using a series of GIS tools, we conducted a comparative analysis of the density and spatial distribution of sites dating to the Hellenistic period (ca. 350–50 B.C.). We used the legacy settlement data collected by previous large-scale, intensive, site-oriented field surveys to test the validity of two competing rural settlement models of early Roman colonization: the conventional model of neatly organized settlements regularly dispersed across the landscape and the recently proposed theory that colonists adopted a polynuclear settlement strategy. After calculating the extent to which the archaeological datasets conform to the regular or polynuclear model, we conclude that only a very small portion of the colonized areas actually meets traditional expectations regarding the organization of early colonial settlements. Our analyses show that the legacy survey data is more consistent with the polynuclear settlement theory, but the data also reveals some completely unexpected patterns, suggesting that early Roman colonial landscapes were more diverse than previously thought.

Keywords: Roman colonization, field-survey, legacy data, settlement organization, density and pattern analysis, GIS

Introduction

Roman colonization is traditionally depicted as an impressive enterprise that entailed the drastic reorganization of conquered territory (cf. Salmon 1969). In this view, Roman colonists lived in newly established towns that mimicked Rome (e.g., Brown 1980). The vast majority of colonists, however, would have settled in the hinterland of the colonial center, which is conventionally imagined by scholars to have been neatly partitioned (typically by centuriation) and characterized by a dense and regular distribution of colonists' farms. Over the last decades, as part of the broader development of landscape archaeology, archaeologists using field survey methods have intensively researched many areas of Italy that were affected by Roman colonization. On the basis of these large datasets, scholars have drawn important inferences about Roman settlement organization, the impact of Roman expansionism on conquered areas, the Roman economy and the relationship between these aspects (e.g., Launaro 2011; Goodchild and Witcher 2010; on legacy survey data see Witcher 2008).

Several salient problems emerge from the legacy datasets when we assess them against historical information about Roman colonization. In particular, if we compare the datasets against literary information about the number of colonists sent to the territories in question (Pelgrom 2008, 2012, 2013), it is evident that, as a rule, field surveys have mapped only a fraction of early colonial sites. In the past, these extremely low recovery rates were attributed to the methodological difficulties of recognizing small, simple rural dwellings in the survey record (Cambi 1999; Millett 1991; Rathbone 1981, 2008; Witcher 2011). Recently, however, an alternative solution to the "missing sites" problem has been suggested, namely, that colonial communities may have adopted settlement strategies that significantly differ from those conventionally envisaged. In a series of articles, two of the authors of this paper have critically reexamined the archaeological and epigraphic evidence of early Roman colonial settlement organization and have proposed an alternative polynuclear settlement scenario, in which colonists settled in large rural settlements, such as villages, separated by wide tracts of much more thinly populated land (Pelgrom 2008, 2014; Stek 2008: 166–215, 2009: 133–170, 2014).

This article is part of a NWO-funded project (Netherlands Organization for Scientific Research) that aims to test the viability of this alternative hypothesis by combining a reassessment of the legacy data with new fieldwork (Stek and Pelgrom 2013).

The two opposing colonial settlement models, which have radically different spatial and social implications, are underpinned by the same datasets, namely those produced by previous regional surveys and published in the form of site distribution maps. Accordingly, the key issue in this debate is the pattern that these large datasets actually present, not the quality of the datasets themselves. In this paper, therefore, we focus on density and pattern analysis using quantitative statistical GIS tools to establish which model of settlement organization the survey data truly supports, while suggesting other settlement models for consideration along the way. We include in our analysis the data collected in the territory of three intensively studied Latin colonies: Venusia (founded in 291 B.C.), Cosa (273 B.C.) and Aesernia (263 B.C.) (FIG. 1). In light of the centrality of these datasets for other important debates on Roman society, such as the nature of the Roman economy, town-countryside relations, demography and the nature of Roman imperialism, the significance of the conclusions of this paper extends far beyond the debate over Roman colonization.

Data

The present analysis capitalizes on the rich datasets compiled during three regional field surveys carried out in the territory of the colonies of Venusia, Cosa and Aesernia (respectively published in Marchi and Sabbatini 1996; Sabbatini 2001; Marchi 2010; Carandini *et al.* 2002; Stek *et al.* 2015). These projects were executed in the late 1970s to mid-1980s (Cosa), in the late 1980s to mid-2000s (Venusia) and, more recently, from 2011 to the present (Aesernia).

A similar survey methodology, which may be described as large-scale, intensive and site-oriented, was used to collect the datasets. Teams composed of 3 to 5 surveyors spaced 5 to 10 m (Venusia and Aesernia projects) or 10 to 20 m (Cosa project) apart systematically walked through all accessible field units in the sample survey area. All observable scatters of archaeological material (site density set at ≥ 5 shards per sq m for the Venusia and Aesernia projects and a density scale of 1 to 5 for the Cosa project) were recorded on IGM maps (1:25,000), CTR maps (1:5000; 1:10,000) or by GPS. Concentrations of material were dated on the basis of diagnostic ceramics, samples of which were collected for laboratory analysis.

Despite the richness and high quality of these datasets, comparable to most reconnaissance research in other areas of the Mediterranean world (e.g., the southwest Argolid project [Jameson *et al.* 1994] and
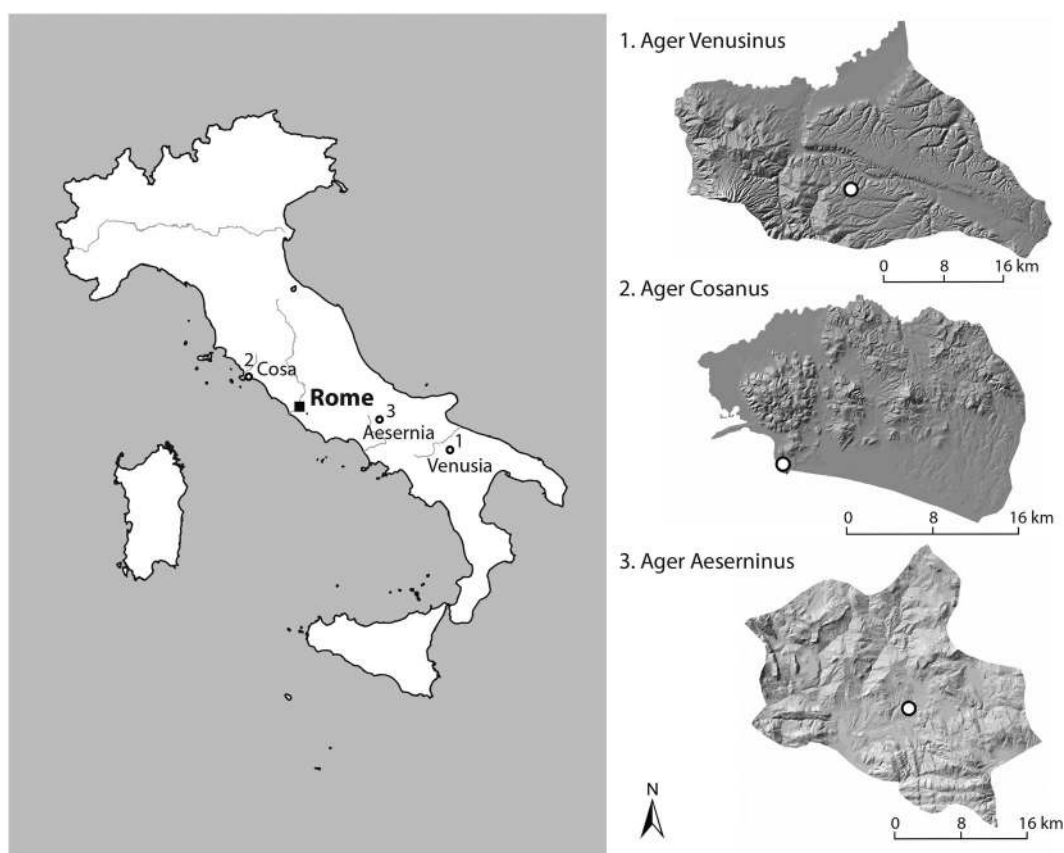

Figure 1   Location of the three Latin colonies and the extent of their territories.

the Boeotia project [Bintliff and Snodgrass 1985]), there are obvious, much-discussed methodological problems with regional site-oriented surveys and with the validity of survey data in general, especially with respect to their completeness (e.g., Barker and Lloyd 1991; Bintliff and Sbonias 1999; Fentress 2000; Terrenato 2000; Terrenato and Ammerman 1996; Van Leusen 2002; Van Leusen *et al.* 2011).

Our focus is on critically analyzing the patterns that can be discerned in these legacy datasets. This is relevant not only because these datasets have significantly influenced several important past and current historical and archaeological discourses, but also because different conclusions have been drawn from them, suggesting radically different settlement scenarios. As we will demonstrate, contrary to what scholars have suggested in the past, these datasets do not corroborate the conventional model of Roman colonial settlement organization, but are reasonably consistent with other types of settlement organization.

Our analyses include all settlement sites recorded inside the proposed colonial territories (TABLE 1) broadly datable to the Hellenistic period (ca. 350–50 B.C.), primarily on the basis of the presence of black-gloss pottery. We adopt this rough chronological range to study early colonial settlement patterns for both practical and theoretical reasons. First, the number of sites that can be dated precisely to the early colonial phase (i.e., 3rd century B.C.) is too small to identify statistically significant patterns. This is a well-known problem that scholars have typically addressed by including a category of possible sites (defined over a broad chronology, e.g., sites generically defined as Hellenistic or Republican settlements) to compensate for the underrepresentation of poorly detectable site types or periods (for this approach, see Goodchild and Witcher 2010: 196–198).

