Italy's Hidden Hillforts: A Large-Scale Lidar-Based Mapping of Samnium

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ABSTRACT

This article presents the first results of the Ancient Hillforts Survey, a large-scale lidar-based analysis and ground-truthing aimed at creating a representative and comparative dataset of hillforts in Italy unbiased by site location or vegetational canopy. An analysis of 15,300 km^2 spanning Campania, Lazio, Abruzzo, Molise, and Apulia detected 305 new suspected hillforts. The area was visually interpreted using image blends of lidar visualizations (VAT method) based on in-house-generated digital terrain models. Interobserver and intraobserver interpretational biases were tested and CORINE Land Cover data used to evaluate the representativeness of the legacy data compared with the new dataset and to estimate the number of sites for no-data areas. The results from the Daunian mountains (Apulia) are presented to demonstrate the effectiveness of this approach in advancing knowledge of historically under-surveyed areas and in addressing long-term debates. Here, the data showed a novel hillfort system interpretable as Samnite, dating between the 6th and 3rd century B.C.

Introduction

It has long been clear archaeologically that the Samnites' territory was distinctive compared to the neighboring societies of 1st millennium B.C. Italy (Stek 2009, 37–39; Scopacasa 2015, 159–160). It was full of hillforts, sanctuaries, and dispersed farms and small agglomerates but with few, if any, apparent cities of the type central to modern narratives of Iron Age Italian state formation, such as the Latin and Etruscan centers (Riva 2009; Fulminante 2013). Hillfort sites have long been considered key to understanding the structure of the Samnite landscape between the 6th and 3rd century B.C. (Oakley 1995). This has been complicated, however, by the fact that current research has not yet identified a representative distribution of hillforts within Samnium.

The identification and study of Italian hillforts, both pre-Roman and medieval, are especially complex due to their location in remote highland areas, which today are often covered by dense vegetation (Masini et al. 2018). Furthermore, despite their remote location, hillfort sites are poorly preserved. This is because these areas of the landscape were used intensively well into the 20th century A.D. before being abandoned and reforested. Archaeologists have often neglected these mountainous and forested regions because they were considered to be peripheral environments and because of limitations in executing systematic surveys in these challenging environments (Barker 1995). Previous studies based on traditional methods of archaeological survey and aerial remote sensing focused on plains and other easily reachable areas lacking vegetational canopy (Conta Haller 1978; Barker 1995; Quilici and Quilici Gigli 2004a, 2004b, 2006, 2010, 2012, 2014, 2016, 2017; La Rocca and Rescigno 2010; Quilici 2011; Quilici Gigli 2012; Renda 2020). Areas more likely to contain hillforts, like steep slopes and peaks covered by dense vegetation, were thus neglected.

Only a few projects ventured into Samnium's challenging mountain and forested regions using systematic survey methods (Cazzella et al. 2018; Stek 2018) or conducted intensive research on sites (Faustoferri and Lloyd 1998; Caiazza and Pagano 2012; De Benedittis 2017). The only available catalog of Samnite hillforts was created from fragmentary archival data and sporadic investigations instead of from systematic endeavors (Oakley 1995). Similarly, no comprehensive data are available for medieval hillforts.

As existing data on hillforts are fragmentary and largely biased by the approaches adopted in past research, they are not representative of the true past or surviving distribution of this site type across Samnium. Consequently, current research does not allow for robust analyses of the settlement patterns of pre-Roman (typically, Samnite) hillforts, or even of later medieval hillforts occupying similar areas.

The use of techniques such as Light Detection and Ranging (lidar) analysis that allow for the systematic and cost-effective investigation of areas under canopy are exceptionally important to address biases in archaeological research. Recent studies have shown their effectiveness in tracing a multitude of past landscapes even in densely vegetated areas (Chase et al. 2011; Evans et al. 2013; Scott 2015) and for detecting site types similar to Italian hillforts (Stott, Kristiansen, and Sindbæk 2019; Menéndez Blanco et al. 2020; Parcero-Oubiña 2021). Lidar data can also be applied to archaeological research on Mediterranean landscapes currently covered by dense vegetation. The goals of this study were to develop an optimal approach for using lidar to analyze mountainous and forested regions of south-central Italy and to generate a representative dataset of hillfort sites. A series of control measures were implemented to test biases in image interpretation. CORINE Land Cover data were used to evaluate the results and estimate the number of

hillforts located in areas with no lidar coverage. While ground-truthing of newly detected potential hillforts is still in progress, the results of the complete analysis of the Daunian mountains are presented as a case study to discuss the impact of a systematic lidar-based approach in addressing historical and methodological biases traditionally present in archaeological research.

Data and Methods

Research area

The boundaries of Samnium have been hypothesized by scholars based on a combination of archaeological evidence for Samnite occupation and data from literary sources, but no specific limits are certain (see Salmon 1967, 25, pl. 1 and Tagliamonte 2017, 425, fig. 2 for two versions). The research area for this study was selected based on the most generous of these reconstructions. The research area covers 23,156 km^2 across a large transect of south-central Italy extending from the Tyrrhenian to the Adriatic Sea. Elevation in this area varies from 0–2792 masl, with the lowest elevations in the Campanian and Apulian plains (the latter of which is known as the Tavoliere delle Puglie) and the highest in the central and southern peaks of the Apennines. The vegetation varies from broad-leaved deciduous plants in the mountains to evergreen and deciduous species, shrublands, and Mediterranean maquis toward the plains. Therefore, the research area presents a variable landscape encompassing mountainous, flat, and coastal regions (Figure 1A).

Lidar data acquisition

Airborne lidar data were analyzed across 15,296 km^2 of the research area. The study used publicly accessible data acquired by the Italian Ministry of the Environment (Ministero dell'ambiente e della tutela del territorio e del mare—MATTM) during the first phase of the Extraordinary Plan of Remote Sensing (Piano Straordinario di Telerilevamento Ambientale) between 2008 and 2013 (Costabile, Cocco, and Petriglia 2013; García Sánchez 2018). This plan aimed to produce remote sensing data suitable for monitoring areas with high hydro-geological risk. Due to this scope, the data collected does not cover the entire Italian territory and instead focuses only on main riverbeds, the coastal regions, and a selection of critical areas. Though the data coverage is continuously integrated with new acquisitions commissioned by other government agencies, it does not yet cover the entire Italian territory or the entirety of this study's research area. This study analyzed all the data available to date, covering 66% of the entire research area (15,296 km^2 analyzed out of the 23,156 km^2 of the research area) (Figure 1B).

Data were collected using Optech ALTM Gemini, ALTM 3100EA, and Pegasus; these sensors can operate on the Near Infrared (1064 nm) spectrum between 33 and 400 kHz, depending on the altitude. Between two and four returns were recorded per pulse with an elevation accuracy of ± 15 cm and a planimetric accuracy of ± 30 cm. Due to the commissioners' heterogeneous nature, no further metadata on the data acquisition process parameters is available.

The MATTM provides data as a raw point cloud in XYZ format and as 1 m GSP Digital Surface Model (DSM) first pulse, DSM last pulse, filtered Digital Terrain Model (DTM), and intensity raster (García Sánchez 2018). The primary means of accessing the processed datasets is through a Web Map Service available from the Geoportale Nazionale. Recent research in Samnium has used the lidar-based DTMs provided by the MATTM without applying visualization techniques (Sardella and Fasolo 2018; Renda 2020). It should be emphasized that there are significant drawbacks in using off-the-shelf lidar DTMs for archaeological purposes. Two main issues emerged during the preliminary phase of this project. First, filling and smoothing techniques were heavily used in creating the DTM, likely to overcome issues related to topography and penetration of wooded canopy. Consequently, archaeological features were also removed, particularly in wooded areas. Second, the DTM exhibits distortions which are easily visible with the naked eye in the majority of the research area, likely the result of errors between reprojections of the data during the creation of different submodels. These distortions caused issues in applying visualization techniques and made interpretation challenging and biased. As such, the DTM provided by the MATTM was deemed unsuitable for archaeological prospection, and the raw point cloud data was instead processed in-house.

Lidar data processing

The low quality of the lidar data available makes the average returns per m^2 below 1 in a wooded landscape, providing few reliable data at a resolution useful for archaeological prospection in dense undergrowth. Two standardized filtering processes implemented in the software suite LasTools (http://rapidlasso.com/lastools/) were used to overcome this problem: a primary filtering process was used for interpreting the entire area and a complimentary process was used for wooded regions and other critical areas. The primary filtering process adopted a conservative approach to preserve the richness of the archaeological record. However, a disadvantage is that it also preserved some returns, usually undergrowth, mis-filtered as ground instead of vegetation. The complementary filtering process used a more aggressive approach to model a bare-earth landform surface devoid of noise. This approach aggressively filtered out all types of vegetation. As such, the fewer remaining returns were more likely to model real ground features but did not preserve small anthropogenic features. By comparing the results of the complementary filtering process with the derivates of the primary filtering process and by using a data gap mask, it was possible to analyze the degree to which the perceived noise area in the primary DTM model still provided data about the real surface or whether it should be discarded as the result of artifacts derived from insufficient data. It is important to note that, although the nominal resolution of the lidar data was 1 m, the analysis showed that around 20% of the final DTM surface was interpolated from no real ground values but instead from neighboring returns. The lack of returns is more evident in areas under the canopy.

