Comparing lidar analysis and field documentation in archaeological surveys: feature recognition, quantification, and land-use modeling with the Small Cycladic Islands Project

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Introduction

Over six field seasons (2019–2024), the Small Cycladic Islands Project (SCIP) has conducted systematic pedestrian surveys of 87 uninhabited islands across the Cycladic archipelago.[1] In 2022 and 2023, SCIP acquired lidar data over 97 currently uninhabited islands in the Cyclades, working with the Thessaloniki-based company Aerophoto (Figure 1). The goals of this work were several: (1) to supplement and expand our knowledge of areas already surveyed by SCIP (2019–2021), many of which are heavily obscured by vegetation cover; (2) as a precursor and guide to our own pedestrian survey work in 2022–2024, especially in large islands that could not be surveyed at the same level of intensity as smaller ones; (3) to supplement investigations of other islands that are well known and have been surveyed by other projects using other methods (Delos, Rheneia, and Despotiko); and (4) to cover areas where it is not possible for the project to carry out pedestrian survey work, due to issues of accessibility, size, or other constraints (Gyaros and Antimilos).

This paper focuses on the first goal, in order to provide a different, and, in some cases, more comprehensive view of archaeological landscapes that have already been subject to intensive pedestrian survey. We present the results of the post-fieldwork examination of aerially acquired lidar data over 34 islands surveyed during the first three field seasons of the project. In the first place, we have a methodological aim of comparing patterns of feature recognition during pedestrian survey

[1] Athanasoulis *et al.* 2021; Knodell *et al.* 2022; Knodell *et al.* 2025

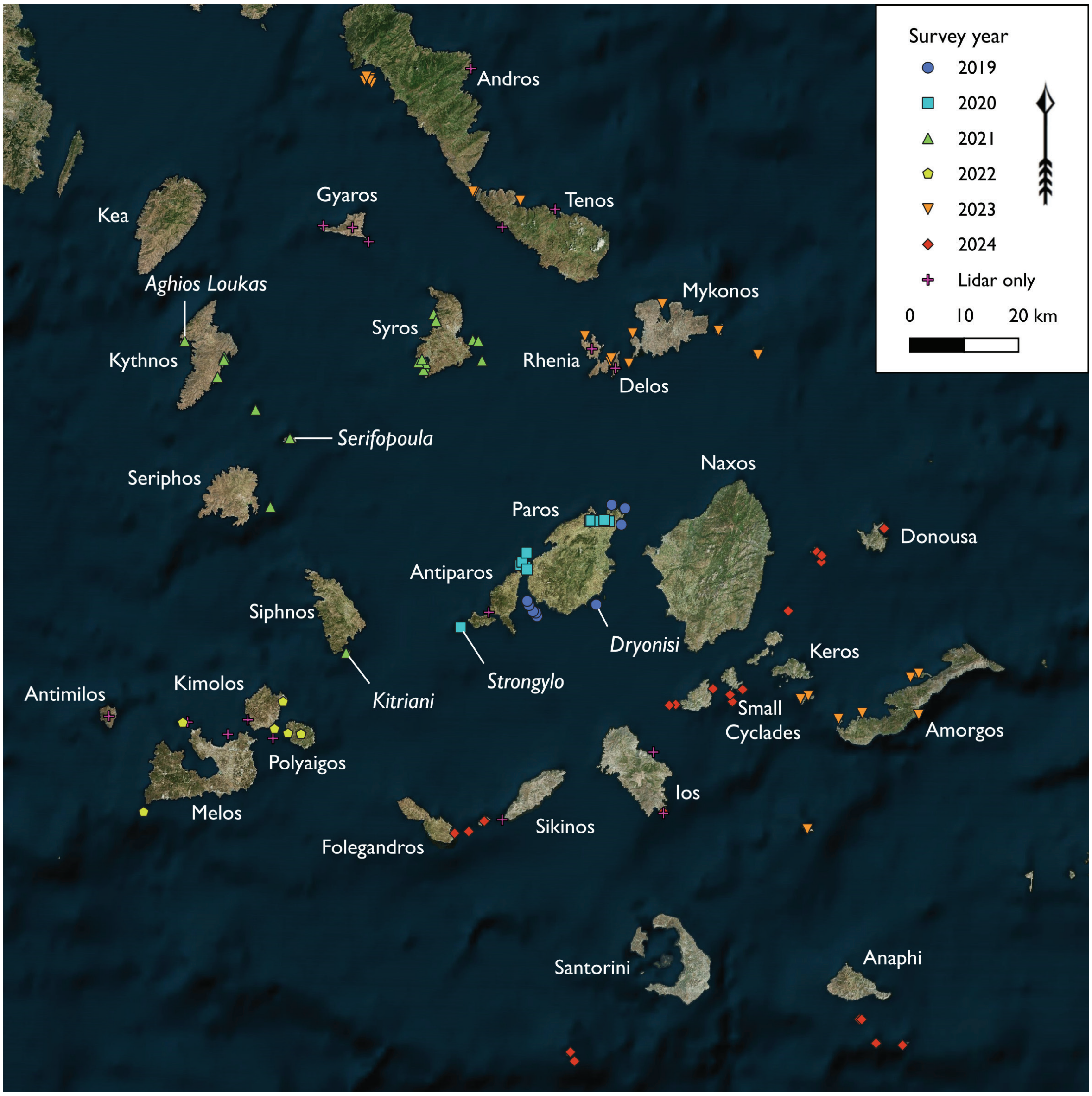

Figure 1. Map showing islands covered by SCIP pedestrian survey and lidar acquisitions, with the main islands discussed in this article indicated in italics. Background: Bing Imagery Basemap.

and lidar analysis. Our second goal is to examine some interpretative issues that arise from this work, especially concerning land use, landscape modification, and chronology.

Methodology and research design

Remote sensing methods are often used proactively in regional archaeological survey projects; they offer a preliminary view of a particular study area and may guide the development of future research plans; remote sensing data may also stand alone to address research questions independent of fieldwork.[2] By contrast, lidar data for the Small Cycladic Islands Project was introduced at a crucial midpoint of the project: after three seasons of fieldwork had been completed and with three seasons of fieldwork (at that point) still to come. Drawing on the results of our first three seasons of fieldwork, we understood that collecting aerial lidar data – for both islands that we had already surveyed and

[2] E.g., Wiseman and El-Baz 2007; Parcak 2009; Comer and Harrower 2013; Forte and Campana 2016; Casana 2021.

those that were scheduled for survey, – offered the opportunity to inform our existing results and to provide new insights, as we turned toward the survey of larger and more topographically challenging islands in the second part of the project.