Including potentially later sites may distort our understanding of early settlement patterns, since 2nd- and 1st-century developments may have differed from earlier conditions. However, since the inclusion of potentially later sites is likely to strengthen rather than weaken the conventional scenario (with higher site densities and more regular patterning), any indication of divergent patterns in the aggregate data (such as clustering) takes on even greater significance. Again, we emphasize that the central aim of this paper is to investigate both the potential of the unfiltered legacy survey data available and the robustness of the various settlement models that have been inferred from them. As a matter of fact, we believe that further detailed research on colonial sites and finds (see Pelgrom *et al.* 2014; Stek *et al.* 2015), and on possible biasing factors related to field-survey recording methods (such as ground visibility and geomorphological processes), is needed to confirm the validity of the patterns identified in this paper (forthcoming article).

Methods

We systematically analyzed the existing survey data on two interrelated levels: the density and spatial configuration of settlement sites. To avoid potential bias from previous scholars' categorization of sites (i.e., function or size), all sites are visualized in GIS as simple, unclassified dots: that is, Hellenistic settlements are represented only by their centroids. On account of the long occupational history of a majority of these sites, their extension (which was recorded during field survey) is not necessarily indicative of the early colonial phase. Therefore, it would be incorrect to use the information about the size of these settlements so as to distinguish potential colonial farms from larger settlement types (such as villages

Table 1 Legacy data and samples.

Colony	Modern Province and Region	Survey project	Project survey area (sq km)	Area of the proposed colonial territory (sq km)	Colonial territory inside survey area (sq km)	Early colonial settlements	Hellenistic settlements*
Venusia	Potenza (Basilicata)	Forma Italiae (Marchi and Sabbatini 1996; Sabbatini 2001; Marchi 2010)	700	890 (based on Coppa 1979)	530	78 0.1 sites per sq km	564 1.1 sites per sq km
Cosa	Grosseto (Tuscany)	Paesaggi d'Etruria (Carandini *et al.* 2002)	300	430 (based on Cardarelli 1924–1925)	135	73 0.5 sites per sq km	200[†] 1.5 sites per sq km
Aesernia	Isernia (Molise)	Landscapes of Early Roman Colonization (LERC) (Stek *et al.* 2015)	120	680 (based on Toynbee 1965)	120	4 0.03 sites per sq km	81 0.7 sites per sq km

[*]In all three case studies, certain, probable and possible Hellenistic settlements are taken into account.
[†]On occasion, when two or more sites were found very close to each other, the Cosanus survey team assigned them the same UTM coordinates (reported in Carandini *et al.* 2002: 379–409). Since we used these coordinates for the site digitalization, sites with the same position appear as a single dot, both in the original distribution maps (published in Carandini *et al.* 2002) and in the Figures 3, 6, and 10B of this paper. In the following density and pattern analyses, however, they are counted as distinct sites.

or villas). Moreover, the scatter size is also strictly depending on invasive plowing activities which can transform small, dense concentrations of archaeological finds into larger, more diffuse scatters (e.g., Given 2004; Feiken 2014; Fentress 2000; Shennan *et al.* 1985; Van Leusen 2002). Therefore, unclassified and homogeneous point distributions are considered the primary evidence for quantitatively testing associated site density and patterns (Orton 2004). It is important to stress that these methodological decisions favor the conventional colonial settlement model, since the pluriform archaeological reality is reduced to equally sized dots in conformance with the notion of regularly settled landscapes dotted with mononuclear farmsteads.

The spatial analyses were conducted in two steps. First, the conventional model, which expects high density of sites in the colonial countryside, was tested in ArcGIS (version 10.2.2) by means of a point-density analysis, which calculates the number of sites per square kilometer. In order to broaden the scope beyond the rival theories of dispersed or nucleated colonial settlements, we also considered alternative scenarios that might explain the density patterns recorded. In particular, we analyzed whether the primary urban settlement of a colony influenced rural settlement densities as predicted by Von Thünen's Isolated State model. The Von Thünen model (1966 [1826]) predicts a gradual decline in settlement density as the travel cost to reach the urban center increases, which is correlated with different agricultural practices utilized in concentric land-use bands around the urban center. This model has already been applied to better understand whether settlement density correlates with distance to city; for example, in Patterson's study (2004) of the Roman economy in the Tiber valley (see also De Neeve 1984: 10–16 and Morley 1996: 11, 58–82 for a discussion in economic terms of the Von Thünen model in Roman contexts). Patterson demonstrates that, despite its abstract and reductive nature, the model closely corresponds to the data on Early Imperial Rome and its hinterland (but see Horden and Purcell 2000: 112–122 and Witcher 2009: 477–478 for a critical position): higher site density was identified closer to Rome, which matches Von Thünen's theory of the intense exploitation and settlement of rural areas closer to urban markets. This was also the main expectation we tested with our datasets.

In a second step, we conducted a point-pattern analysis to detect regular, random or aggregated patterns (Hodder and Orton 1976: 30–98; Kintigh and Ammerman 1982; Roberts 1996: 56–57). Translating the two competing colonial settlement models into spatial-analytical terms, we then tested for the presence of either a regular (conventional model) or

clustered (polynuclear model) settlement pattern. In this analysis, we focused on the interactions between settlements over local distances (so-called second-order effects in pattern analysis [cf. Bevan and Conolly 2006; Orton 2004; Palmisano 2013]). In essence, by looking at how settlements are located in relation to other settlements (and over what distances), we aimed to identify dispersed (regular distributions of farms) or agglomerative (villages) processes underpinning the colonial settlement system in different parts of the landscape. The influence of environmental and cultural landscape characteristics on settlement location preferences will be analyzed in a forthcoming paper (i.e., first-order effects: on how to incorporate them in pattern analysis see Bevan and Conolly 2006: 229–230; Bevan and Wilson 2013; Palmisano 2013; Winter-Livneh *et al.* 2010: 288–293; see also how predictive modeling investigates first-order effects in Judge and Sebastian 1988; Kvamme 1990; Van Leusen and Kamermans 2005; Verhagen 2007).

We applied a Multi-Distance Spatial Cluster analysis (global Ripley's K-function) in ArcGIS to highlight statistically significant clustered or dispersed patterns over a wide range of scales of analysis (ESRI 2014b). This statistical tool graphically illustrates how the spatial arrangement of dots changes as the scale changes (thus in tandem with the size of the study area being evaluated around the dots). Although the more popular Nearest Neighbor analysis by Clark and Evans (1954) also is a valuable approach to point-pattern analysis, we feel that it is less effective in evaluating the patterns in our datasets. The Nearest Neighbor analysis, indeed, calculates a clustering index based only on the mean Euclidean distance from each site to the next nearest (Bailey and Gatrell 1995: 90–91), whereas the global Ripley's K-function measures the average number of sites from each source site within several given distances (i.e., at every scale of analysis); it thus can identify significant correlations (if any) between distribution and density at various scales of analysis. On the contrary, since the Nearest Neighbor analysis considers only one scale corresponding either to the extent of the sample area (in our case, the survey sample area of the colonial territory) or to a rectangle enclosing all the dots, it can detect only the dominant pattern characterizing the entire study area sample.

To answer the question posed in this paper, it is crucial to deal with the fact that the pattern changes as the scale used to observe the spatial distribution changes (see the discussion in Lock and Molyneaux 2006). As way of example, a cluster of dots will appear as composed by dispersed points if we look at it at a narrow scale. In reverse, as we scale up, the cluster configuration will again become apparent. The Ripley's K-function calculation offers a formal

approach to this problem, which is why it is best suited to our analysis: it takes into account several scales of analysis (i.e., progressively larger sample areas around the dots) and thus has control over pattern variability as the scale changes.

The Ripley's K-function is calculated as $K(d) = E/\lambda$, where E is the number of events within distance d from a randomly chosen centroid location, and λ is the average intensity of events per unit area (Bailey and Gatrell 1995: 92–94; Bevan and Conolly 2006: 220–221; Dixon 2002: 1796; Palmisano 2013: 350; Ripley 1976; Sayer and Wienhold 2013: 77). In practice, this tool evaluates the dot pattern at several progressively greater distances from the source sites: it computes the degree of clustering or dispersion by comparing the average number of neighboring sites from each source site, at every distance being evaluated (scale of analysis), with the average density of sites throughout the study area (ESRI 2014b).

As part of this pattern analysis we then selected physically and culturally uniform areas with constantly high point density that are large enough to support farm-based intensive agriculture. The goal then was to test, on a small-scale and with environmental and cultural conditions as equal as possible, whether an even distribution of farms manifests itself in the data. This is, indeed, the typical settlement organization pattern anticipated in the conventional colonial model: in principle, wherever favorable physical conditions (i.e., smooth/flat morphology) in the conquered territory allow for orderly land partition, we should expect to find farms distributed regularly across the terrain, corresponding to a highly precise, grid-based allotment system and, thus, dependent exclusively on regular local distances between farms (i.e., second-order effects).

As a last step of this pattern analysis, we also carefully examined the cluster pattern that seems to characterize large tracts of colonial territories. We tested further by using Bintliff's approach to the study of territorial organization (Bintliff 1999, 2000, 2009). First, we indicated possible early colonial nucleated settlements (or villages) and then analyzed the polynuclear configuration of the dot clustering. Bintliff's socio-ecological approach to modeling Mediterranean village-based systems serves as a useful comparandum as we calibrated the pattern of our datasets and establish parallels (if any) to a nucleated form of settlement (Roberts 1996: 15–37).