Visual interpretation took place on two image blends of multiple visualization techniques, one for each set of outputs of the two filtering processes. A modified version of the Visualization for Archaeological Topography (VAT) method (Kokalj and Somrak 2019) was adopted and implemented
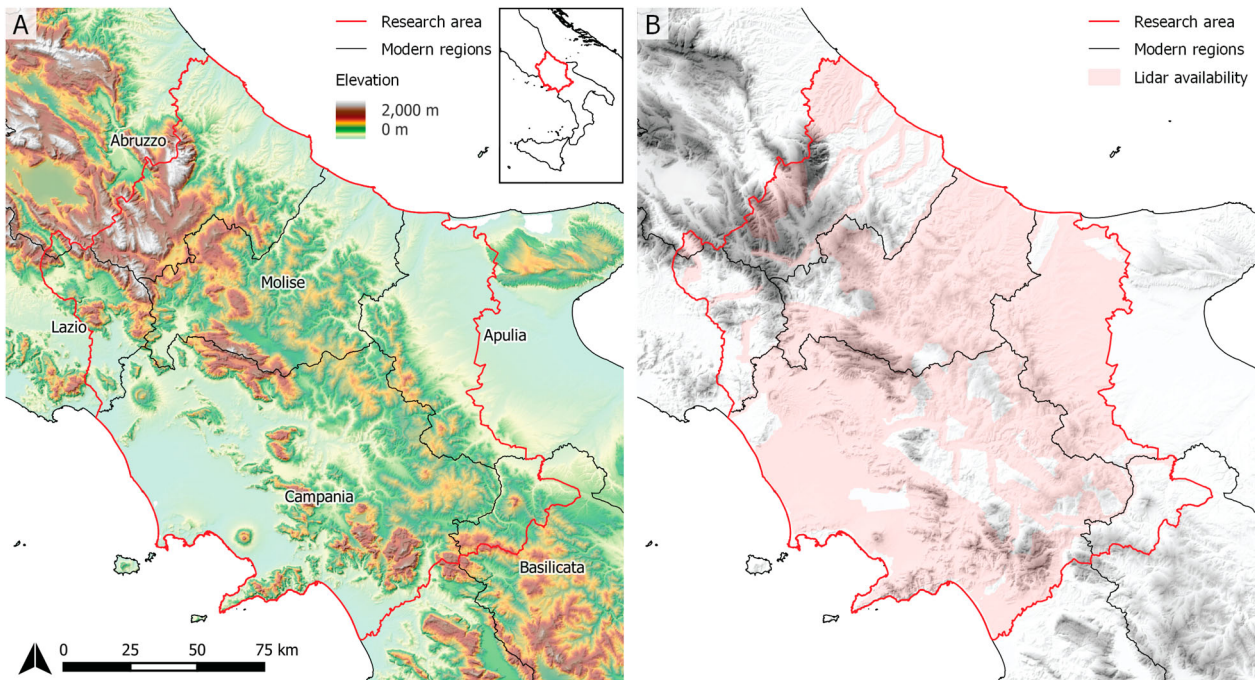
Figure 1. A) Research area and B) lidar availability.

in the software suite Relief Visualization Toolbox (RVT) (Zakšek, Oštir, and Kokalj 2011; Kokalj and Somrak 2019) (Figure 2). The VAT method is increasingly used in archaeological research, and it has been shown to be very effective (Bonhage et al. 2021; Kwoka et al. 2021; Šprajc et al. 2021; Thuestad et al. 2021). Its reliability and the possibility of comparing the results with different studies were the primary motivation for adopting this method in the current research. A detailed description of the issues encountered in processing the lidar available, the decisions made to overcome them, and the modified VAT used are reported in Supplementary Material 1.

Lidar data interpretation

Recently, artificial intelligence (AI) applications for analyzing lidar data have been under development (see Lambers et al. 2019, fig. 1 for an overview). These techniques are increasingly influential, as they promise fast and interregional analyses on a scale that would be impossible with visual interpretation (Bennett, Cowley, and De Laet 2014). Despite their great potential, these techniques have not been implemented in this study because of 1) the extremely heterogeneous appearance of the target feature (hillforts), 2) the small usable training dataset, 3) the variable topography,
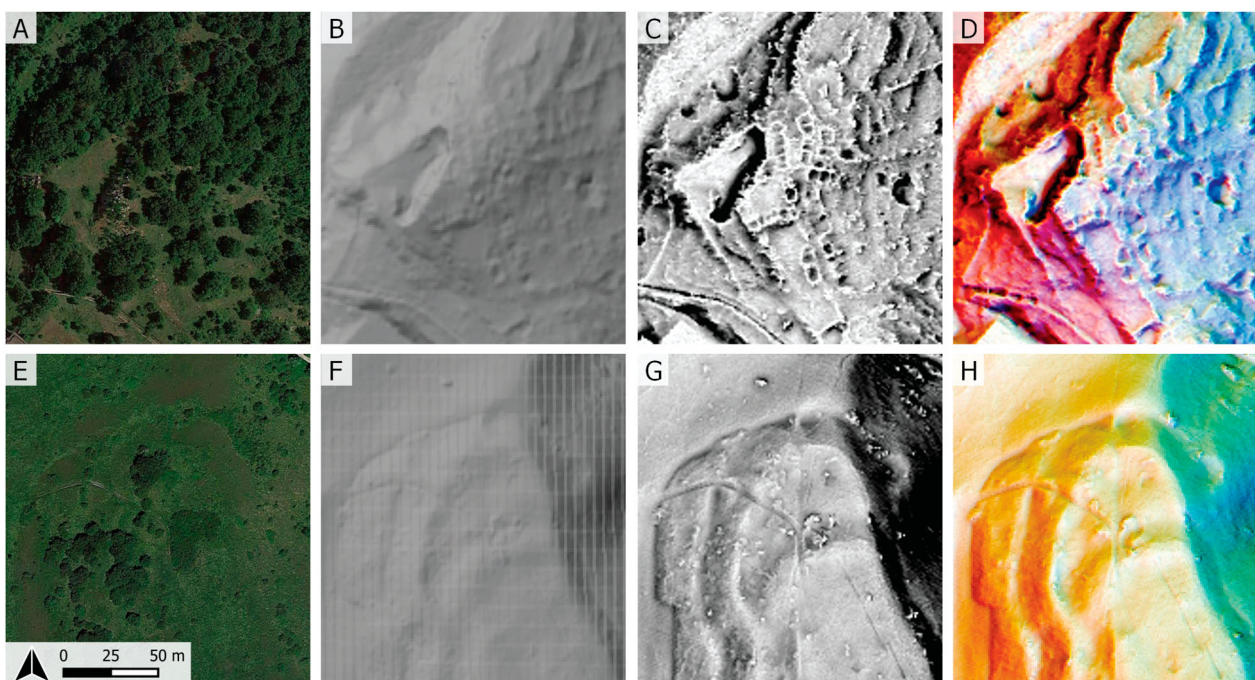
Figure 2. From left to right: A, E) satellite image; B, F) off-the-shelf MATTM lidar-DTM; and, C, G) primary and D, H) complementary image blends of lidar visualizations developed in this study. The filling and smoothing techniques (B) and the regular distortion (F) present in the off-the-shelf MATTM lidar-DTM drastically hinder its use for archaeological purposes. The primary and complementary image blends instead provide a remarkably better representation of the remains.

geomorphology, and land use of the research area, and 4) the significantly low quality of the lidar data available.

The large majority of AI applications have targeted a narrow range of archaeological objects characterized by regular and homogenous shapes. Circular elements such as barrows, charcoal kilns, mounds, and pits are the most studied (Trier, Zortea, and Tonning 2015; Trier, Salberg, and Pilø 2016; Trier, Cowley, and Waldeland 2019; Verschoof-Van Der Vaart et al. 2020; Bonhage et al. 2021), along with other features such as Celtic fields, hollow roads, and ring fortresses (Stott, Kristiansen, and Sindbæk 2019; Verschoof-Van Der Vaart et al. 2020; Verschoof-van der Vaart and Landauer 2021). Unlike these site types, Italian hillforts do not exhibit regular and repetitive shapes, sizes, and typologies of features and therefore differ greatly from the traditional targets of automated approaches. In particular, fortifications range from negative features such as trenches to positive ones such as earthworks and stone walls (see Oakley 1995). Importantly, these features do not always occur together. In some sites, fortifications survive today as shallow earthworks and others as massive polygonal walls up to 10 m tall, as in the hillfort of Treglia (Caiazza and Pagano 2012). AI approaches can only detect objects similar to known objects of which sufficient examples are available. The known hillforts in the research area did not provide a suitable training dataset, due to their variable appearance. Furthermore, the variability of the research area would likely cause issues of interoperability with the use of AI methods. Recent studies have shown that AI methods are limited when the topography, geomorphology, and land use of the research area differ from the area on which they have been trained (Trier, Cowley, and Waldeland 2019; Verschoof-van der Vaart and Lambers 2021). Finally, all the AI studies cited above have used high-quality lidar data largely devoid of noise and with resolutions up to 25 cm. The quality of the lidar available for the Italian territory is considerably lower, particularly under canopy, and therefore results are more difficult to read. The development of increasingly sophisticated AI methods and availability of new, higher-resolution lidar coverage of Samnium would make future experimentation with automation much more appealing.