The first three campaigns resulted in the systematic pedestrian survey of 38 islets in the Paros-Antiparos archipelago (2019, 2020) and the islets surrounding Kythnos, Siphnos, Seriphos, and Syros (2021). Each island was divided into survey units measuring 100 x 50 m (with some variance at coastal edges). Teams of fieldwalkers spaced 10 m from one another walked in parallel lines across each survey unit, counting all material culture found within 1 m on each side of their transect, resulting in a 20% sample of each survey unit and allowing for the generation of find distributions across the surface of each island. Counted finds were subdivided into categories, including pottery, tile, lithics, other ancient materials, and modern trash. Diagnostic ceramic sherds, representative ceramic fabrics, all anthropogenic chipped stone, and other ancient materials were collected and subjected to specialist study to determine the chronological, functional, and economic characteristics.[3]

An additional team was responsible for the general description of each island (including geological characteristics, flora and fauna, and other observations), the production of high resolution drone orthophotos and digital elevation models (DEMs), and the documentation of all archaeological features – a broad term encompassing all evidence of nonportable material culture including built architecture, landscape modification, agricultural activity, quarrying and mining, and other evidence of human activity. Each feature was systematically documented with detailed field sketches, photographs, description, and measurements. Photogrammetric models were produced for features of particular interest or complexity using an unmanned aerial vehicle (UAV, or drone) or DSLR camera, depending on their size and characteristics. Spatial data for the location and orientation of each feature was collected with a real-time kinematic GPS (RTK) or through the digitization of georeferenced orthophotos and integrated within the larger project geographic information system (GIS). Of the 38 islands surveyed by SCIP between 2019 and 2021, 34 are included in this study (not all were documented by the lidar survey). On those 34 islands we documented 1,218 survey units, 532 features, and found 50,881 pottery fragments and 3,877 lithic artifacts (Figure 2).

Following the 2021 field season, several challenges and opportunities were apparent. While the coverage and results of SCIP were already impressive, we had significant questions concerning island size and accessibility, which could only be addressed by investigating larger islands. We had also faced obstacles in the comprehensive documentation of certain types of features across large landscapes that were heavily obscured by vegetation, such as terrace systems. A next phase of funding (for 2022–2024) proposed to integrate lidar analysis with survey-based archaeological fieldwork in the ways indicated above.[4] By integrating lidar surveys alongside existing datasets from UAV-derived orthophotos and intensive pedestrian survey, we aimed to test and demonstrate exactly what lidar technology could offer and what it misses in Mediterranean environments, where lidar had been underutilized in archaeology, at least at scales above the individual site.[5]

Aerial lidar data were collected on 26–27 April 2022, by an HB-TEN Cessna 208B aircraft, flying three sorties, targeting 79 islands.[6] Flying at 120 knots with a mean altitude of 3,000 or 4,500 ft (914 – 1372 m), based on target island size, terrain data and RGB imagery were collected in parallel strips with a 30% side overlap.[7] This data collection methodology resulted in a raw lidar point cloud dataset with

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3 Knodell *et al.* 2022: 481-483.

4 Funding was awarded in the form of a US National Science Foundation Senior Archaeological Research Grant (Award ID 2150873; project: *Research in Undergraduate Institutions: Relationship between Area Size and Population History*; PI: Alex R. Knodell).

5 Knodell *et al.* 2023; Vinci *et al.* 2024. For positive examples, see Grammer *et al.* 2017; Masini *et al.* 2018; Rom *et al.* 2020.

6 Data collection and initial processing was undertaken by AeroPhoto co. ltd. A second acquisition in 2023 targeted 18 additional islands in the southern Cyclades for a total dataset of 97 islands.

7 Lidar sensor: RIEGL VQ1560II with integrated Applanix 610/IMU-57; RGB camera: PhaseOne iXU-RS 1000 50mm RGB 100MP.

Island code	Island	Size (ha)	SUs	Pottery	Lithics	Feature count (field)	Feature count (field and lidar)	Feature length (field)	Feature length (field and lidar)
K-AL	Aghios Loukas	39.51	76	12,189	19	17	23	9,860	9,860
K-PP	Piperi	43.57	48	1,040	155	6	6	202	202
K-SP	Serifopoula	135.59	114	1,658	517	44	58	1,684	4,500
K-VS	Vous	16.15	12	161	0	4	4	43	43
P-AA	Aghios Artemios	0.59	1	31	2	2	3	216	245
P-AK	Aghia Kali	1.22	4	370	0	18	21	457	720
P-DN	Dryonisi	37.60	80	1,114	77	44	54	751	6,187
P-DP	Diplo	26.81	45	1,129	156	15	15	672	694
P-EK	Vriokastro	12.20	20	1,669	46	12	7	2,752	2,664
P-FI	Filizi	16.80	37	823	12	44	46	1,054	1,222
P-FR	Firo	46.42	90	11,621	932	76	89	2,103	2,894
P-GN	Gaidouronisi	13.50	26	71	1	3	4	104	115
P-GP	Glaropounta	21.00	47	34	0	1	1	68	68
P-GS	Galiatsos	1.48	4	65	1	6	7	292	305
P-KA	Kampana	0.70	2	6	0	3	3	162	162
P-MG	Magrines	1.38	4	232	15	0	1	N/A	69
P-MI	Mikronisi	1.60	2	4	0	1	1	11	10
P-ON	Oikonomou	21.34	43	2,903	369	34	50	1,320	1,613
P-PR	Panteronisi	47.60	93	67	5	8	8	149	147
P-SG	Saliagos	0.87	1	317	12	6	6	158	423
P-ST	Strongylo	164.90	162	5,146	285	61	70	4,849	19,758
P-TG	Tigani	7.70	15	383	1	18	15	355	508
P-TR	Tourna	3.30	6	4	0	2	2	37	37
Si-KT	Kitriani	83.96	147	4,366	1,253	62	66	1,120	14,084
Sy-AS	Aspronisi	10.98	23	2	1	8	11	859	1,310
Sy-DD	Didymi	48.00	82	5,299	17	20	20	874	890
Sy-DF	Delfini	0.23	1	6	0	1	1	6	6
Sy-DK	Diakoftis	3.01	7	27	1	3	6	60	436
Sy-GN	Glaronisi	N/A	0	0	0	0	2	N/A	1,216
Sy-PS	Psathonisi	0.63	2	0	0	2	2	26	26
Sy-SG	Strongylo	2.51	3	2	0	3	2	10	10
Sy-SN	Schoinonisi	4.88	8	69	0	2	2	6	6
Sy-ST	Strongylo	5.05	8	16	0	3	3	35	35
Sy-VV	Varvarousa	2.68	5	57	0	3	3	15	15
–	**Total**	**823.76**	**1,218**	**50,881**	**3,877**	**532**	**612**	**30,310**	**74,080**

Figure 2. Table of islands included in this study, including basic parameters and finds documented during pedestrian survey and lidar analysis (see figure 7 for locations, labeled with island codes).

34 points collected per square meter for islands flown at 3,000 ft, and 8 points per square meter for islands flown at 4,500 ft, alongside RGB imagery of 7.5 cm pixel resolution.