In contrast to Bintliff's studies, our analysis does not focus on the definition of territorial catchments (Vita-Finzi and Higgs 1970), but rather operates on a simpler descriptive level whereby distances between colonial settlement clusters are compared with Bintliff's distance predictions. He identifies settlement catchment radii of comparable length according to

different degrees of rural infill (and demographic growth) and different fission levels of the village system at issue (related to dynamics of territorial competition). In the Ager Venusinus and the Ager Cosanus, we analyzed the distance between neighboring hotspots with high localized settlement density (potential villages) to see how these distances match the standard inter-distances proposed by Bintliff.

Testing Settlement Density: Point-density Analysis

According to the conventional understanding of Roman colonization, a majority of the colonists sent by Rome to populate freshly conquered lands settled in farms on individual plots carved out of the *ager* of the colony (i.e., the territory under the jurisdiction of the colony). Colonial urban centers were small and thus could have hosted only a limited number of colonists. Literary evidence on colonial populations and the size of the allotments they received, in particular Livy's *Ab Urbe condita*, suggests large colonial populations, usually ranging between 2500 and 6000 colonists. This translates into farm densities of at least eight farms per sq km, if one accepts a sensible urbanization percentage of 20–30% (for in-depth discussion on these estimates, see Garnsey 1979; Pelgrom 2008, 2013: 74–75; on estimating population densities for colonial landscapes, see Fentress 2009).

In order to test whether such densely populated landscapes are visible in the survey data and, if so, where they are located, we used the Point Density tool in ArcGIS. This tool estimates the density of points around each output raster cell in a user-defined neighborhood (ESRI 2014a). In this case, we chose a circle of one sq km. This results in a raster surface in which the value of each cell (set at 20×20 m) represents the number of sites found in the circle. Cells with a density higher than twenty, ten, eight, five, three and one settlements per square km were then isolated and the extent of their respective areas was calculated. In this way, we calculated the percentage of the landscape that corresponds to the expected farm density of eight sites per square km.

The results shown in Table 2 clearly demonstrate that the extent of rural landscape characterized by a settlement density equal to or higher than eight sites per square km barely approaches 1% in all three case studies. Significantly, this enormous divergence from conventional expectations even appears when we consider the "best-case" scenario for early colonial occupation. Even if we assume *all* broadly dated Hellenistic settlements are early colonial farms, the actual field survey data exhibits no observable correlations with historically expected site densities.

One explanation for this enormous discrepancy may be sought in adverse survey conditions, which may

Table 2 Percentages of rural territory defined by different settlement density.

Density (sites per sq km)	Ager Venusinus		Ager Cosanus		Ager Aeserninus	
	With unfeasible survey conditions	Without unfeasible survey conditions	With unfeasible survey conditions	Without unfeasible survey conditions	With unfeasible survey conditions	Without unfeasible survey conditions
$d \geq 20$	0.03%	0.03%	0	0	0	0
$d \geq 10$	0.79%	0.84%	0.385%	0.40%	0	0
$d \geq 8$	1.38%	1.24%	0.93%	1.04%	0.05%	0.285%
$d \geq 5$	4.81%	4.29%	4.44%	4.15%	0.78%	2.55%
$d \geq 3$	13.21%	12.12%	18.53%	20.07%	6.08%	10.175%
$d \geq 1$	45.535%	43.56%	55.31%	59.86%	36.58%	54.41%
$d = 0$	54.465%	56.44%	44.69%	40.14%	63.42%	45.59%
Total area (sq m)	530,066,147.317	396,770,118.377	135,337,975.878	81,257,583.851	120,401,979.430	14,977,976.518

have prevented archaeologists from recording a majority of sites. Such factors as poor visibility of the walking surface or the frequent erosion of the steepest slopes may have had a detrimental effect on site detection (these factors are discussed at length in a forthcoming paper). As a result, the representativeness of the samples under consideration here may be significantly undermined.

To assess the potential impact of such factors, we conducted a second point density analysis, this time excluding possible biased samples. As an experiment, we only considered zones and settlements located in modern arable land characterized by good surface visibility and gentle slope conditions, which is widely known to afford ideal surface visibility for site discovery. For the Ager Venusinus and Cosanus, the areas covered by forest, artificial surfaces and water bodies (extracted from the CORINE Land Cover 2000 and 1990–1:100,000, Sambucini *et al.* 2010: 9–15), and slopes steeper than 20% (cf. Arnoldus-Huyzendveld 2007 and FAO 2006: 11–12), were excluded from the colonial territory sample. We followed a broadly similar but more precise procedure for the Ager Aeserninus, for which we have detailed information on the survey visibility conditions and land use of each unit walked. The number of Hellenistic sites located in the remaining zones with favorable field survey conditions in the colonial territories is respectively 493 in the Ager Venusinus, 164 in the Ager Cosanus and 69 in the Ager Aeserninus.

Despite our effort to exclude the most common adverse conditions for field surveys, the percentage of territory characterized by a site density equal to or higher than 8 per square km remains very small (lower than 1.5%) in all the three colonial territories (TABLE 2). Even when we analyzed select samples of the field survey area and possibly more representative site samples, the traditional scenario of a radically reorganized, evenly dotted Roman countryside is virtually invisible in the archaeological record.

This major discrepancy between expected site densities and the survey record can readily be appreciated in Figures 2–4. Areas with a density of eight or higher are very limited. Certain spatial patterns, however, are visible in the data. For example, site densities of five and higher are located primarily in fertile plains close to urban centers (e.g., the Piani di Camera in the case of Venusia, and the middle of the Valle d'Oro in the case of Cosa) and are scattered more widely the further away they are from the centers. In the Ager Venusinus, there is also an area in between these two "bands" of higher density that is relatively devoid of settlements. The spatial configuration of high-density areas in the territory of Aesernia is rather different (FIG. 4). The highest and most homogeneous site density is not located near the urban center, as in Venusia and Cosa, but rather is concentrated in a river valley (the Valle Porcina), far west of Aesernia.

Testing trends in density: Von Thünen's Isolated State model

Cultural attractors, such as an urban center with its political and economic facilities, can influence land-use strategies and settlement density in the surrounding territory, varying according to the distance from them. In *Isolated State* (1966 [1826]), the German agronomist Von Thünen depicts an idealized scenario in which a market located in the middle of a flat isotropic landscape naturally tends to organize the surrounding hinterland in several concentric land use bands. Von Thünen proposes the following system of land use, moving from the town outwards: intensive production: horticulture and dairy-farming; silviculture; extensive agriculture (intensive arable rotation, arable with long ley, three-field arable); and ranching (Chisholm 1968: 20–32; Goodchild 2007: 31–35; Grotewold 1959; Haggett *et al.* 1977 [1965]: 205–207). According to this model, settlement density decreases as the distance from the town increases.

We tested the Von Thünen density trend against the survey data. Since several variables, such as the
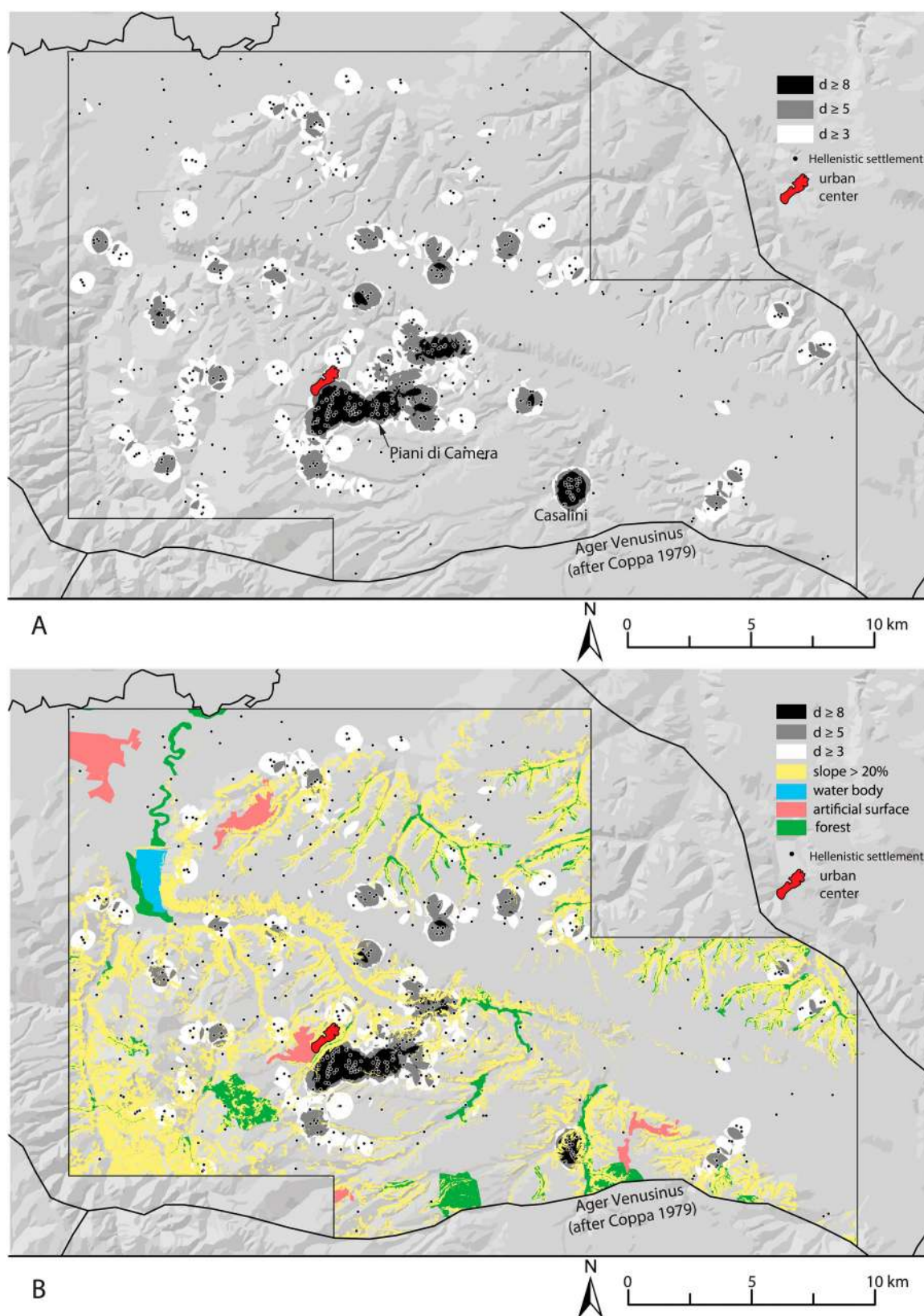
Figure 2   A) Point-density analysis of the Hellenistic settlements (black dots) in the survey sample area of the Ager Venusinus; B) Point-density analysis excluding sites and zones in unfeasible survey conditions (forest, artificial surfaces, water bodies and slope > 20%). Base map: hillshade elaboration of the 10 m-resolution DEM named TINITALY/01 (Tarquini *et al.* 2007, 2012).