Considering the significant obstacles to applying currently available AI methods within this study's research area, visual interpretation was applied instead. Currently, visual interpretation presents the most reliable and time-efficient method for detecting hillforts in Italy. Precision of detection and ease of use were deemed essential for creating a reliable dataset for the spatial analysis planned for the next phase of this research. Additionally, the significant degree of interpretative flexibility offered through visual inspection was fundamental for detecting a wide range of hillfort typologies.

Due to the variability present in known hillfort sites, the following criteria were used to identify potential hillforts in the visual interpretation. Sites were considered if they 1) consisted of one or a few parallel linear features, positive or negative, that enclose, even partially, a specific area and 2) were located on hilltops or other similarly elevated areas which 3) must stand out from the context (to differentiate terraced hills from possible hillforts) and 4) cannot be attributable to modern structures or be closely associated with them in satellite and aerial images.

Visual interpretation took place on groups of four square tiles of 250 m per side, simultaneously visualized on display at a fixed scale of 1:2500. Real-time adjustment of the data displayed on-screen according to standard-deviation histogram stretch was used to guarantee contrast at the topography change. Although not useful for feature comparison because it distorts pixel values, this approach is very effective for feature detection because it enhances the detectability of new features. A fixed linear histogram stretch was used instead to compare different features.

The detection process took place on the visualization image blend derived from the primary filtering process and, in the case of dense vegetation, additionally on the image blend derived from the complementary filtering process. Once a possible site was detected, it was further investigated using historical images available in Google Earth and the set of non-combined lidar visualizations. A class for the certainty of detection was then given to the sites ranging from certain to likely and uncertain.

Control measures for interpretational biases and estimation of missing sites

A series of control measures was implemented in the interpretation process to overcome possible biases in image interpretation and thus reduce intercomparability issues. A single interpreter (the author) carried out the analysis. As such, biases in interpreting specific types of features can substantially affect this study's reliability. To counter this, repeated mapping of sample areas and paired mapping was implemented during a drone/UAV archaeology course organized by Tesse Stek for the Royal Netherlands Institute in Rome between May and June 2019. This allowed for testing of interobserver interpretational biases for specific types of features. Similarly, the same analyst can interpret the same area differently at different stages of their work as their experience grows, creating the possibility for intraobserver bias. Following analysis of the entire research area, the author re-interpreted a sample of initially interpreted areas to identify possible intraobserver issues. No substantial biases were highlighted during the implementation of either of these control measures. This suggests the present study provides data on the presence/absence of hillforts without significant intercomparability issues.

As lidar data is not available for all of Samnium, CORINE Land Cover (CLC) data (2018 edition) were used to investigate the distribution of suspected hillforts in different land cover classes and to predict the likely number of unknown sites in the areas for which lidar is unavailable. This was done by scaling the distribution of suspected hillforts across different CLC classes and their extensions to the extensions of these CLC classes in the areas not analyzed in the current study. An estimate of the number of known hillforts in the area was subtracted from the total number of estimated hillforts. This was calculated using the percentage of known sites relative to the total number of hillforts detected during remote sensing for the area where lidar is available. The analysis used land cover as a proxy for ground visibility and obstruction to simulate the limitations of previous archaeological surveys. Despite only providing approximate results, this analysis was useful for evaluating the study's contribution of a representative dataset and for estimating the total number of hillforts in Samnium.

Ground-truthing techniques

Following the lidar-based analysis, a selection of suspected hillforts was ground-truthed in the field by the author making physical visits to the sites. At the time of writing, visits have been conducted on 109 suspected hillforts. Using GPS tracking to trace the areas effectively surveyed, searches for structures and materials were undertaken both in enclosed areas and along the outer perimeters of potential sites. Georeferenced photographs were taken of all archaeological remains and, in the case of standing walls, photo series were taken to produce three-dimensional models. Artifacts were not collected in the field. Instead, all sherds were described, geolocated, and photographed in situ. For diagnostic pieces, a spongy phenolic foam (a type used for flower arranging) was used to record imprints of their profiles. These were then scanned at high resolution and digitized to produce standard pottery drawings after returning from the field.

This non-invasive technique for recording materials was developed for two reasons. First, hillfort sites do not generally produce large pottery assemblages, and thus it is important to preserve the archaeological record in as intact a state as possible. Casual collection and/or incomplete publication and museum storage of sherds from ground-truthing could deplete a site's potential for future systematic intrasite work. Second, Italian legislation does not yet effectively regulate large-scale but punctuated surveys typical of ground-truthing for remote sensing. As such, the collection of materials would fall under other types of permits, which are demanding from an administrative perspective. Non-invasive techniques drastically reduce the administrative demand, and for this reason, they were the only feasible approach at this stage of the study.

Results of the Lidar Analysis: Contributions and Limitations

The initial lidar interpretation resulted in 514 detections, which comprised both known and unknown sites dated to different periods. Existing archaeological catalogs (Conta Haller 1978; Oakley 1995; Quilici and Quilici Gigli 2004a, 2004b, 2006, 2010, 2012, 2014, 2016, 2017; Caiazza 2007; Quilici 2011; Quilici Gigli 2012; Sardella and Fasolo 2018; Renda 2020) were used to identify previously known hillforts that were simply re-identified in the current lidar analysis. After this, a total of 305 sites remained in the dataset as suspected hillforts. Some of these (n = 299) were potential hillforts for which no information was found in published materials, while others (n = 6) consisted of known archaeological sites that had not previously been interpreted as hillforts but which the lidar data suggested could be. Of the 305 suspected hillforts, 111 were classified as certain, 73 as likely, and 121 as uncertain (Table 1, Figure 3).

Interpretation of the images was undertaken without prior awareness of which sites were previously known. As such, an initial validation of the process involved verifying the number of known Samnite hillforts independently detected during the current study. Of the 115 known Samnite hillforts for which lidar data are available, 109 (95%) were detected in this study. In fact, for two of the six known sites not detected, it has been debated whether these should be interpreted as hillforts. This study therefore adds weight

**Table 1.** Total detections divided by type.

Total detections: 514
a. Known hillforts: 209 (41%)
b. Suspected hillforts: 305 (59%)
b.1 Unknown sites: 299 (58%)
b.2 Known sites which are potentially interpretable as hillforts based on the lidar analysis: 6 (1%)

to an argument for rejecting this interpretation. The results indicate that the analysis was extremely effective in detecting hillfort sites across the region.

The distribution of the suspected hillforts across different land cover classes (Table 2) demonstrates the effectiveness of this study's approach for investigating forested regions, in particular. A comparison of the distribution of known and suspected hillforts showed that sites under forest are significantly underrepresented in the existing dataset, while the number of sites in other CLC classes are similar in both the existing and newly generated dataset (Figure 4). This confirms that representativeness is an issue within the legacy dataset of Italian hillforts. Similarly, comparison of the spatial distribution of known and suspected hillforts shows that known sites are concentrated in the western part of Samnium, in the proximity of the last Apennine ridges overlooking the Campanian plateau (Figure 5). It is not surprising to see larger clusters of known sites here, because this is the area of Samnium that has been most extensively studied (Conta Haller 1978; Quilici and Quilici Gigli 2004a, 2004b, 2006, 2010, 2012, 2014, 2016, 2017; Caiazza 2007; Quilici 2011; Quilici Gigli 2012; Renda 2020). The new data shows that substantial clusters of suspected hillforts are also present in the eastern mountain ridges of Samnium in areas overlooking the Adriatic coast that have been traditionally under-surveyed. One of these areas, the Daunian mountains, is discussed later in this article.

The use of CLC also allowed for an estimation of the number of unknown hillforts that may be present in the area for which lidar data are not available. The analysis estimated a total of 221 hillforts in the no-data area. After subtracting the percentage of known sites identified during remote sensing for the area with lidar coverage (41%), the final estimate was 131 unknown hillforts in the no-data area. This would bring the total population of suspected hillforts in the research area to 436. If land cover was not considered, an estimated 157 unknown sites would be expected based on a simple proportion between areas with and without lidar data. Consideration of land cover produces a lower estimated number of potential hillforts due to the high presence of CLC classes unlikely to host hillfort sites in the no-data area. Although these numbers are approximations, this type of analysis is helpful for evaluating the representativeness of the area analyzed in this study compared to the entire research area. The results suggest the area analyzed is representative of the broader research area.