Point clouds for each of the 79 target islands in the initial acquisition were interpolated in TerraScan software to create a normalized dataset and then classified into nine classes, including ground points, medium vegetation, high vegetation, building, water, wall-structure, and various types of noise. The classified and interpolated point clouds were then used to produce digital surface models (DSMs), digital terrain models (DTMs), and orthorectified RGB photomosaics, clipped to the extent of exposed landmass for each island with a c. 25m buffer to capture any features found at

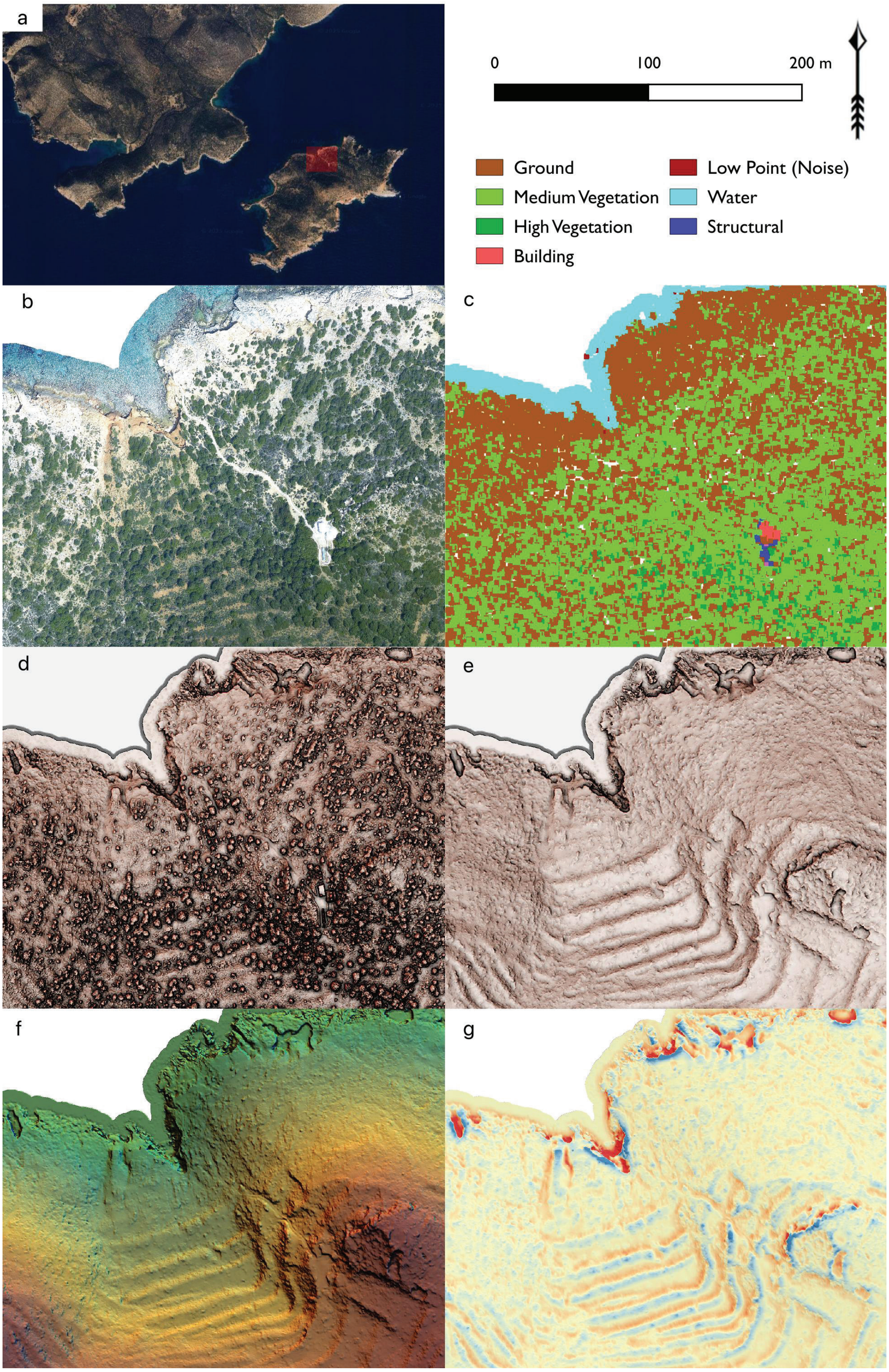

Figure 3. Tiles illustrating remote sensing data and visualizations used in this analysis: (a) Finder map showing the location of images b–g on the island of Kitriani, southeast of Siphnos; (b) Aerial photograph, showing a church complex and path leading to it from the natural harbor of the island; (c) LAS point cloud classification; (d) DSM rendered with a combination of slope (in red) and Archaeological VAT visualizations; (e) DTM rendered with a combination of slope (in red) and Archaeological VAT visualizations; (f) DTM rendered with a combination of colorized elevation, layered with Archaeological VAT and Multidirectional Hillshade visualizations; DTM rendered as a Local Relief Model layered over a Multidirectional Hillshade visualization.

the shore. DSMs included all classifications, presenting the topography of the island with vegetation and built architecture included, while DTMs were processed using only ground points, presenting a 'bare earth' terrain model with all vegetation removed (Figure 3). Because DTMs made from automatically classified point clouds typically remove anything not classified as ground, including built architectural features, initial analysis made use of DTMs, DSMs, and orthophotos together, while subsequent processing was undertaken to create Digital Feature Maps (DFMs) that included classes of 'wall-structure' and 'building'. For the purposes of this article and to maintain statistical relevance across datasets, analysis was limited to visualizations produced by the DSMs and DTMs.

While these rasters on their own offer excellent insight into the variation between the surface and terrain for each island, they also serve as key data for additional processing into a series of visualizations, that further highlight archaeologically relevant information at multiple scales. We employed the open-source Relief Visualization Toolkit in QGIS to batch process our lidar-derived DSMs and DTMs into multidirectional hillshades, slope gradients, simple local relief models, sky-view factors models, openness indices, and local dominance (LD) calculations, and visualization for archaeological topography (VAT) rasters.[8] This final visualization, specifically aimed to highlight features relevant to archaeological study, is calculated from a combination of multidirectional hillshades, slope indices, positive openness, and sky-view factors to highlight areas of variability between complex and normal topographies, factors which can be attributed to the built environment. We find that the use of LD and VAT visualizations of DSMs and DTMs (often combined with slope gradient) offer the most effective identification of archaeological features at the small and large scale.

The integration of these visualizations into our larger project GIS allowed us to refine the in-person feature documentation carried out in the 2019–2021 field seasons. Using the lidar data visualizations for each island, all features and areas of interest were recorded with both line and polygon vectors, which we could juxtapose with our existing feature documentation. Areas of interest and identified features were assigned qualitative and quantitative information, including type, function, analysis notes, and (in cases of features documented in the field) a feature number that connects the feature to previous documentation by SCIP.[9] An example from Kitriani shows the features documented in the field in contrast with the features documented via lidar analysis, classified according to function (Figure 4). We can also draw important statistical information from this dataset, for example that over 12 kilometers of terrace walls provide about 19 hectares of arable land. Strongylo provides another good example, where we documented some terracing on the ground, but failed to appreciate the full extent and potential productivity of these systems, including in areas that were not noticed (let alone documented) while in the field (see further below).

Analysis and quantification

One simple metric for comparing field and lidar-derived datasets – and from there the effectiveness of field and lidar methods for feature recognition – is the number of documented features. We find the total length of documented features to be a slightly more useful metric. On all islands surveyed in 2019–2021, we documented a total of 532 features in the field (Figure 5a). Subsequent lidar analysis resulted in a total dataset of 612 features, or 80 newly discovered features. The difference is more pronounced when comparing total length, where about 38 km of features were documented in the field, with 70.5km in the final combined analysis (Figure 5b).

However, we should note that not all features documented in the field are also visible in the lidar. Some 28% of total features were observed only in the field, but these features accounted for only 2.3% of the feature length. About 46% of total feature length was only visible in the lidar (Figure 5c

[8] Zakšek *et al.* 2011; Kokalj and Somrak 2019; Lozić and Štular 2021; Štular *et al.* 2021.
[9] See also Manquen *et al.*, this volume, Figure 5.