topography, routes, rivers and secondary markets (Haggett *et al.* 1977 [1965]: 211–222), may distort the Von Thünen's idealized land-ring pattern we adjusted the model accordingly (cf. Dodson 1991; Thornton

and Jones 1998). In IDRISI GIS (Selva edition), we incorporated the effects of landscape morphology, arguably the most important factor on the movement of people, by implementing a cost analysis (using the
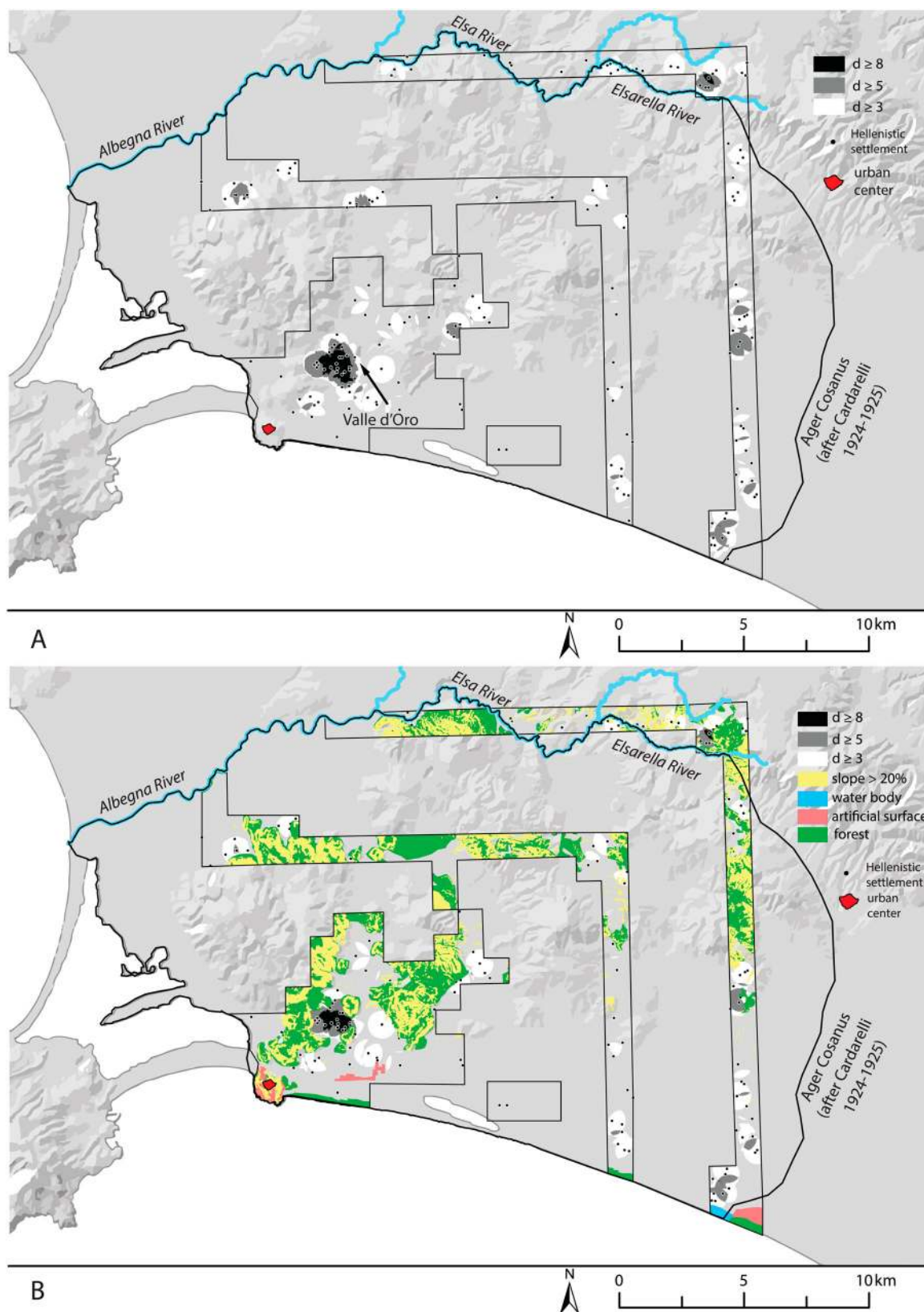
Figure 3   A) Point-density analysis of the Hellenistic settlements (black dots) in the survey sample area of the Ager Cosanus; B) Point-density analysis excluding sites and zones in unfeasible survey conditions (forest, artificial surfaces, water bodies and slope > 20%). Base map: hillshade elaboration of the 10 m-resolution DEM named TINITALY/01 (Tarquini *et al.* 2007, 2012).

VARCOST module; see Eastman 2012: 277–281) based on slope and aspect values, which are extracted from the 10 m–resolution DEM named TINITALY/01 (Tarquini *et al.* 2007, 2012). In conducting this cost

analysis, we modeled the cost of moving from the city to its hinterland as a good approximation of the cost necessary to walk the other direction, from the hinterland to the city. Moreover, we treated distance simply
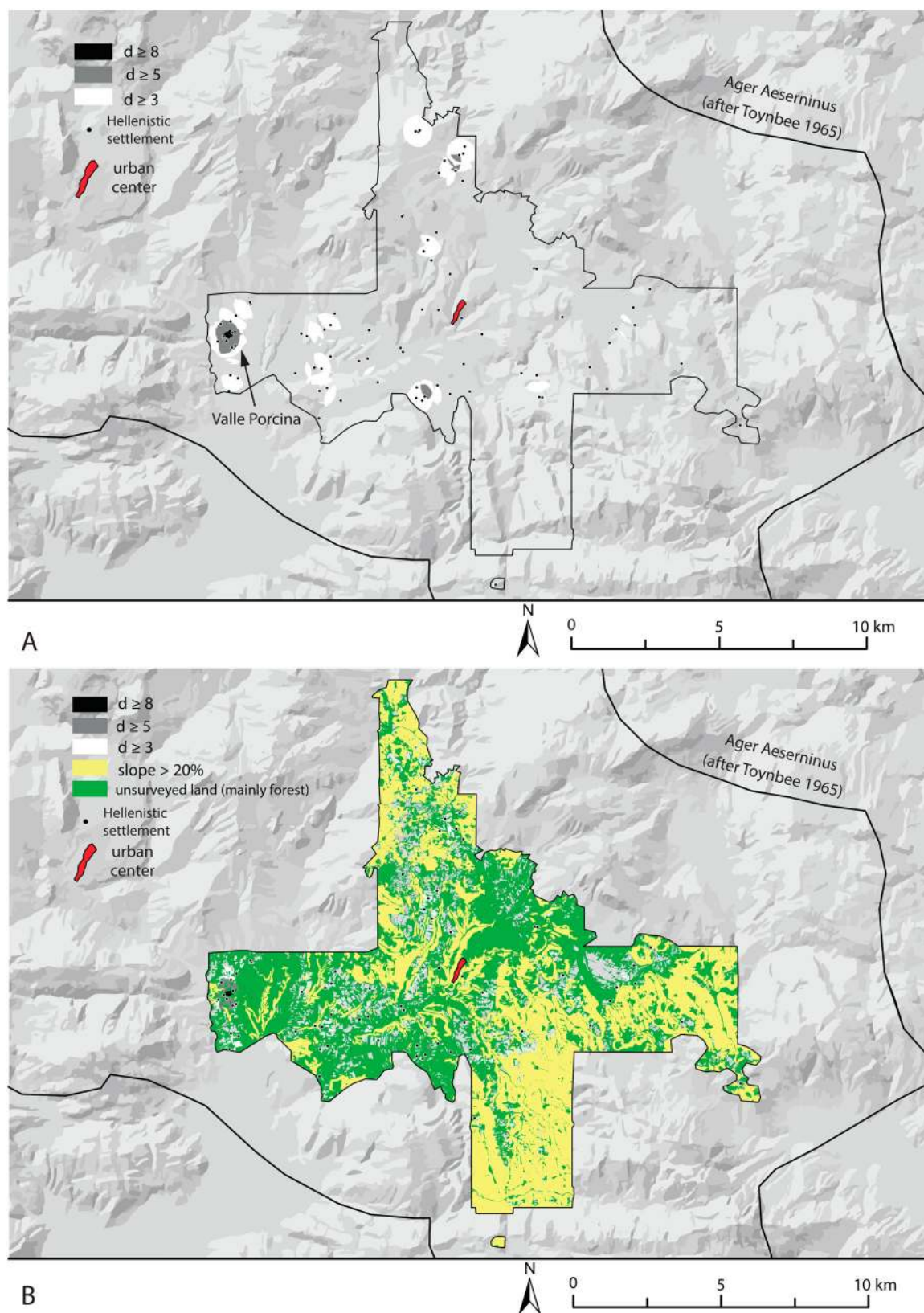
Figure 4   A) Point-density analysis of the Hellenistic settlements (black dots) in the survey sample area of the Ager Aeserninus; B) Point-density analysis excluding sites and zones in unfeasible survey conditions (unsurveyed land and slope > 20%). Base map: hillshade elaboration of the 10 m-resolution DEM named TINITALY/01 (Tarquini *et al.* 2007, 2012).