The study also allowed for the detection of a wide range of other possible sites not interpretable as hillforts, such as farms or field systems. However, it is essential to note that the variable quality of the lidar data across the study region effectively hinders the identification of subtle features across heterogeneous landscapes. For this reason, and because this study protocol was not designed to locate non-hillfort sites, the other identified finds are not necessarily representative of the
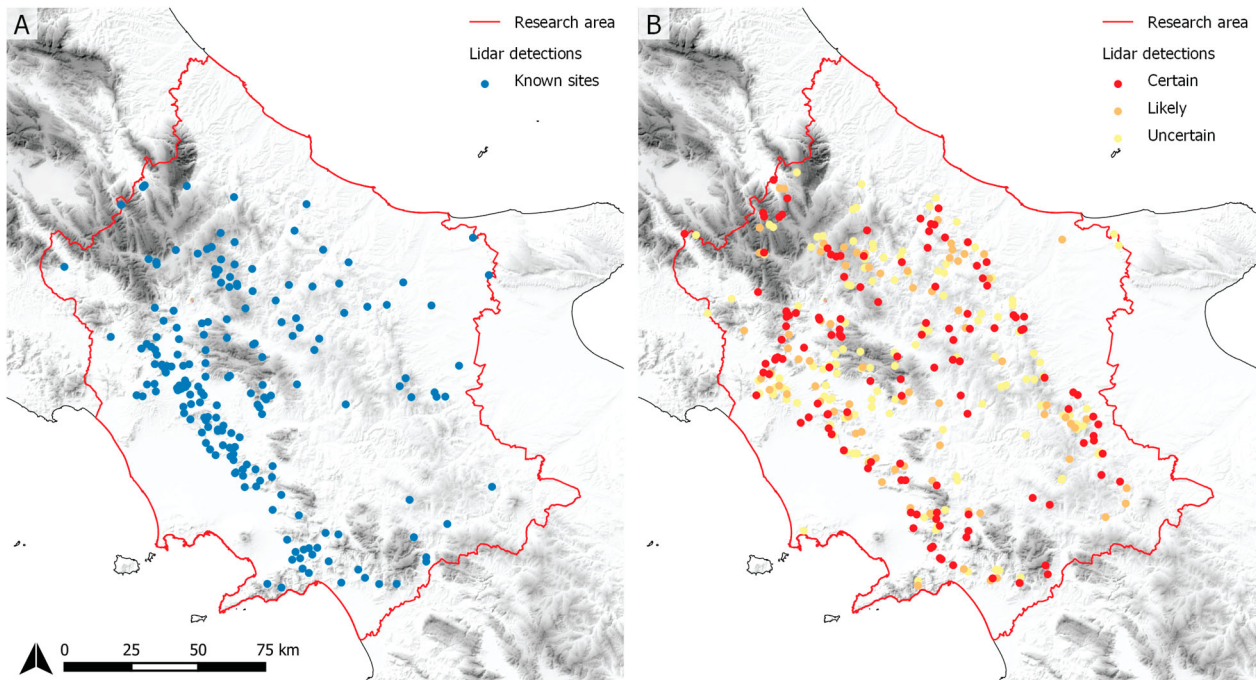
Figure 3. Distribution of A) known and B) suspected hillforts detected from lidar data.

distribution of these site types across the entire analyzed area and are therefore of limited use in large-scale studies. Despite these limitations, these new data help enrich the existing knowledge of local regions as shown, for example, by the identification of new traces of Roman centuriation on the area of mount Tifata, in Campania (Fontana in press).

Table 2. Distribution of detections by CORINE Land Cover (CLC) classes and estimation of hillforts present in the areas where lidar data are missing, calculated proportionally to the number of suspected hillforts by the area of each class.

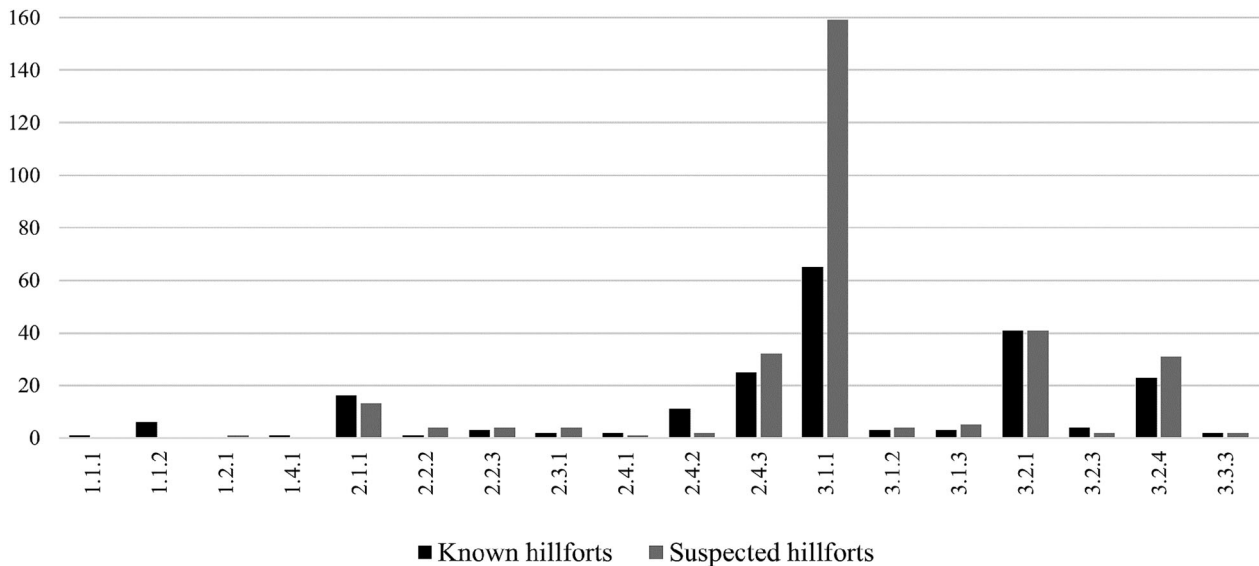| CLC Codes	CLC Code Description	Lidar Available (km²)	Lidar Missing (km²)	Known Hillforts	Suspected Hillforts	Estimated Hillforts
1.1.1	Continuous urban fabric	233	82	1	0	0.0
1.1.2	Discontinuous urban fabric	419	201	6	0	0.0
1.2.1	Industrial or commercial units	106	59	0	1	0.6
1.2.2	Road and rail networks and associated land	4	4	0	0	0.0
1.2.3	Port areas	0	6	0	0	0.0
1.2.4	Airports	6	0	0	0	0.0
1.3.1	Mineral extraction sites	20	15	0	0	0.0
1.3.2	Dump sites	2	0	0	0	0.0
1.3.3	Construction sites	3	0	0	0	0.0
1.4.1	Green urban areas	4	4	1	0	0.0
1.4.2	Sport and leisure facilities	4	5	0	0	0.0
2.1.1	Non-irrigated arable land	5473	1964	16	13	4.7
2.1.2	Permanently irrigated land	242	6	0	0	0.0
2.2.1	Vineyards	257	111	0	0	0.0
2.2.2	Fruit trees and berry plantations	511	123	1	4	1.0
2.2.3	Olive groves	494	389	3	4	3.2
2.3.1	Pastures	119	125	2	4	4.2
2.4.1	Annual crops associated with permanent crops	222	48	2	1	0.2
2.4.2	Complex cultivation patterns	1688	811	11	2	1.0
2.4.3	Land principally occupied by agriculture, with significant areas of natural vegetation	1096	710	25	32	20.7
2.4.4	Agro-forestry areas	1	0	0	0	0.0
3.1.1	Broad-leaved forest	3073	1952	65	159	101.0
3.1.2	Coniferous forest	86	53	3	4	2.5
3.1.3	Mixed forest	97	86	3	5	4.4
3.2.1	Natural grasslands	429	523	41	41	50.0
3.2.2	Moors and heathland	3	12	0	0	0.0
3.2.3	Sclerophyllous vegetation	46	38	4	2	1.6
3.2.4	Transitional woodland-shrub	550	405	23	31	22.8
3.3.1	Beaches, dunes, sands	6	10	0	0	0.0
3.3.2	Bare rocks	11	27	0	0	0.0
3.3.3	Sparsely vegetated areas	42	76	2	2	3.7
3.3.4	Burnt areas	1	4	0	0	0.0
4.1.1	Inland marshes	4	1	0	0	0.0
4.2.1	Salt marshes	0	1	0	0	n/a
5.1.1	Water courses	4	0	0	0	0.0
5.1.2	Water bodies	38	6	0	0	0.0
5.2.1	Coastal lagoons	0	0	0	0	0.0
5.2.3	Sea and ocean	0	3	0	0	n/a

Figure 4. Bar graph of the distribution of known and suspected hillforts by CLC classes. Table 2 reports the CLC code descriptions.

The Samnite Presence in the Daunian Mountains: A Case Study

A current area of interest within the archaeology of northern Apulia involves the Samnite presence in this region and how the Samnites and their settlements related to the Daunian people. Salmon (1967, 67) and La Regina (1989, 17–25) identify contrasting ways of inhabiting mountainous and flat areas as a key theme for understanding the relationship between these two groups. Despite this, research in this area has focused almost exclusively on the flat Tavoliere delle Puglie due to the favorable conditions the plains present for developing regional studies through aerial and satellite remote sensing and pedestrian surveys (Marchi et al. 2015, 2019). The Daunian mountains have instead seen far fewer research activities, often limited to data from rescue archaeology. This is particularly true for the pre-Roman period; despite the known presence of hillforts, interpretations of these sites have rarely been integrated within broader discussions about settlement strategies within this territory (Gravina 2007; Marchi 2016).