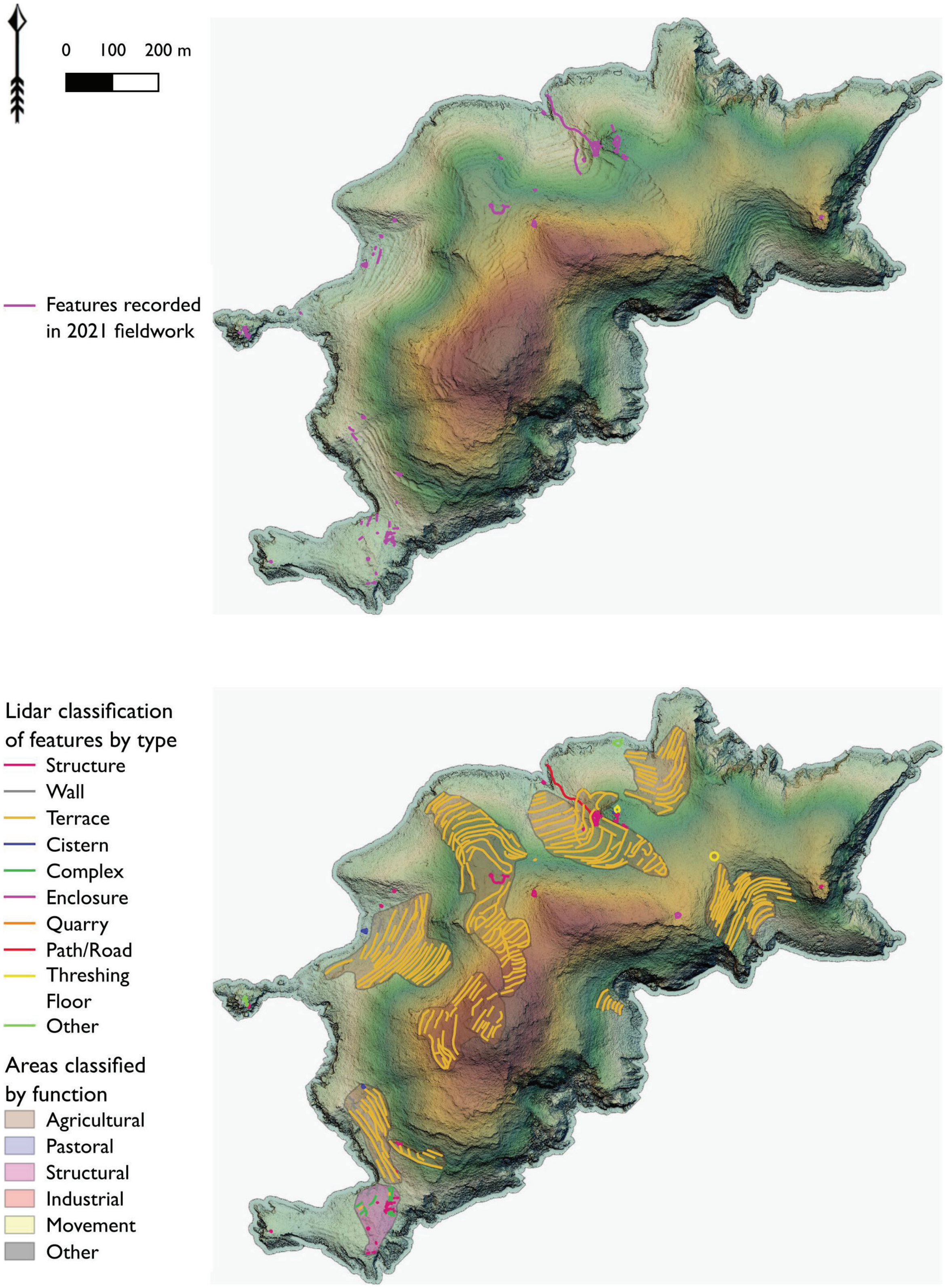

Figure 4. Map of Kitriani, showing features documented in the field versus features documented and classified during lidar analysis.

Figure 5. Statistics showing feature counts (a) and total length of features (b) per island, along with overall number of features (c) and overall length of features (d) across all islands, according to type of documentation.

and 5d). This leads to the somewhat obvious conclusion that small features are less visible in the lidar than large ones. Nevertheless, there is substantial overlap. Where lidar revealed the most was in situations – mostly on larger islands, such as Kitriani and Strongylo (Si-KT and P-ST) – where heavy vegetation obscured the surface and large terrace systems were present. Unsurprisingly, there is a strong, inverse relationship between the amount of new information gained from lidar analysis and average visibility documented in the field. There is also a correlation between island size and 'lidar only features. Researchers can therefore predict the utility of lidar data in project areas by considering vegetation indices and project area size.

We have also aimed to identify and quantify trends in the recognition of certain types of features in the field versus in lidar analysis (Figure 6). In the first place, we see that lidar is good at identifying large-scale landscape features, such as terraces and walls, as well as distinctly linear features, especially structures. When breaking down features by category, we see that terraces, paths, and roads are highly recognizable. Types of features that lidar is likely to miss include: small, low-to-the ground features; interior walls of buildings; and walls that can be identified visually by partly buried stone lines. However, we note that the types of features that may be missed frequently occur in the vicinity of features that are conspicuous in the lidar data. Therefore, they are still likely to be identified during the ground verification or site documentation phase of a project.

Some of the most interesting results of the lidar analysis and feature classification come from quantifying these datasets. More specifically, aggregate length and area calculations can be used to compare overall levels of investment in different islands for different purposes (Figure 7). We can also compare these aggregate calculations for each island to environmental data, like island size, and other data collected in the course of the pedestrian survey, such as overall pottery counts. For example, an early hypothesis that there is a correlation between island size and scale of investment (represented by feature construction) and use (represented by overall pottery counts) is largely confirmed, though there are of course variations (Figure 8). When islands are sorted according to size, the overall scale of investment, as represented by built features, and the overall level of use, as represented by pottery finds, follow a general upward trend. Of the ten largest islands in this dataset,