as the physical distance people walked and did not consider the effect of moving different types of goods on transport costs (economic distance: see Chisholm 1968: 30; Zipf 1949).

After creating cost surfaces based on slope and aspect conditions (see also Conolly and Lake 2006: 215–225; Wheatley and Gillings 2002: 151–159), we divided the colonial territories into concentric land-

use cost-bands centered around the city. To do this, we have accepted previous scholars' reconstructions of the colonial *agri* (Cardarelli 1924–1925; Coppa 1979; Toynbee 1965) as the maximum territorial extents of these colonies (for a critical discussion of these modern territorial reconstructions see Pelgrom 2014; Stek 2014). Within these territories, we distinguished the four main zones of agricultural activity as described above. If we apply the calculations of Haggett and colleagues (1977 [1965]: 205), the first band (intensive agriculture) covers 1% of the territory, the second band (forest) 3%, the third band (extensive agriculture) 58% and the fourth band (ranching/grazing) 38%. We reclassified the cost surfaces accordingly. As a result, the *agri* are carved up into four land-use cost-bands (FIGS. 5–7).

In a final step, we used the Attwell-Fletcher test of association (Attwell and Fletcher 1985, 1987; Kamermans 2000) to analyze the number of sites located in the cost-bands in the three survey sample areas: first, the number of settlements located in each band was compared to the percentage of surface surveyed in that band (i.e., the number of observed settlements was confronted with the proportion of settlements expected in that surface); second, significant associations (if any) were then indicated. The Attwell-Fletcher test evaluates whether the concentration of sites in each cost-band is positively significant (i.e., there are significantly more sites than expected from a random distribution: category weight > than the critical value for 95th percentile), negatively significant (i.e., significantly fewer sites than expected: category weight < than the critical value for 5th percentile) or merely due to chance.

This statistical analysis permits us to recognize significant density patterns as cost-distances from the colonial town increase. As displayed in Tables 3 and 4, there is a significant tendency in the Ager Venusinus for settlements to cluster in the first concentric cost-band around the colonial town. Moreover, significant evidence of avoidance allows us to confidently infer that site concentration decreases significantly in the third and fourth zones. In the Ager Cosanus and Aeserninus, no significant correlations are found. This may be due to the smaller size and narrower and more irregular shape of the survey transects that do not allow for the observation of the pattern in extension (transects of ca. 1 km wide regularly spaced with a wider one covering the Valle d'Oro are present in Cosa, a cross-shaped transect in Aesernia). Sample choices may also affect the following point-pattern analysis.
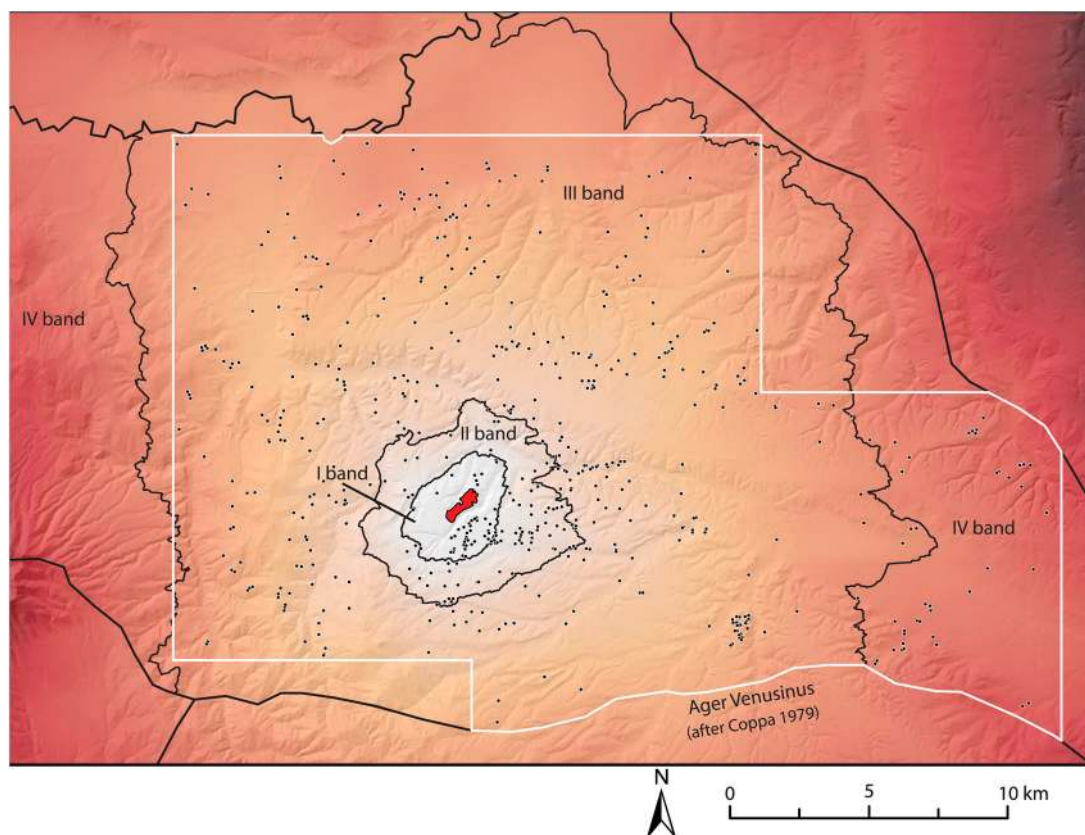

Figure 5   Von Thünen's model implemented in the Ager Venusinus. Cost-surface created from the 10 m-resolution DEM named TINITALY/01 (Tarquini *et al.* 2007, 2012) and calculated in IDRISI GIS (VARCOST module): the increasing cost from the city to the hinterland ranges from low (white) to high (dark red).

Figure 6 Von Thünen's model implemented in the Ager Cosanus. Cost-surface created from the 10 m-resolution DEM named TINITALY/01 (Tarquini *et al.* 2007, 2012) and calculated in IDRISI GIS (VARCOST module): the increasing cost from the city to the hinterland ranges from low (white) to high (dark red).
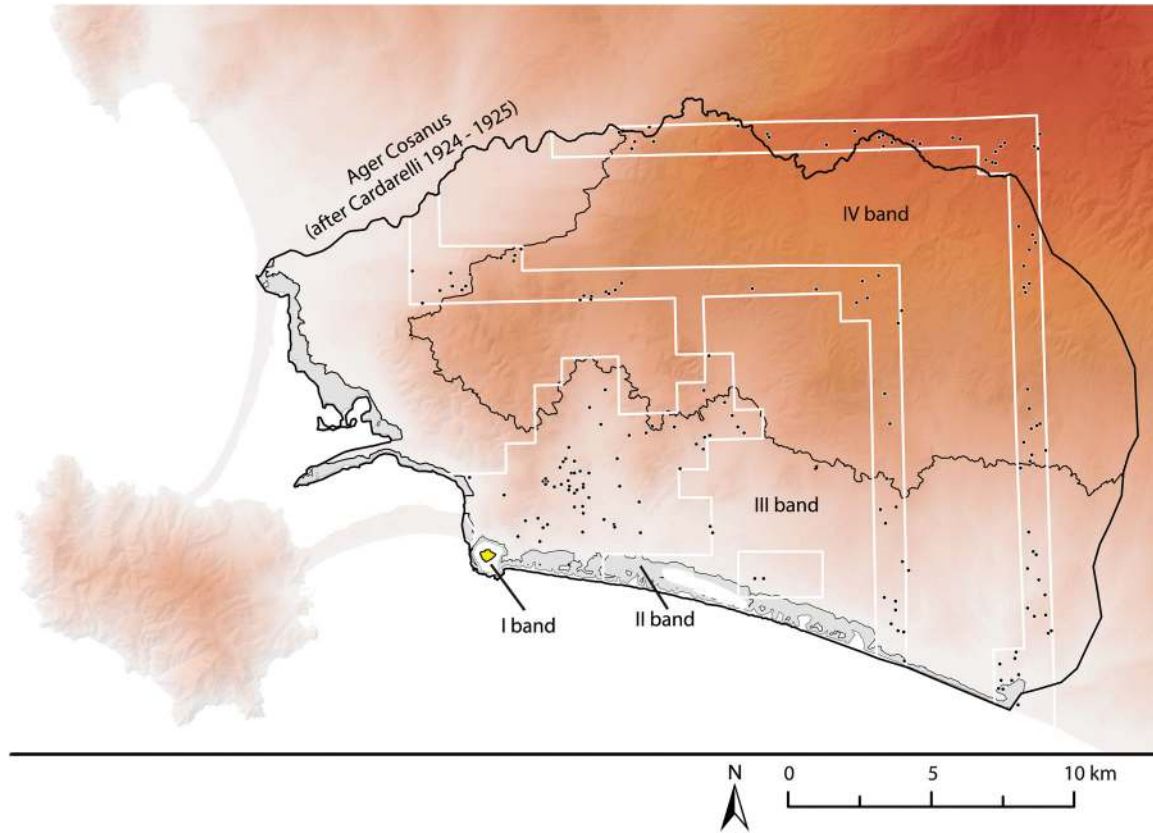
Testing Settlement Distribution: Point-pattern Analysis