The lidar analysis developed in northern Apulia lays the foundation for a much more complete understanding of the function and role of this mountainous region during the pre-Roman period. The lidar analysis allowed 1) the discovery of new sites, 2) the re-interpretation of known sites, 3) the contextualization of material finds in areas where fortifications are almost invisible today, 4) the collection of comparative data on size, typology, systems of fortification, and internal organization of hillforts, and 5) the production of the first representative and comparative dataset on the presence of pre-Roman hillforts in the Daunian mountains.
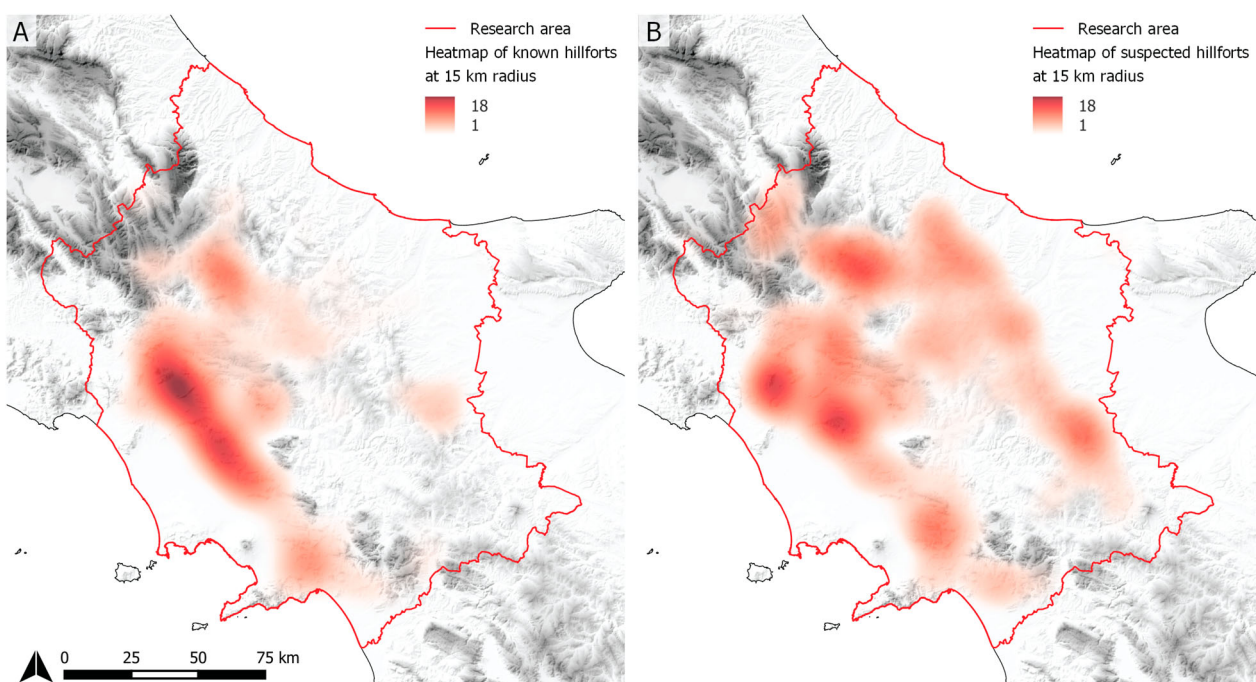

Figure 5. Heatmap of A) known and B) suspected hillforts at a 15 km radius.

Table 3. Pre-Roman hillforts in the Daunian mountains (est: estimated, min: minimum, int: internal, ext: external, and ram: rampart).

| Ref.	Name	Elevation (masl)	Total Size (ha)	Circuits Size (ha)	Length of Fortifications (m)	Length by Type (m)	Coordinates (WGS84)
A	Monte Sambuco-Orlando	985	13.2	9.5 int 3.7 ext	4447	4447 ram	41°.52747 15°.07909
B	Valva	380	13.4	0.7 int 12.7 ext	1743	1270 wall 473 ram	41°.53142 14°.94883
C	Monte San Giovanni	640	4.7	0.9 int 3.8 ext	1287	1287 wall	41°.60091 14°.97588
D	Monte Rotaro	540	1.8	n/a	703	545 wall 158 ram	41°.60884 15°.06230
E	Monte Saraceno	1145	4.7	n/a	1748	856 wall 892 ram	41°.36185 15°.14631
F	Monte Cimato	505	10.9	1.1 int 10.9 ext	2253	860 wall 1393 ram	41°.30483 15°.32094
G	Monte Cerchio di Magliano	570	39.3 (est)	3.3 int 36.1 ext	1739	1739 ram	41°.31448 15°.30069
H	Monte Ultrino	586	6.3 (est)	0.1 int 6.2 ext	984	984 ram	41°.16695 15°.39071
I	Monte Serbaroli	811	0.1	n/a	137	137 ram	41°.14309 15°.34667
J	Monte Alvaro	588	0.3 (min)	n/a	260	260 wall	41°.10719 15°.43092

Eleven pre-Roman hillforts were identified (two forming a single complex), of which at least seven are likely to be Samnite sites (Table 3; Figure 6). All these sites were ground-truthed in the field. These attest a previously unknown system of fortifications and suggest the Daunian mountains were an integral part of Samnite territory that was settled in the same ways known in other parts of Samnium (Oakley 1995, 143–147).

Starting in the north, a system of five sites controlled the middle valley of the Fortore river where it curves from the inner Apennines toward the Adriatic Sea. Of these, the newly identified complex spanning Monte Sambuco and Monte Orlando (Figures 7A, 8A) occupies the most dominant position on one of the highest peaks of the Daunian mountains overlooking both the Tavoliere to the east and the mountainous hinterland to the west. On Monte Sambuco, lidar data allowed for the identification of a main body and two annexes of fortifications that form an articulated system extending toward a third annex on the nearby Monte Orlando, where fragments of impasto and black gloss pottery compatible with the finds reported from Monte Sambuco were identified during ground-truthing. Survey materials and burials date occupation on Monte Sambuco to as early as the 6th and 5th century B.C., with more consistent data from rescue excavation available for the period between the 4th and the 1st century B.C., including black gloss and Heracle figurines (Volpe 1990, 134; Gravina 2007). The dense vegetation and poor preservation of the structures make identifying fortifications challenging on the ground, and only later was it proposed the site could be a hillfort (Gravina 2007). The new data support the presence of a hillfort complex and provide the first mapping of the site.

The Monte Sambuco-Orlando complex is centrally located in relation to three other hillforts in the area. These are located on the lower ridges that, from the peaks of Monte Sambuco-Orlando, extend west and north toward the Fortore valley floor. The largest of these is Valva (Figures 7B, 8B). This site is located on a prominent spur at the intersection of the Fortore and Tappino valleys in a commanding position over the *tratturo* (transhumance route) Lucera-Castel di Sangro. The site has two distinct systems of fortifications that can be dated to different periods. The lower

fortifications enclose the northern, more easily accessed part of the spur. They are composed of polygonal masonry (Figure 9A) with large blocks of stone up to 1.6 m long, preceded at around 20 m by a rampart that creates a pathway leading to a possible entrance. The other fortification system encloses the summit, but the wall is instead composed of small blocks of stones consolidated with mortar, with masonry types indicative of the Medieval period (Figure 9B). The materials identified during ground-truthing support these interpretations. The presence of possible structures on the hill of Valva was previously reported by Cerulli (1964), along with the presence of burials dating to the 6th–5th century B.C. and survey materials ranging from the Hellenistic period to the 16th century A.D., when the site was destroyed (Cerulli 1964; De Benedittis 2006, 17; Gravina 2007). Information was, however, fragmentary, and no clear interpretation of the site had been proposed. The newly identified polygonal masonry allows for an interpretation of the lower fortification system as Samnite. The site is now under investigation by the Ager Lucerinus Project (Marchi et al. 2020).