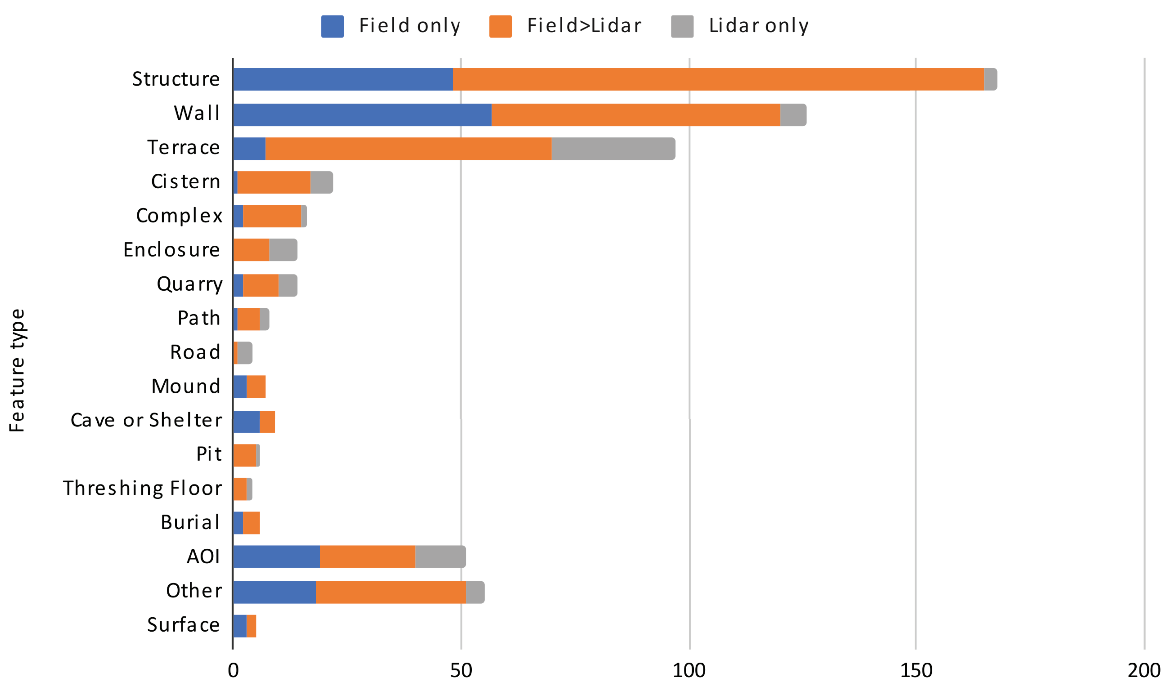

Figure 6. Number of features identified on all islands, according to type and showing method of identification.

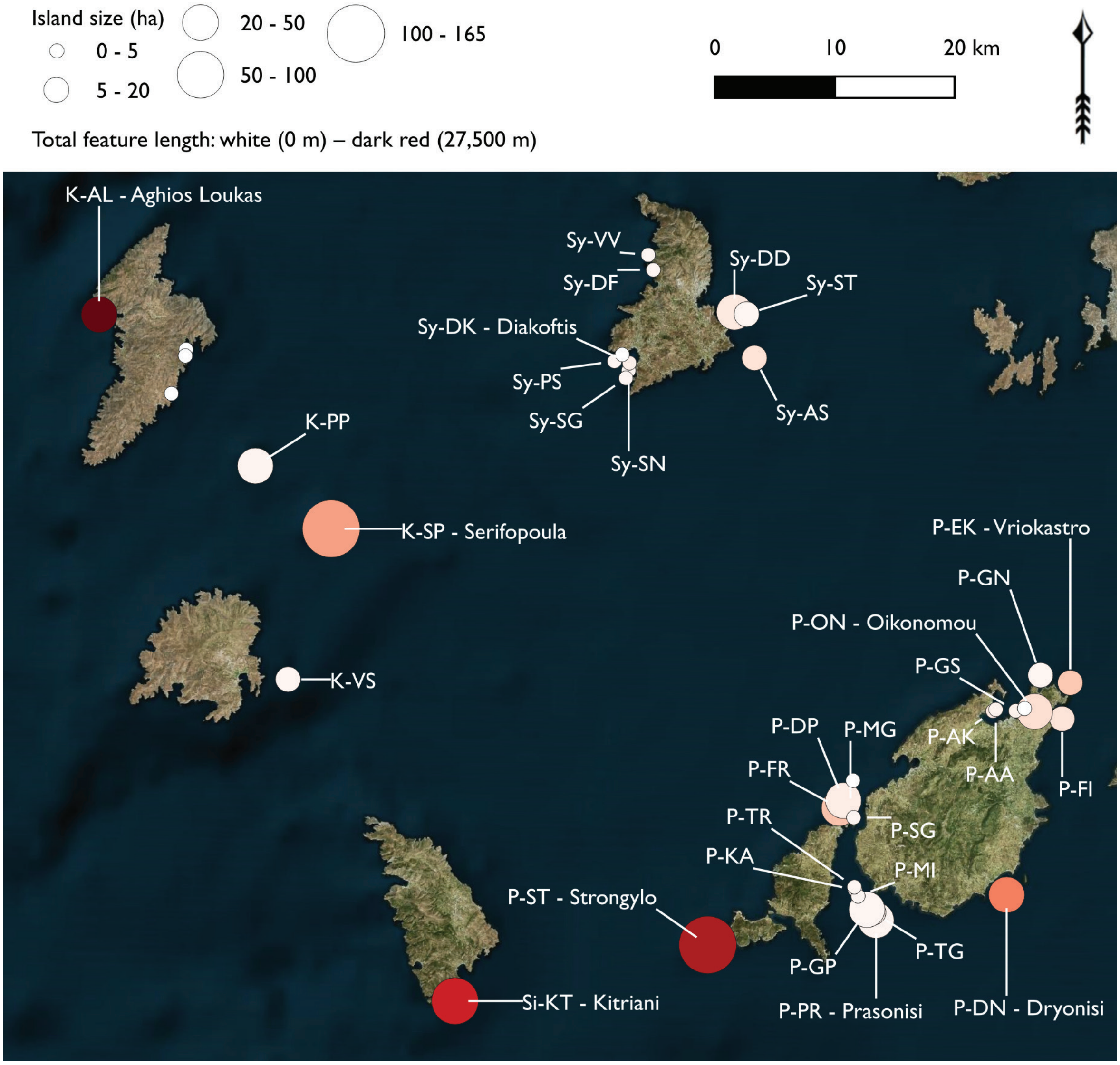

Figure 7. Map of islands surveyed by SCIP, showing the overall island size, represented by graduated sizes of dots, and scale of material investment, as represented by graduated colors of dots from white to dark red. Islands are labeled with abbreviations used in Figure 2, with main islands discussed in the text labeled fully. Background: Bing Imagery Basemap.

only one was largely insignificant in terms of documented material remains (P-PR: Prasonisi); the seven highest 'combined scores' of lidar length and total pottery are also in this group of the ten largest islands. Only Oikonomou (P-ON) and Vriokastro (P-EK) have higher combined scores than some others in the top ten for size and these would rank eighth and ninth; and they are still in the top 50% for size. So while anomalies are certainly present (and indeed should be expected) the overall correlation between island size and investment and use is quite strong. This correlation is not surprising, since larger islands provide additional space and opportunity for construction but it is nevertheless significant and has allowed for the identification of various size thresholds among small islands, supported also by findings from later field seasons.[10]

Interpreting agrarian landscapes

Lidar also provides the opportunity to quantify and interpret evidence for agricultural economies on small Cycladic islands. Here, we focus on two particular avenues of research related to agrarian

[10] Knodell 2025; Knodell *et al.* 2025.