We turn now from density to spatial configuration. Our aim here is to discern significant settlement patterns and to assess to which colonial scenario they correspond more closely. A regular pattern would nicely fit the conventional model, because it predicts farms located in regularly distributed modular plots (see Hodder and Orton 1976: 54–85; Hudson 1969; Perles 2001: 132–147 for a discussion of regular patterns in rural areas). A random (but dense) arrangement might also conform to the conventional scenario: in that case, random distribution may be explained by the variable position of farms within their allotments (Celuzza 1984: 159). A clustered pattern separated by tracts of empty space, however, might indicate a polynuclear, village-based settlement system.

In order to detect potential clustered or regularly dispersed site distribution patterns, a global K-function calculation was run in ArcGIS. We performed a Multi-Distance Spatial Cluster analysis with ArcGIS inside the survey sample areas of the colonial territories (thus excluding the unsurveyed zones outside the transects) and we applied the correction method to simulate outer boundary sites in order to limit the edge-effect problem (i.e., likely underestimation of

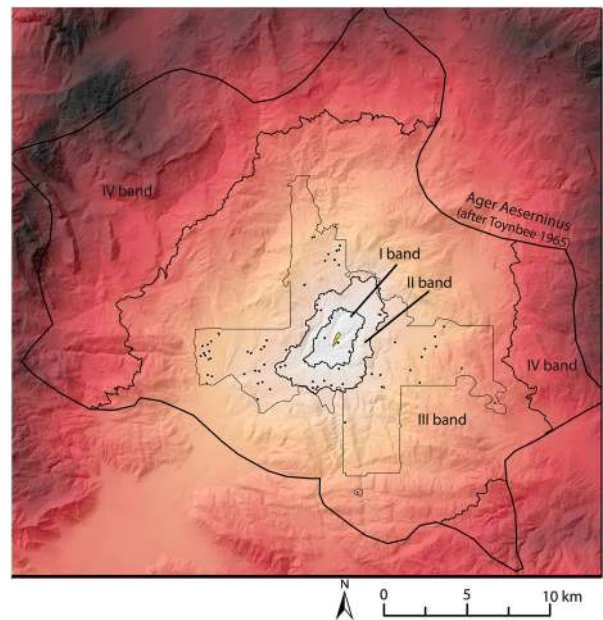sites next to the borders between surveyed and unsurveyed areas). The site densities found in increments of

Figure 7 Von Thünen's model implemented in the Ager Aeserninus. Cost-surface created from the 10 m-resolution DEM named TINITALY/01 (Tarquini *et al.* 2007, 2012) and calculated in IDRISI GIS (VARCOST module): the increasing cost from the city to the hinterland ranges from low (white) to high (dark red).

Table 3 Outcomes of the Attwell-Fletcher test, comparing the number of settlements observed in each cost-band of the Venusian survey sample. Number of sites = 543 (the cluster of dots—22 points—in the 3rd band, representing the nucleated village of Casalini, is counted as a single point); number of categories = 4; number of simulations = 200. 95th percentile for max weight = 0.35 ± 0.016 ; 5th percentile for min weight = 0.14 ± 0.004.

Ager Venusinus (including sites and zones in unfeasible survey conditions)						
Cost band	Number of sites	Expected proportion	Observed proportion	Category weight	More sites than expected	Fewer sites than expected
1st	47	0.019	0.09	0.52	yes	no
2nd	81	0.052	0.15	0.32	no	no
3rd	375	0.792	0.69	0.10	no	yes
4th	40	0.137	0.07	0.06	no	yes

Table 4 Outcomes of the Attwell-Fletcher test, comparing the number of settlements observed in each cost-band of the Venusian survey sample. Number of sites = 471 (the cluster of dots—22 points—in the 3rd band, representing the nucleated village of Casalini, is counted as a single point; sites located in unsuitable survey conditions are excluded, in total 72); number of categories = 4; number of simulations = 200. 95th percentile for max weight = 0.37 ± 0.006; 5th percentile for min weight = 0.11 ± 0.021.

Ager Venusinus (excluding sites and zones in unfeasible survey conditions)						
Cost band	Number of sites	Expected proportion	Observed proportion	Category weight	More sites than expected	Fewer sites than expected
1st	46	0.015	0.10	0.61	yes	no
2nd	75	0.057	0.16	0.26	no	no
3rd	314	0.786	0.67	0.08	no	yes
4th	36	0.142	0.08	0.05	no	yes

50 m to 5 km from each site were averaged and a Monte Carlo simulation consisting of 99 permutations of randomly distributed points was performed to set the confidence interval at 99% (alpha = 0.01) (ESRI 2014b; Winter-Livneh *et al.* 2010: 289). The K(d) function is transformed and the L(d) function is calculated as $\sqrt{(K(d)/\pi) - d}$ (Bailey and Gatrell 1995: 94). For the L(d) function, the null hypothesis is zero (Sayer and Wienhold 2013: 78): when L(d) is greater than 0 there is clustering; in contrast, if L(d) is less than 0 there is regularity in the point distribution. The mathematical transformation of the Ripley's K-function performed in ArcGIS, however, is slightly different, and as a final result the expected index of a random pattern is equal to the input distance (ESRI 2014b). In order to assess the pattern type, the observed L(d) value has to be compared with the value expected.

In each distance increment, the actual distribution is compared against a random distribution, and if the observed L(d) value (black curve in the graphs in FIGS. 8 and 9) is greater than that expected (light gray curve), a clustered pattern is dominant at that scale of analysis. In turn, if this value is smaller than that expected, the distribution appears dispersed. Moreover, in order for the index of clustering or dispersion to be statistically significant, it must respectively be greater or smaller than the high or low level of the confidence interval (dark gray lines in the graphs). This index is indicated by the black curve (observed K): when this curve rises above the expected K curve (in light gray) and the high level of the

confidence interval (superior dark gray line), the distribution is significantly clustered at that particular scale of analysis (distance). When, instead, the curve drops below the expected K curve and the low level of the confidence interval (lower dark gray line), the distribution is significantly dispersed at that scale of analysis.

In the Ager Venusinus and Aeserninus a statistically significant clustered pattern is predominant at most scales of analysis (graphs A and C in FIG. 8). In the Ager Venusinus, the clustering of Hellenistic sites is evident (the only distance increment in which clustering is not statistically significant is the first, from 0 to 50 m). In the Ager Aeserninus, a statistically significant nucleated pattern is attested from 100 m to 4.1 km and continues until 5 km (but for this latter distance it is not statistically significant). A different situation is encountered in the Ager Cosanus sample, where significant clustering appears only up to a maximum cumulative distance of 1.2 km. From 1.25 km to 5 km the sample seems more dispersed than a random distribution, and from 3.2 to 5 km this pattern even becomes statistically significant (graph B in FIG. 8).