While the hillforts of Monte Sambuco/Orlando and Valva occupy similar extensions of around 13 ha, the other two sites in the area are much smaller. Although these sites were known and have been studied (D'Alena 2006; De Benedittis 2006, 2012; Gravina 2006, 2007), lidar data allowed for the identification and mapping of numerous previously unknown structures. The first, Monte San Giovanni (Figures 7C, 8C), occupies 4.7 ha on a dominant position overlooking where the Fortore river curves east. Traces of human occupation range from the Neolithic to the Medieval period until the destruction of the site in the first half of the 15th century A.D. (De Benedittis 2006). The wall circuits visible in the lidar data are related to the later phase of occupation, and it can only be assumed that the site had similar dimensions during the Samnite period. Samnite occupation of this site is, however, well attested by the nearby necropolis of Santo Venditti dated from the 6th–4th century B.C. (De Benedittis 2006; Gravina 2006), by burials from the modern center of Carlantino dated to the 4th and 3rd century B.C. (Gravina 2007), and from the recovery of materials dated to the 4th and 3rd century B.C. during the survey and excavation of the site (De Benedittis 2012, 44–46).
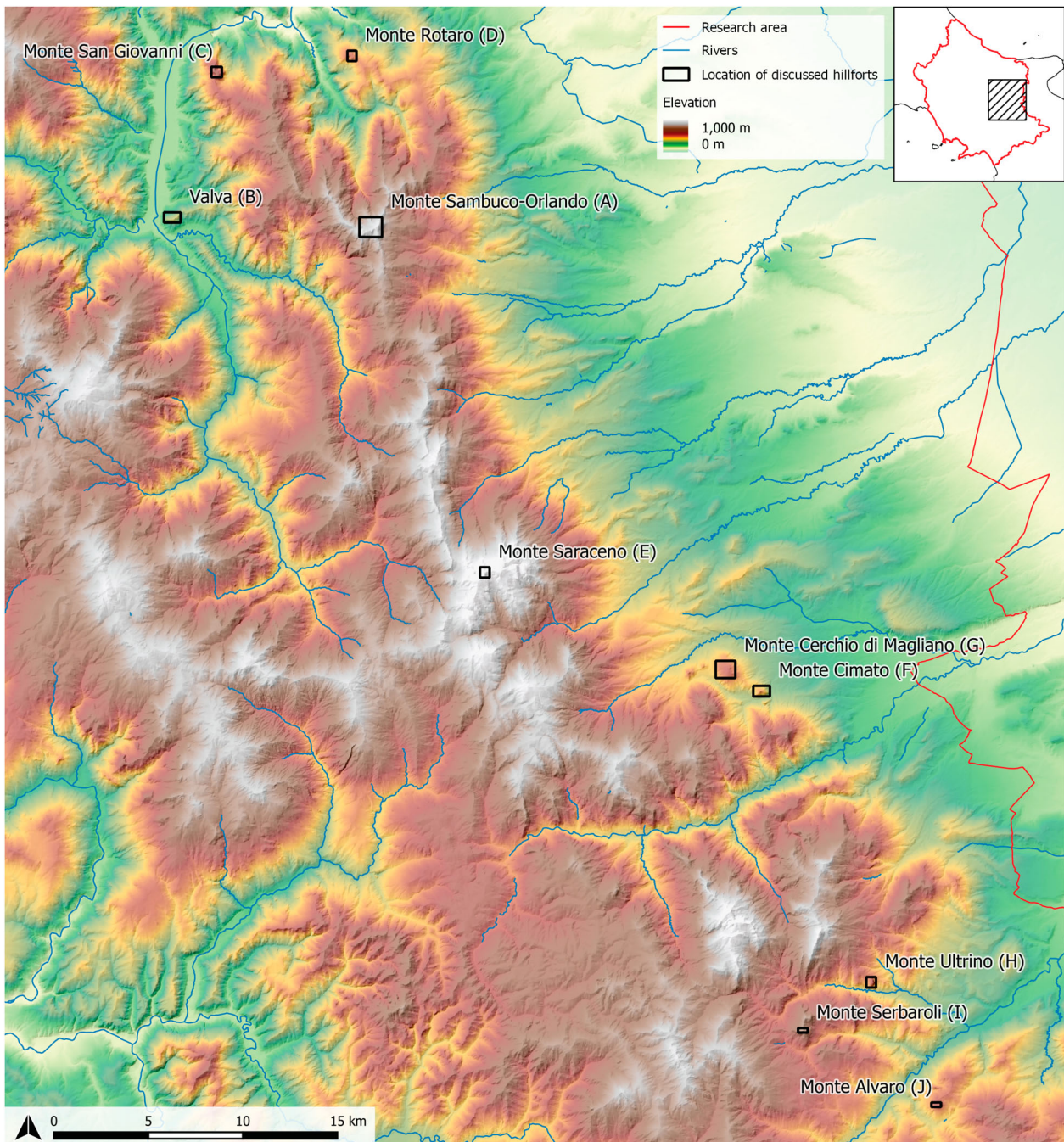
Figure 6. Distribution of the hillforts in the Daunian mountain range discussed in the text. The letters following the site names correspond to the letters in Figures 7 and 8.

The second site is Monte Rotaro (Figures 7D, 8D), which lies on a small hilltop on the last mountainous offshoots overlooking the Tavoliere. Here, a circuit encloses 1.8 ha, where numerous structures are located around a medieval tower on the northern part of the site. The recovery of materials indicates pre-Roman occupation from the 5th/4th–1st century B.C. (D'Alena 2006; Gravina 2007).

The dominant location of Monte Sambuco-Orlando plays a crucial role in visually connecting sites within this system and between this system and the southern hillfort of Monte Saraceno (Figures 7E, 8E). Monte Saraceno is located along the same mountain range on the second highest peak of the Daunian mountains between the mouths of the rivers Fortore, Vulgano, and Celone. Here, stone wall remains are present on the top of a scarp and a counterscarp system identified through lidar that, on the eastern side, present four circular depressions of unknown function, each 14 m

in diameter. The site encloses an area of 4.7 ha, similar to Monte San Giovanni. Materials from surveys and a rescue excavation undertaken in 1999 attest to the site's occupation between the 4th and 3rd century B.C. and during the Medieval period (Russi 2000). Recent surveys also indicate several small farms in the surrounding area that date to the 4th and 3rd century B.C. and have been interpreted as Samnite (Marchi 2016). This combination of evidence, showing hillforts and surrounding farms, is typical of Samnite occupation in the nearby area of the Tappino valley and contributes to the interpretation of this section of the Daunian mountain as Samnite.

Southeast of Monte Saraceno, further evidence of Samnite occupation has been identified on the hillfort of Monte Cimato (Figures 7F, 8F). The site is located on an isolated spur overlooking the stream Lavella, on the offshoot of the Daunian Mountains at the north of the river Cervaro. On

the summit, a small circuit (Figure 10A) composed of a rampart was previously identified through aerial remote sensing by the University of Foggia, which interpreted it as medieval. Despite being in a deplorable state of preservation, the lidar analysis and ground-truthing allowed for the identification of a previously unknown, much larger lower circuit made of polygonal masonry (Figure 10B–D) remarkably similar to that of Valva. Here too, the polygonal wall is preceded by an outer rampart 20 m away from it, and, to the east, a double rampart forms a pathway leading to the site from the lower fields. Both the sites are located on spurs naturally fortified on one side, with fortifications built only on the most easily reachable area, and each encloses a similar area of 11–13 ha. This evidence suggests a connection between the two that, based on the extension of the fortifications and sizes, could