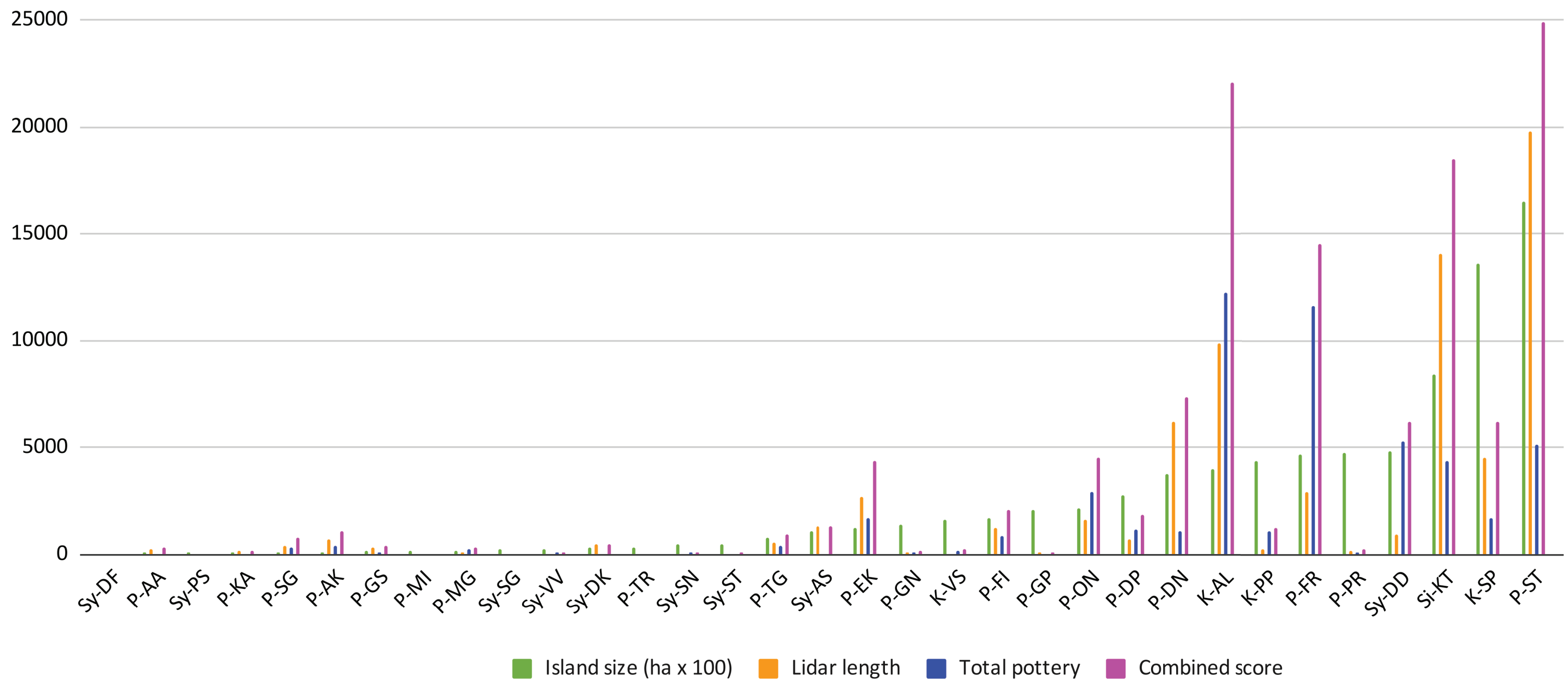

Figure 8. Graph showing all islands, ranked according to size (smallest on the left and largest on the right), with total feature length documented in lidar (in orange), total pottery counted in survey units (in blue), and a combined score reflecting both of these metrics (feature length plus total pottery, in pink).

Island code	Island	Size (ha)	Terrace systems	Terraced area (ha)	% of island terraced	Cereal yield (kg/annum)	Population supported
K-AL	Aghios Loukas	39.5	7	21.9	55.5	16,443.0	43.8
P-DN	Dryonisi	37.6	4	9.8	26.2	7,387.5	19.6
P-ST	Strongylo	164.9	6	35.8	21.7	26,887.5	71.6
Si-KT	Kitriani	84.0	10	18.9	22.5	14,175.0	37.8
Sy-DK	Diakoftis	3.0	1	0.2	7.0	157.5	0.4
–	**Total**	**329**	**28**	**86.6**	**132.9**	**65,050.5**	**173.2**

Figure 9. Cereal production and population carrying estimates based on documented terrace system.

landscapes and life: (1) statistics concerning agricultural features documented by lidar and fieldwalking and (2) the relationship between agricultural productivity and potential carrying capacity.

While a range of feature types offer insight into diverse agropastoral practices on Cycladic islands, agricultural terraces provide the clearest point of comparison across islands and also represent the largest-scale evidence for investment in terms of total feature length. Terraces served to control and reshape the landscape of these islands, normalizing the often steep topography to create discrete zones of agricultural productivity. While recent efforts have refined our ability to categorize, date, and interpret agricultural terraces, these features remain difficult to treat with the same rigor as other forms of historic architecture.[11] There is therefore a wide range of interpretive approaches in Greek contexts and throughout the Mediterranean.[12] In the context of the Aegean islands, research on agricultural terracing has highlighted positive correlations between the construction of these features and population estimates for a given island.[13]

In the case of the Cyclades, lidar offers important new insights into these complex networks of iteratively built, repaired, abandoned, and reused agricultural spaces, offering the opportunity to ask new questions regarding the occupation and exploitation of rural landscapes on a diachronic scale (even if it offers little direct evidence for the notoriously challenging issue of terrace chronology).

The total area of the 34 islands included in this study was 824 ha with an average area of 24 ha per island. Between fieldwalking and lidar analysis, we isolated a total of 612 individual archaeological features and clearly interconnected features (terraced fields, pastoral enclosures, structures, etc.). Feature complexes whose areal extent was significant for their function were demarcated by 97 polygons in a GIS environment, in order to facilitate the quantification and comparison of different types of activity zones on different islands. The most common functional category of these zones were systems of agricultural terracing (n=28), present on five islands. These terrace systems covered a total area of 86.7 hectares, with an average area of 3.1 hectares per system, and were documented on both larger and smaller target islands (Figure 9).[14] While these terraced areas are by no means homogeneous and contemporaneous, they do indicate the regular use of particular islands for intensive cereal cultivation, as well as for other crops. At the same time, their variability highlights

[11] Brown *et al.* 2020a; Brown *et al.* 2020b.

[12] For Greek contexts, see Frederick and Krahtopoulou 2000; Hope Simpson *et al.* 2004; Price and Nixon 2005. For further Mediterranean contexts, see Turner *et al.* 2021; Srivastava *et al.* 2023.

[13] Bevan *et al.* 2012; Krahtopoulou and Frederick 2008.

[14] While these calculations presuppose that all terraced fields are under cultivation simultaneously (not accounting for crop rotation or simple abandonment) they also assume that our data represent the maximum cultivation area for each island. We posit that the error rate between these two factors roughly offset one another for the purposes of rough calculations offering insight into the general patterns of production scale for these islands, clearly differentiating between sustenance and surplus.

the widespread use and modification of diverse terrace typologies and field sizes during periods of intensive cultivation.

Premodern cereal yields in the Aegean islands are notoriously difficult to quantify and rainfed agricultural production in the region varies both annually and over longer timescales. Premodern cereal cultivation in manured fields on the Greek mainland has been demonstrated to produce up to 1,500 kg/ha of grain, from which ⅔ of the grain could be appropriated for human consumption and the remainder allotted for replanting and livestock feed.[15] By contrast, the arid environment, variable rainfall, and thin soils of the Cyclades may have reduced the productivity of cereal cultivation by as much as half, resulting in a raw output of some 750kg/ha, from which 500 kg could be allotted to human consumption, with the remainder designated for replanting and animal feed.