Having established these clustered patterns with our pattern analysis, in a second, more detailed step, we tested for the regular dispersion of sites within these areas by zooming in on an ecologically uniform zone in each colonial territory. These three zones were selected on the basis of two criteria. First, these zones stand out for their extensive area of high site
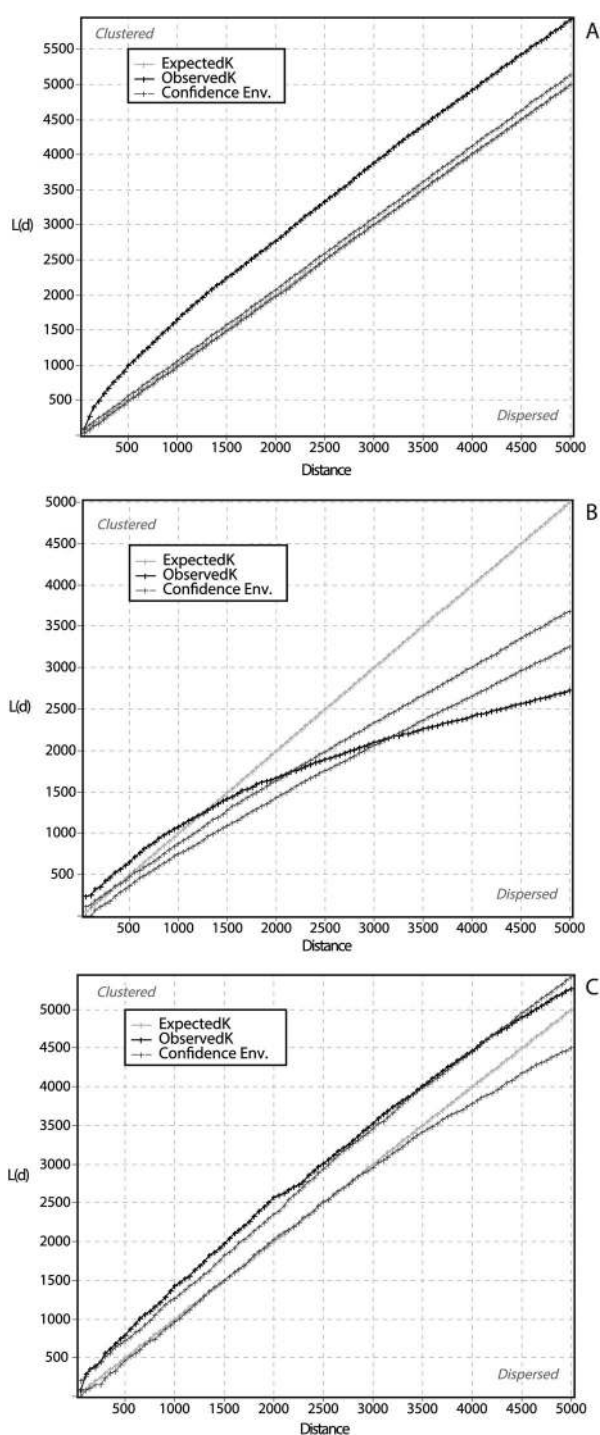
Figure 8 Ripley's K-function analysis of the Hellenistic settlements. A) Ager Venusinus; B) Ager Cosanus; C) Ager Aeserninus.

density. Second, the specific environmental and cultural characteristics of these zones are as homogeneous as possible. In this way, we limited the potential effect of attractive or repulsive socio-environmental factors on settlement distribution (i.e., first-order effects) while focusing on local distances between the settlements (i.e., second-order effects).

For the Ager Venusinus, the best candidate that meets these criteria is the wide plateau facing the colonial urban center, an area now called the Piani di

Camera (Marchi and Sabbatini 1996: 111–115). This zone is close to the urban center, is characterized by uniformly smooth geomorphology, and presents remarkably high settlement density and good survey-visibility conditions (Marchi and Sabbatini 1996: 107). In the Ager Cosanus, we selected a comparable area located close to the colonial town (Carandini *et al.* 2002: 137–138, 164–168; Celuzza and Regoli 1982). The valley floor of the Valle d'Oro is now used as arable land where the survey resulted in a relatively high site recovery rate (Carandini *et al.* 2002: 36–47). In the Ager Aeserninus, we focused on the western arm of the survey sample (Stek *et al.* 2015: 258–262), which is characterized by three river valleys and plateaus. The survey coverage in this zone is relatively high and more evenly distributed than in the other parts of the survey sample, average visibility is moderate, and the highest and most uniform site density is attested here.

The analysis was repeated on this selection of small eco-zones, looking at a maximum cumulative radius of 3 km. As can be seen in graphs A and C in Figure 9, no significant patterns are found on the Piani di Camera plateau and in the western transect. Sites seem to be located at random here. The analysis of Valle d'Oro, in contrast, showed significant nucleation up to 2.4 km (graph B in FIG. 9): generally, the pattern is clustered rather than randomly distributed. For the western transect of the Ager Aeserninus survey sample, there is some evidence of agglomeration found at a cumulative distance of 2.05 km, but this is not statistically significant, and we concluded that the site distribution here is random (graph C in FIG. 9). To sum up, according to this targeted statistical analysis of the small eco-zones, the settlement pattern of the Piani di Camera in the Ager Venusinus and of the western transect in the Aeserninus survey sample may conform to the conventional model of Roman colonization assuming a sparse dispersion of rural farms (see also Marchi and Sabbatini 1996: 112–113). The opposite holds true for the Valle d'Oro in the Ager Cosanus, where the central cluster may indeed indicate a nucleated settlement strategy (but see Carandini *et al.* 2002: 103–144; Celuzza and Regoli 1984; Rathbone 1981 for a different interpretation).

Modeling a village-based settlement system

In this section, we aim to further test the identified clustered pattern in several portions of the colonial territories. We compare the inter-village distances reconstructed from Bintliff's study of the evolution of Greek settlement systems with those of our potential early colonial villages. Bintliff (1999, 2000, 2009) developed a socio-ecological theory to investigate the origin of Greek city-states. He argues that the formation of
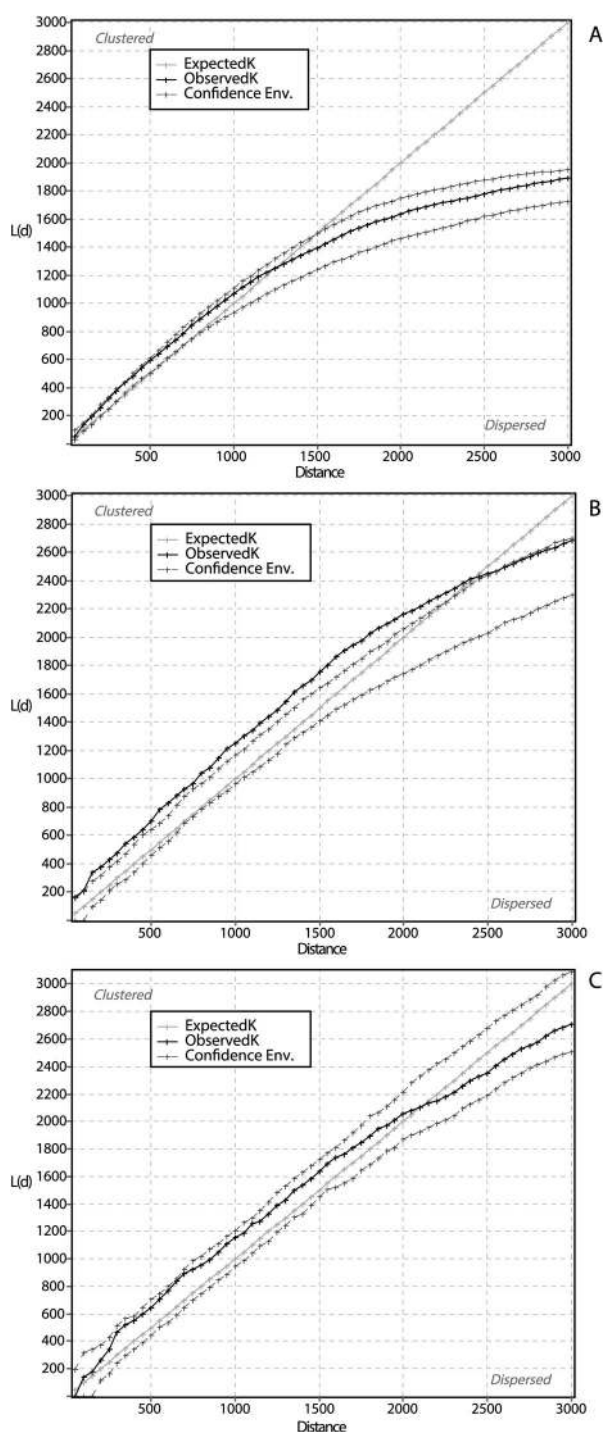
Figure 9 **Ripley's K-function analysis of the Hellenistic settlements. A) Piani di Camera (area: 7 sq km; number of sites: 78); B) Valle d'Oro (area: 15.65 sq km; number of sites: 47); C) western transect (area 29.62 sq km; number of sites: 39).**

Greek city-states in the period ca. 750–500 B.C. was triggered by the fission of scattered Dark Age settlements and the subsequent absorption of denser networks of Archaic settlements and territories by the most powerful village-states. In general, depending on the level of rural infill and demographic pressure, territorial catchments with radii of 5 km, 3–4 km, 2–3 km and 1–2 km can be recognized at different evolutionary stages in a village-based settlement model. On the basis of these estimations, it is possible to

calculate Euclidean inter-village distances from 2 to 10 km. Bintliff (2000: 23) highlights that a sustainable rural infill in a Mediterranean landscape reveals village territories with radii of 2–3 km (4–6 km inter-village distance), and a 1–2 km catchment radius (2–4 km inter-village distance) may indicate noteworthy population pressure on the land. We tested these distance predictions against the distances between the potential early colonial villages we discerned.

First we selected potential early colonial nucleated settlements on which we can conduct this kind of comparative analysis. We selected the parts of the colonial landscape that displayed a very localized, high settlement density: cell clumps of at least 4–5 ha in area, with a density threshold equal to or higher than five sites per sq km (colored in gray in FIG. 10). We specify here that areas for which a random/dispersed pattern (conventional model) was ascertained with the Ripley's K function were not considered (i.e., the Piani di Camera plateau in the Ager Venusinus and the western transect of the Ager Aeserninus). This means that inter-village distances in the Ager Aeserninus could not be compared, since only one scattered high-site-density zone remains north of the city.