also be tentatively extended to Monte Sambuco-Orlando. Assessment in the field confirmed medieval occupation for Monte Cimato's upper circuit. It also allowed for the identification of a considerable amount of material on the margins of the ploughed fields leading to the lower wall circuit from the north. These date to the 9th–8th century B.C. and include matt-painted ware (proto-Daunian geometric) and impasto (Figure 11). Occupation after the Iron Age is not confirmed, but the dense vegetation made it virtually impossible to survey the area inside the walls, where it would be most likely to find traces of Samnite occupation in future research. This interpretation is not far-fetched, considering that data from the surrounding valley of Celone shows numerous traces of Samnite occupation in the necropoleis of Monte Calvello, La Murgetta, and Masseria Festa/Pezza S. Michele, in the
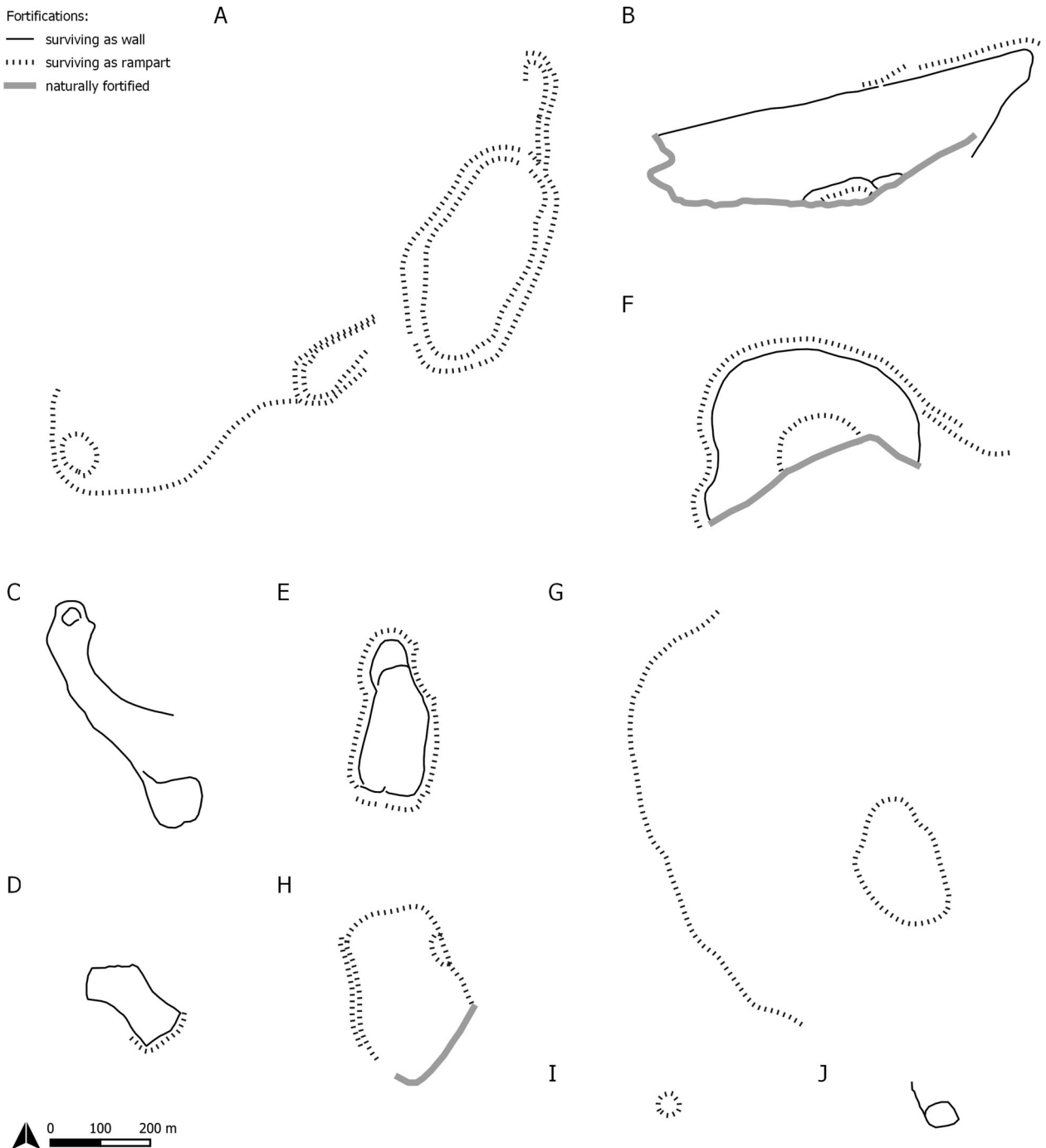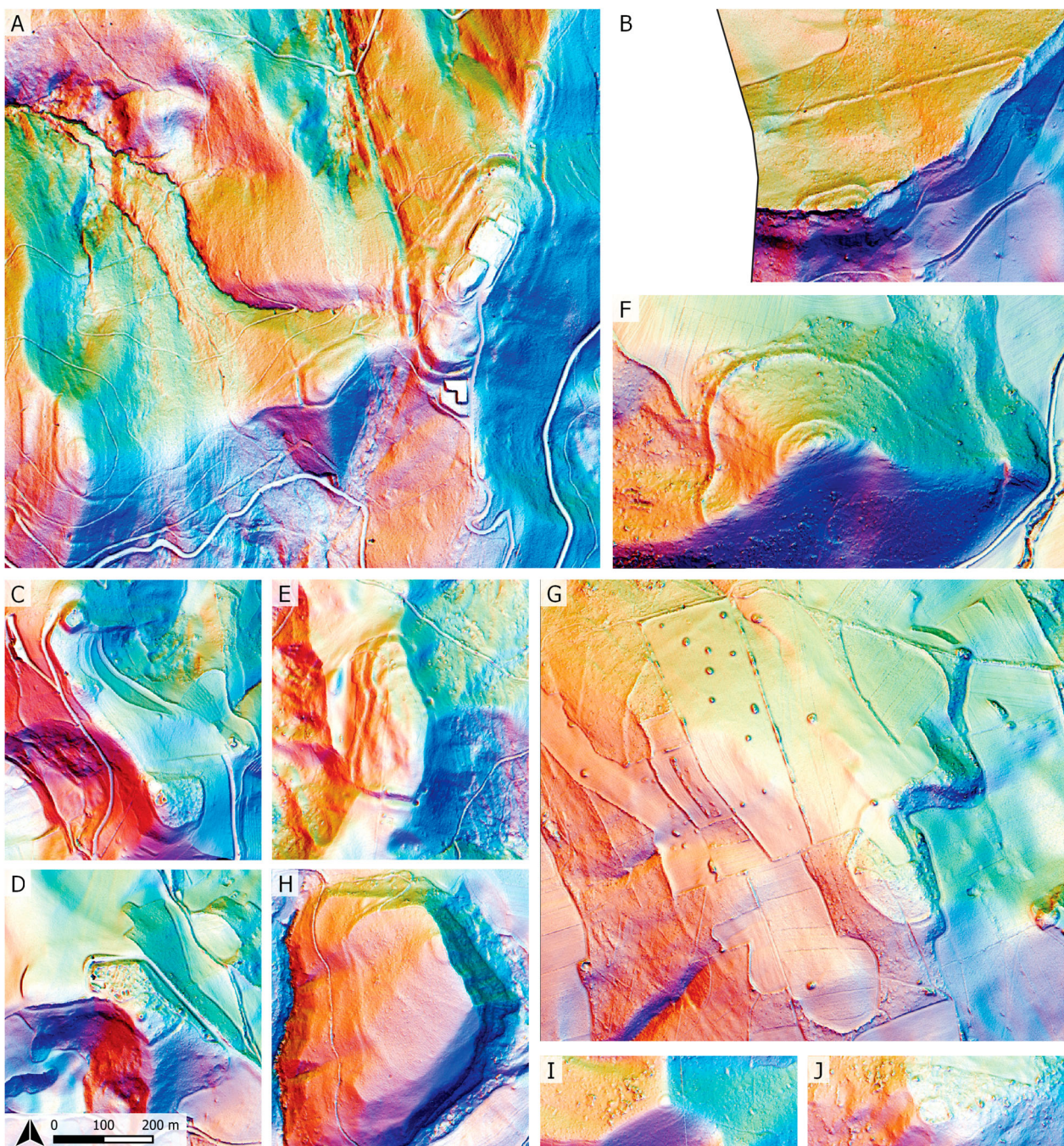

Figure 7. Comparative planimetry of the hillforts analyzed in this study on the Daunian mountains. The numbering follows their order of appearance in the text, also summarized in Table 3. The mapping is based on lidar in combination with the data collected during ground-truthing.

excavated structures of Macchia di Pierno, and in the recovery of Heracles figurines from Castelluccio Valmaggiore and Bovino (Corrente et al. 2008a, 2008b, 2010; Marchi 2016). The evidence suggests the site is not only similar to other hill-forts discussed above but that it is also similarly inscribed within the landscape, specifically, in a strategic position controlling the trans-Apennine routes that connect the Samnite Hirpinian region with the Tavoliere.

The strategic importance of this area is also attested by the nearby known Roman villa of Località Nardusciello and the newly identified site of Monte Cerchio di Magliano (Figures 7G, 8G). The latter lies only 1.5 km northwest of Monte Cimato on a large and gentle plateau. Two circuits of fortification enclose an estimated area of 39 ha. A large amount of impasto pottery was found in the ploughed fields around the inner ramparts. No diagnostic pieces were recovered, although the typology of materials and decorations with *bugne* (protusions) and *cordoni* (rope decorations) points to late prehistory. Although a monastery dedicated to San Nazario on Monte di Migliano has been reported (De Fino 1996), no traces of it were located during a brief inspection of the site. The dimensions and location of the enclosed area support the interpretation of the site as one of the large, low-density settlements typical of the Daunian region (Marchi 2009, 2014, 2016; Marchi and Forte 2012). If confirmed, the site's location only a few kilometers from Monte Cimato becomes particularly interesting. This may suggest either co-existing Daunian and Samnite settlements or a shift in the modality of occupation of the area at a time of political change. In the latter scenario, an earlier Daunian settlement could have been substituted by a Samnite hillfort, but this is only a hypothesis that requires further investigation.

Figure 8. Hillforts of the Daunian mountains analyzed in this study as seen on the complementary image blend of lidar visualizations. The numbering follows their order of appearance in the text, also summarized in Table 3. No complete lidar coverage is available for the site of B) Valva.
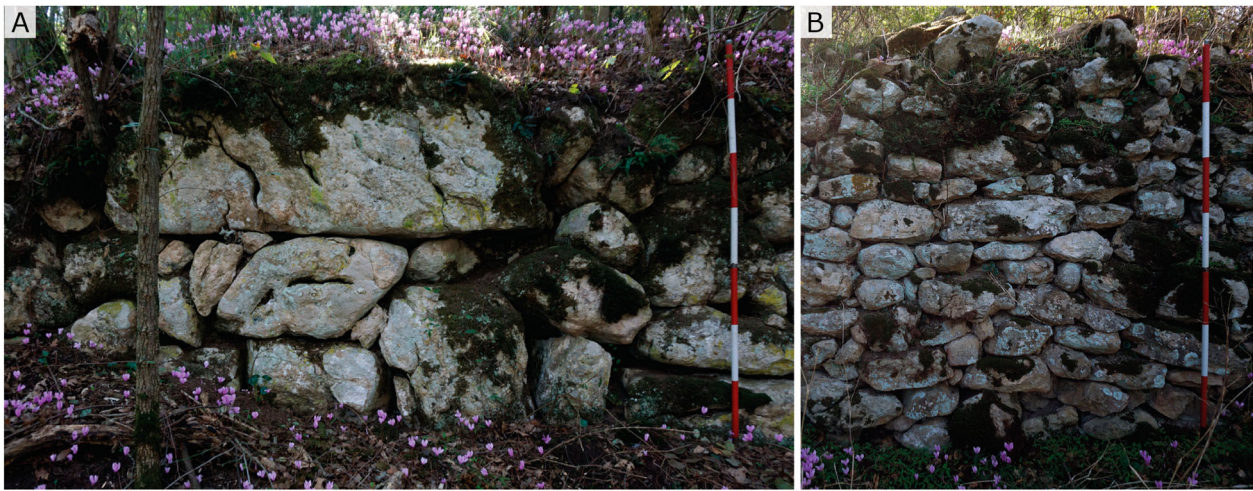
Figure 9. Fortification wall of the A) lower and B) upper circuits of the hillfort of Valva.