Standard figures in both modern and premodern diets regularly adopt a minimum nutritional requirement of 200 kilograms of grain per person per year, in a grain-only diet.[16] However, the ratio of grain consumption within regional diets varies throughout the Aegean. Foxhall and Forbes have demonstrated that grain could account for as little as 65% in traditional rural diets.[17] On these islands, then, we can assume the presence of simultaneous vegetable cultivation, alongside oil production or acquisition and the consumption of meat and fish, following broader trends in premodern and traditional rural diets. If we adopt a conservative figure of 160 kg of cereal consumption per person per year in a rural Cycladic context, the 500 kg crop yield from a single hectare of terraced grains would offer enough nutrition to support just over three individuals. If we account for the taxation of this product (which has seen variable rates throughout history but could be as high as 30% in the 18th century), we can safely estimate that one hectare of terracing would produce enough grain to feed two individuals. While various factors would further influence these estimates, adopting a baseline assumption that 1ha of terracing could support 2 individuals provides an important baseline for more substantively interpreting the agricultural practices recorded on these islands – allowing us also to differentiate between family-unit, subsistence-scale agricultural production from surplus production for external consumption or exchange on a given island.[18]

As we can see in Figure 9, four out of the five islands where agricultural terrace systems were documented far exceed the output that one would expect for subsistence farming, providing the caloric load for a population beyond what one would expect for islands of this size and based on the range of archaeological data documented. Instead, the agricultural output of these islands appears to have been maximized to integrate this excess product into the broader networks of trade and exchange. By contrast, the small area of terracing documented on Diakoftis – the one island where this practice does not allude to a surplus in production – may instead point to small-scale vegetable or fruit cultivation.

A closer look at the terrace systems of two islands in particular – Dryonisi (slightly above average size at 37 ha, Figure 10) and Strongylo (the largest island surveyed in the Paros-Antiparos archipelago at 165 ha, Figure 11) – helps contextualize these estimates, offering insight into how they can be mobilized to better understand patterns of occupation and exploitation on these islands over time.

On Dryonisi, fieldwalking and lidar survey isolated four areas of terraced cultivation, covering nearly 10 of the island's 37-hectare area (27%). During periods where these fields were under simultaneous cultivation, the island could have nearly 5,000 kg of cereals for human consumption – supporting a population of about 20, far greater than one would expect on an island of its size. Moreover, a large

[15] Halstead and Isaakidou 2020: 92.
[16] For specific insight on grain consumption in premodern diets, see Rosenstein 2008.
[17] Foxhall and Forbes 1982: 67.
[18] This follows patterns documented on Kythera during the 16th-18th centuries, where outputs of this scale would support a family of 4-5 after accounting for taxation (Kiel 2007: 41).

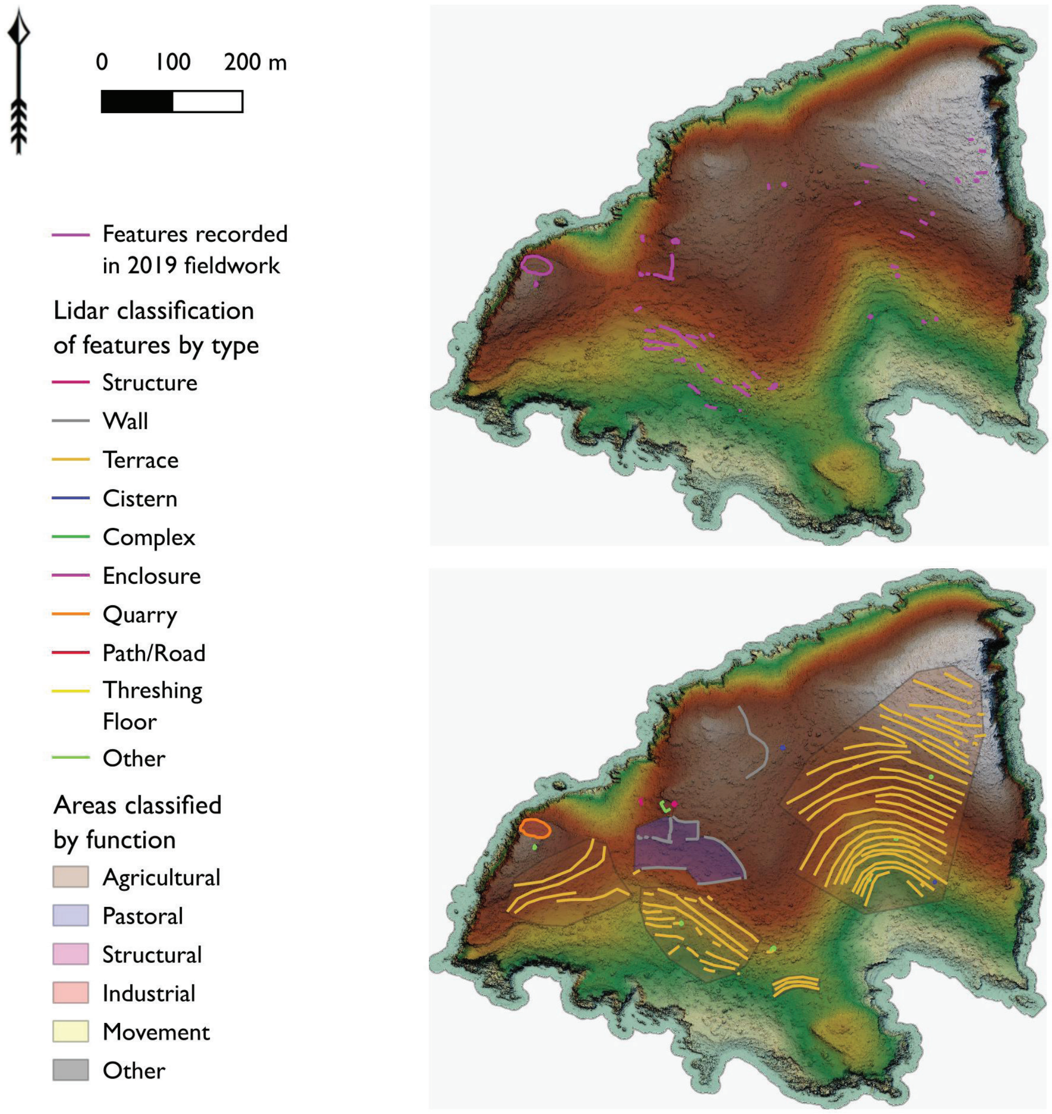

Figure 10. Map of Dryonisi, showing lidar classification and features recorded in the field.

enclosure in the center of the island indicates the presence of livestock on the island, making use of the ample feed produced by cereal cultivation and providing manure to maximize productivity.

In contrast to this evidence for intensive agricultural production, fieldwork revealed almost no evidence for built structures on the island, with only a single modern structure and no clear indication of durable premodern architecture. This profile calls into question whether an intensively cultivated Dryonisi would have supported a permanent or even seasonal population, or whether its close proximity to the nearby settlement of Dryos on Paros suggests a more fitting characterization as an agricultural satellite of Paros, offering additional arable land during periods of low yields or population growth. The chronology of activity on Dryonisi, as documented by surface pottery, is quite similar to that of Dryos, lending support to the close relationship between the two.[19]

Evidence for a more permanent population engaged in intensive agricultural production may be found on the island of Strongylo, where six large terrace systems were documented that account for over 35 hectares of arable land. These terraces represent a range of typological characteristics that likely allude

[19] Knodell *et al.* 2022: 483-486.