Both in the colonial territory of Venusia and Cosa, the distances between possible nucleated settlements match Bintliff's predictions. As displayed in Figure 10A, the twenty-three zones of interest in the Ager Venusinus (their centroids are marked in yellow) have a minimum inter-distance of 1.5 km and a maximum inter-distance of 6 km from the nearest neighbor (average: 2.7 km). The most well-known pre-Roman villages (blue triangles, i.e., Casalini, Allamprese, La Cupa-Masseria La Gala) overlap these gray polygons of high site density. We are currently revisiting these (allegedly) Daunian and Samnite nucleated settlements in the context of the "Landscapes of Early Roman Colonization" project (Stek and Pelgrom 2013; https://www.universiteitle iden.nl/en/research/research-projects/archaeology/ landscapes-of-early-roman-colonization; http://land scapesofearlyromancolonization.com/) to obtain additional information about a potential early colonial occupation. A detailed (re-)examination of the black-gloss pottery collected at these villages very plausibly suggests continued occupation from the 4th to the 2nd century B.C. (Pelgrom *et al.* 2014). In the Ager Cosanus, as shown in Figure 10B, the twelve zones of interest have a minimum inter-distance of 1.3 km and a maximum inter-distance of 5 km from the nearest neighbor (average: 2.8 km). The corner of the outmost transect probably belongs to the Ager Saturninus (Carandini *et al.* 2002: 159) and thus is not included in the analysis. Many of these zones coincide with or are very close to documented
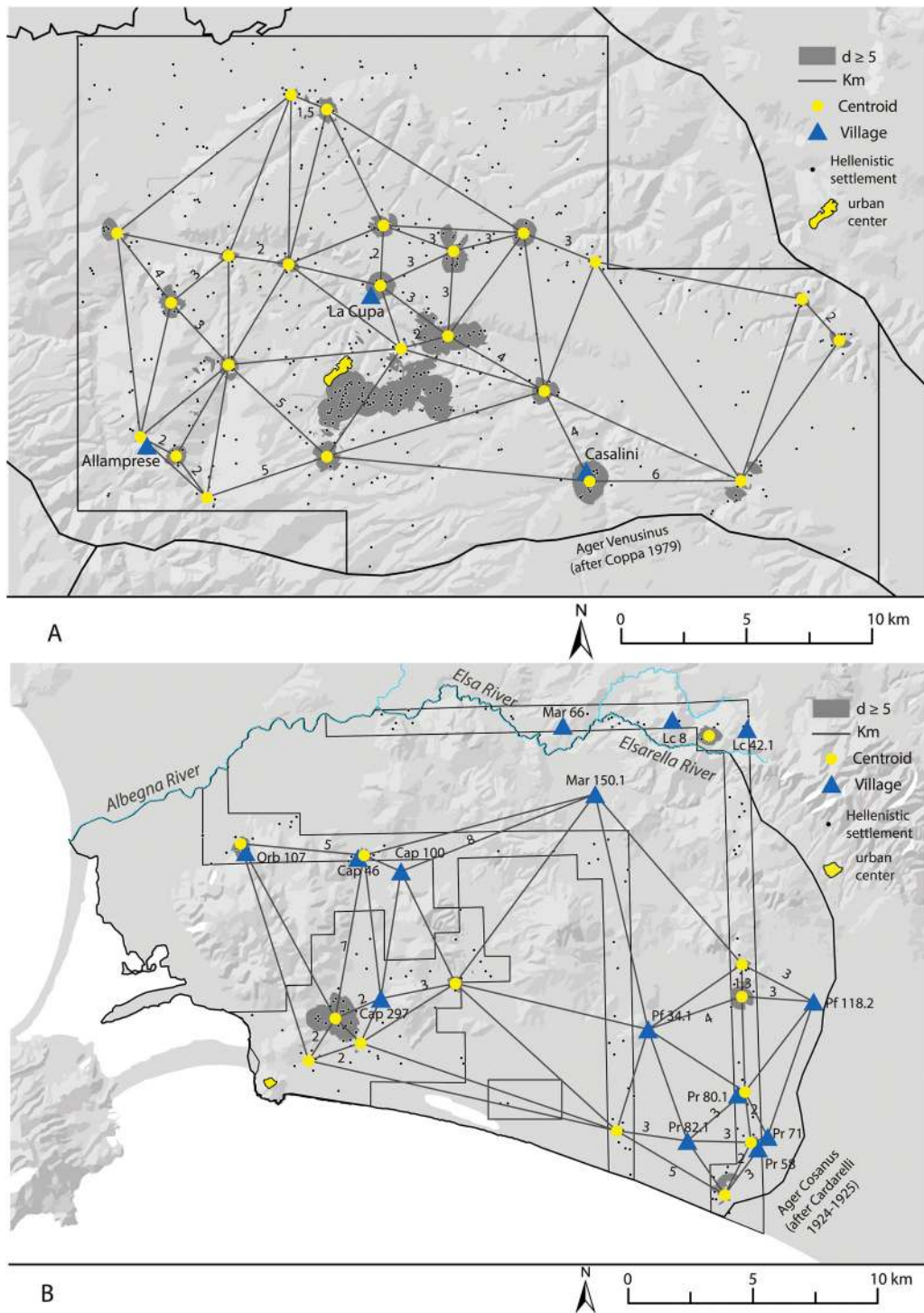
Figure 10 Distances between centroids of scattered polygons (in gray) with site density ≥ five per sq km in the Ager Venusinus (A) and Cosanus (B). If a polygon is located less than 300 m from another one, they are merged and the centroid is placed centrally. Base map: hillshade elaboration of the 10 m-resolution DEM named TINITALY/01 (Tarquini *et al.* 2007, 2012).

Etruscan and Roman villages (blue triangles, indicated by their acronyms [Carandini *et al.* 2002: 375–409]); if these are incorporated, they reduce the nearest-neighbor distance average to 2.5 km.

Conclusions

In this paper, we have tested the robustness of different settlement models that have been proposed for three mid-Republican colonies in Italy on the basis of

regional field-survey projects. The existing datasets for Venusia, Cosa and Aesernia have been systematically subjected to point-density and pattern analysis. In all the three case studies, the results of the point-density analysis clearly indicate an enormous discrepancy from demographic reconstructions based on literary sources. Even if we accept the "best-case" scenario of early colonial occupation (by including all attested Hellenistic sites as possible early colonial

sites) and select ideal visibility conditions for site discovery (modern arable areas and gentle slopes), three different survey teams, at three different moments and in three different landscapes (modern Basilicata, Tuscany and Molise), did not detect the supposedly numerous mid-Republican farms expected by traditional reconstructions. The pattern that emerges, instead, clearly indicates that the density of only a tiny portion of the territory is compatible with the expected number of sites. These small areas of high site-density are located primarily in the vicinity of the urban center (as at Venusia and Cosa), although this is not the rule (as in the case of Aesernia). In the rest of the survey samples, a scattering of localized high site densities suggests a patchier, clustered pattern.

It is clear that these results challenge conventional interpretations of colonial settlement organization in Republican Roman Italy. The significant differences in site density and pattern highlighted in our analysis are difficult to reconcile with conventional expectations of neatly partitioned territories, but fit the newly proposed polynuclear settlement scenario. It is true that some variants of the conventional model have suggested as well the presence of areas of nucleated settlement within colonial territories. In such cases, however, they have been interpreted as villages where the indigenous population settled (Coarelli 1991; Cornell 1995: 367; see Bradley 2006 on the inclusion of indigenous populations in colonies). In this view, the clustered pattern is reconciled with a scenario in which the native population is relocated in marginal zones of the *ager*, where it would have been allowed to continue settling in villages (Carandini *et al.* 2002: 108–110).

What then remains to be explained is where the colonists lived. If we consider the collected data to be largely representative of the early colonial settlement organization, there are two ways to answer this question. First, if we adhere to conventional interpretations, which consider densely and evenly distributed sites to be a diagnostic indicator of Roman colonial settlement, we must imagine an "agro-town" (Garnsey 1979) in which a majority of colonists lived in the urban center and in a relatively small rural territory nearby, whereas the remaining indigenous population settled in clustered settlements farther away. Such a scenario, however, must assume that either Livy's demographic estimates are corrupt (cf. discussion in Pelgrom 2013) or include an additional population component, such as the colonists' family members or the indigenous population that continued living in their traditional villages (Bradley 2006; Torelli 1999: 94). Secondly, if, however, we accept Livy's colonial population numbers as a roughly correct representation of adult male colonial settlers,

we must assume that the majority opted for a more nucleated settlement strategy (see also Torelli 1991: 22). They therefore may have colonized distant pockets of the conquered landscape at fairly standardized distances, which, as we have seen, match those set out by Bintliff (1999, 2000, 2009) in his village landscape model.

The latter explanation accords well with the recently proposed polynuclear colonial settlement strategy and further undermines the traditional model, which assumes that the indigenous people and the colonists would have followed radically different settlement patterns (villages versus evenly distributed single farms). Our analyses moreover show that the dispersed-versus-nucleated settlement dichotomy may be too limited and that other settlement rationales may be identified in the existing datasets. In the case of the Ager Venusinus, for instance, site density patterns correspond reasonably well to Von Thünen's density model of decreasing site concentration in progressive concentric bands around the urban market.

To sum up, the unilateral hinterland-city relationship projected by both the conventional colonial scenario (city provides political, administrative and defensive services to colonial farmers) and Von Thünen (farmers supply the city with their products) may not be the only way the countryside interacted. A complex network of powerful villages may indeed have had an important role in early colonial societal organization, and Roman rural settlement and economic strategies in colonial contexts may have been more diverse than previously assumed (see discussion in Stek in press). The spatial-statistical analyses we have performed have provided an effective and methodologically sound way to test different settlement scenarios. At the same time, these analyses have enabled us to advance new, more flexible conceptual models for understanding colonial settlement strategies, which now may be tested further in the field and laboratory.

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