Moving south toward the end of the Daunian mountain, where it meets Campania and Basilicata, a cluster of three other new sites was detected. The interpretation of these as Samnite is, however, uncertain. Although not as well-defined in lidar as the other sites discussed so far, two circuits enclosing 6.3 ha have been identified on Monte Ultrino (Figures 7H, 8H) in association with pottery sherds identified during ground-truthing. Another circuit, of very small

Figure 10. A) Aerial view of the hillfort of Monte Cimato. It is noticeable how only the rampart forming the upper circuit is visible in aerial photos. B–D) The vegetation hides the remains of the lower stone wall circuit.
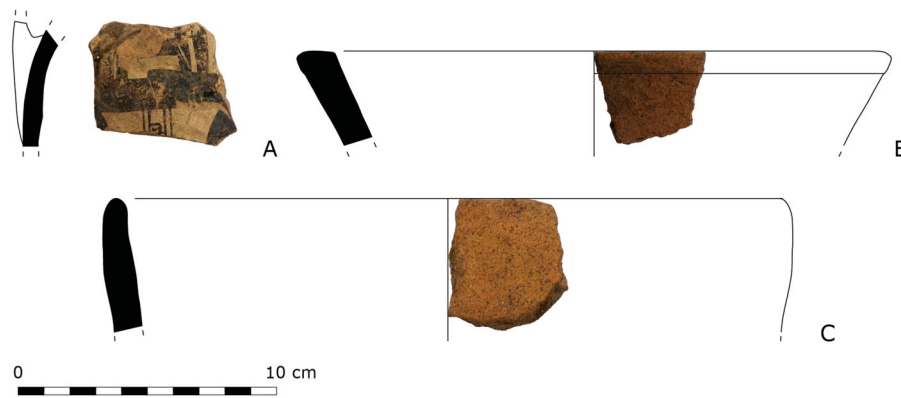
Figure 11. Drawings of the diagnostic materials found in Monte Cimato. A) H. 5 cm; thk. 0.7 cm; pale brown color 2.5YR 7/3; matt painted ware (cf. De Juliis 1977, 27, tav. XXVIII, n. 23); 9th–8th century B.C. B) H. 4 cm; thk. 1.2 cm; dia. 23 cm; brown color 10YR 5/3 surface, grey 10YR 5/1 core; impasto, smooth surface (cf. Natali 2006, n. 149); Early Iron Age. C) H. 5 cm; thk. 1.1 cm; dia. 26 cm; yellowish-brown color 10YR 5/4 surface, grayish-brown 10YR 5/2 core; impasto, smooth surface (cf. Gatti 2004, 88, fig. 69, 3); Early Iron Age.

dimension, is present on Monte Serbaroli (Figures 7I, 8I), where a rampart encloses a small area of less than 0.1 ha located at the control of the trattturo Pescasseroli-Candela. This site may be compared with small Samnite outposts common in western Campania (Calastri 2014). Although few fragments of coarse ware were found, it was impossible to confirm its chronology, leaving space for a possible interpretation of the site to the Medieval period. Moving east along the same trattturo, on Monte Alvaro (Figures 7J, 8J), a small circuit encloses 0.3 ha. The dense vegetation made it impossible to reach the wall; however, the site was confirmed by the large amount of material identified on the prospicient field to the north, preliminarily dated from the Iron Age to the Roman period. Evidence of similar materials has also been reported for the southern foothill of Monte Alvaro, where recent investigations were undertaken ahead of construction of a power plant (Mesisca 2020, 48).

Are these mountains Samnite?

The results from Apulia provide a glimpse of the real potential of this study. The lidar analysis allowed for the detection of the new sites of M. Orlando, M. Cerchio di Magliano, M. Utrino, M. Serbaroli, and M. Alvaro and provided substantial new data for reinterpreting the sites of Valva, M. Sambuco, and M. Cimato and mapping the fortifications of M. Rotaro, M. San Giovanni, and M. Saraceno. Until now, archaeological research in this region primarily focused on the plain of the Tavoliere. Because of this, current debates had largely neglected questions regarding ancient strategies of habitation and use of the Daunian mountains. This study provides the first cohesive picture of the organization of the landscape through hillfort sites. Most importantly, the new data demonstrate a structured Samnite occupation of this area and offer evidence for the interpretation of investigated sites as Samnite.

The Apulian hillforts are located strategically to form a system consistent with examples known in other parts of Samnium, particularly in Campania or Molise (Oakley 1995, 143–147; Caiazza 2007). From the known hillforts of Montagna di Gildone (Oakley 1995, 126–128) in Molise, the newly identified Daunian mountain hillforts extend the pattern of sites south until reaching a series of suspected hillforts this study detected in Campania. These sites, if

confirmed as hillforts, would continue the system all the way to the isolated hillfort of l'Incoronata (Oakley 1995, 68–69), which is situated at the border between Campania, Apulia, and Basilicata in the southernmost part of Samnium. This interpretation of a hillfort system is supported by the fact that the general assemblages found in the Apulian sites closely resemble materials found in association with Campanian hillforts by this project and with Molisian sites like Montagna di Gildone by the Tappino Valley Survey (Stek 2018).

It is possible to envision a border zone between the Samnite and the Daunian areas where a system of hillforts likely played a key role. This suggests two different ways of inhabiting the landscape coexisted and interfaced. In the mountains and their foothills, recent studies have revealed a series of small farms interpreted as Samnite holdings that span the entire territory (Marchi 2009, 2019; Marchi et al. 2016). The present results show that a series of hillforts likely served as focal points among these minor settlements. In contrast, in the plains, Daunian villages consisted of houses interspersed with cemeteries, fields, and empty spaces in forms comparable to the low-density urbanism present across much of temperate Iron Age Europe. These sites were naturally defended to a certain degree thanks to their location on the plateau, while fortifications with banks are attested only at Arpi, possibly at Tiati (Marchi 2009, 2014, 2016; Marchi and Forte 2012), and possibly by the new site of Monte Cerchio di Magliano. Evidence of Samnite cultural elements mixed with the indigenous Daunian structure shows that this dichotomy was fluid (Marchi 2009, 2014; Corrente et al. 2010).

The hillforts identified in the current study are unlikely to reflect isolated Daunian experiments in the landscape, as this type of occupation is so characteristic of the neighboring Samnites. It is particularly likely these sites are Samnite considering the geographical continuity of hillforts from the Molisian, Apulian, and Campanian areas. This, together with the growing archaeological evidence of Samnite presence in the area described above, supports the interpretation of the hillfort system as Samnite. The exact timing of the consolidation of this hillfort system is unknown and is mostly inferred based on sporadic chronological data from surrounding necropoleis instead of from the hillforts themselves. The available data show Samnite presence in the northern hillfort areas as early as the 6th and 5th century

B.C. However, the southern aspect of the hillfort system was probably not complete until a later phase. Whether Samnite occupation of the mountains happened peacefully or violently is yet unknown, but the imposing fortifications of some of these sites, like the complex of Monte Sambuco-Orlando or the polygonal masonry of Valva and Monte Cimato, would suggest at least some degree of conflict. What is certain now is that with the arrival of the Romans in the 4th century B.C., Samnite occupation consisted not only of small, minor settlements, as previously assumed, but also of hillforts. These sites must have served an essential function in the Samnite occupation of the landscape, as they directly faced Roman occupations of the sites of Teanum Apulum and Lucera in the Tavoliere toward the end of the 4th century B.C. Lidar analysis has allowed for these interpretations and, for the first time, provided a systematic and comparative tool for studying how the landscape of the Daunian mountains was structured.

Conclusions

This study presents the first systematic analysis of Samnium tailored to detect and study unknown hillfort sites. Simultaneously, it constitutes one of the first large-scale, lidar-based analyses of the Italian territory. It contributes methodological developments in the use of lidar data for archaeology and generates critical archaeological data about the presence of hillforts in Italy.

The processing of lidar data for archaeological purposes was essential to the development of this study. This enabled the identification of sites invisible in the off-the-shelf ministerial DTM and provided much greater detail for visible sites, allowing for further interpretation. In particular, the double filtering process effectively addressed the qualitative limits of the lidar data available. The proposed approach is tailored around these intrinsic limits, allowing time-efficient processing of the entire research area, producing standardized products, and allowing for speed and ease of use without compromising the detection of targeted site types. This is extremely important, considering that archaeological research in central and southern Italy still relies on the use of pre-made lidar DTMs, which hinders the reliability of the data and their interpretation.

As lidar data is only available for only a portion of the research area, the number of suspected hillforts detected in this study cannot be considered exhaustive. Exhaustive detection was not the aim of this study, however. Instead, this research aimed to produce a systematic study of an extensive portion of Samnium while avoiding biases related to different archaeological visibilities. Research biases were the central problem inherent in previous studies, as the available dataset was not representative of the real typologies and distribution of Samnite hillforts. The study effectively addressed certain biases associated with traditional archaeological surveys by identifying hillforts independently of the level of vegetation or accessibility of sites. Therefore, the new dataset can be considered representative of the surviving distribution of hillforts across Samnium, providing data that can be used in comparative studies both locally and cross-culturally. It provides the first comprehensive overview of the presence or absence of hillforts sites across a large sample area of Samnium. The partial coverage of the lidar data will be accounted for in the next phase of this research through spatial statistical modelling, using the now-analyzed area as a reliable sample suitable to develop robust inferences. Additionally, the new sites detected during this study contribute to the creation of a rich training dataset of hillforts suitable for future development of machine learning-based approaches to archaeological object detection.

Initial results from the Apulia region show the potential contributions of this approach for interpreting settlement patterns across the landscape. The new data show a consistent Samnite presence in the Daunian mountains that is similar in form to hillfort systems known in other parts of Samnium. This prompts us to think about this region not only in terms of the occupation of the Daunian lowlands, as has traditionally been discussed, but also as an integral part of the Samnite settlement system. Beyond adding to regional site catalogs, lidar-based analyses have the power to address old debates and theories biased by historiographical approaches and the limitations of previous archaeological research. Most important, they support the development of new frameworks for understanding mountain societies through original and representative datasets.

Notes on Contributor

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