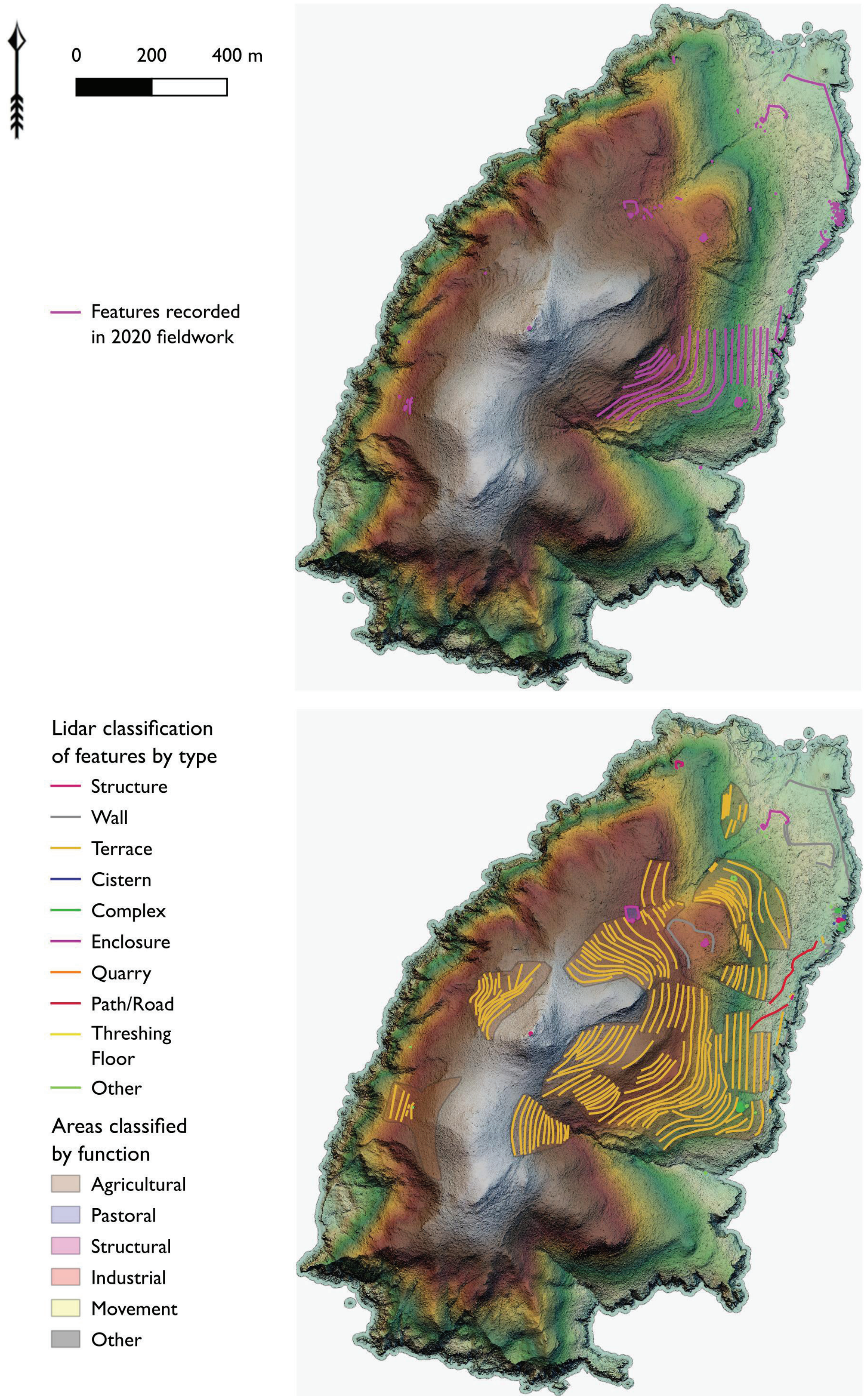

Figure 11. Map of Strongylo, showing lidar classification and features recorded in the field.

to long term investment in an island, with evidence for more sustained occupation from the Neolithic to the Middle Byzantine Period.[20] Moreover, the presence of fresh water on the island was maximized by the construction of several check-dam systems that served to redirect springs and rainwater into nearby field systems, in order to maximize crop yields. Even if these agricultural systems were not functioning simultaneously, the high yield potential of these fields and the need for sustained agricultural labor, alongside evidence for large livestock enclosures, and the comparative isolation of the island vis-a-vis known settlements suggests a stronger case for a sustained population. While a population of 71 seems quite high, a permanent population of some kind using agricultural surplus to trade for other goods is quite plausible. This hypothesis is further supported by the island's rich surface artifact assemblage and six areas of structural remains, that were documented across the island.

While these summary results and case studies highlight coarse patterns and rough statistics, they spotlight the extent to which the landscapes of small islands in the Cyclades were transformed to maximize agricultural potential, either for local consumption or as part of larger economic networks. Evidence for production and processing of the cereals under cultivation is quite often documented on the same island, in the form of threshing floors (documented on Aghios Loukas, Kitriani, and Prasonisi), grinding or mill stones (documented on Kitriani and Strongylo), and bread ovens (documented on Aghios Loukas). However, on islands where these features are absent, we can infer either the need to transport these goods for production or a lack of surface preservation of these features. Finally, we note that the numbers in Figure 9 would look quite different if they were based only on in-field documentation, which mapped only a fraction of the terrace systems on Dryonisi, Strongylo and Kitriani (see Figure 5; recognition rates were more comparable on Aghios Loukas). The application of lidar, therefore, changes the interpretation of these islets considerably in terms of their function, productivity, and history of settlement and use.

Questions of chronology

In addition to the interpretive contributions that these data provide for discussions of land use, post-fieldwork analyses raise new questions concerning chronology. In particular, artifact data may provide insights on the chronology of landscape features like terrace systems; lidar alone may allow us to discern phasing in the form of earlier substructures and the extension of existing features. Much of this information is difficult to comprehend on the ground and comes out only in the post-fieldwork processing of artifact data, viewed side-by-side with feature and lidar documentation.

One notable example pertains to a pastoral complex on Dryonisi. Structural walling was identified in the field, suggesting a single, open construction, for which the ceramic assemblage in and around the structure suggested a Byzantine date. Lidar analysis of the island revealed additional areas of walling around the structure, expanding the area of interest to a broader complex with at least two areas of pastoral enclosures in addition to the field-identified structure (Figure 10). These pastoral areas are certainly related to the structure, although it is unclear whether their construction was contemporaneous or represents a different phase. Regardless, their identification allows us to refine our understanding of the feature's chronology. While the ceramic data from the structure itself comes from multiple periods, with the Byzantine period as the best represented, the assemblage from the complex as a whole dates predominantly to ancient and prehistoric periods. The expanded area of the complex may therefore indicate an earlier phase.

A second case study concerns Aghios Loukas, where landscape modifications, especially in the form of terrace networks, are widespread (Figure 12). Many such terraces were identified in the field, especially in the central and eastern areas of the island and were initially considered early modern to contemporary constructions. Post-fieldwork lidar analysis filled in and expanded these networks

[20] Levine *et al*., forthcoming.

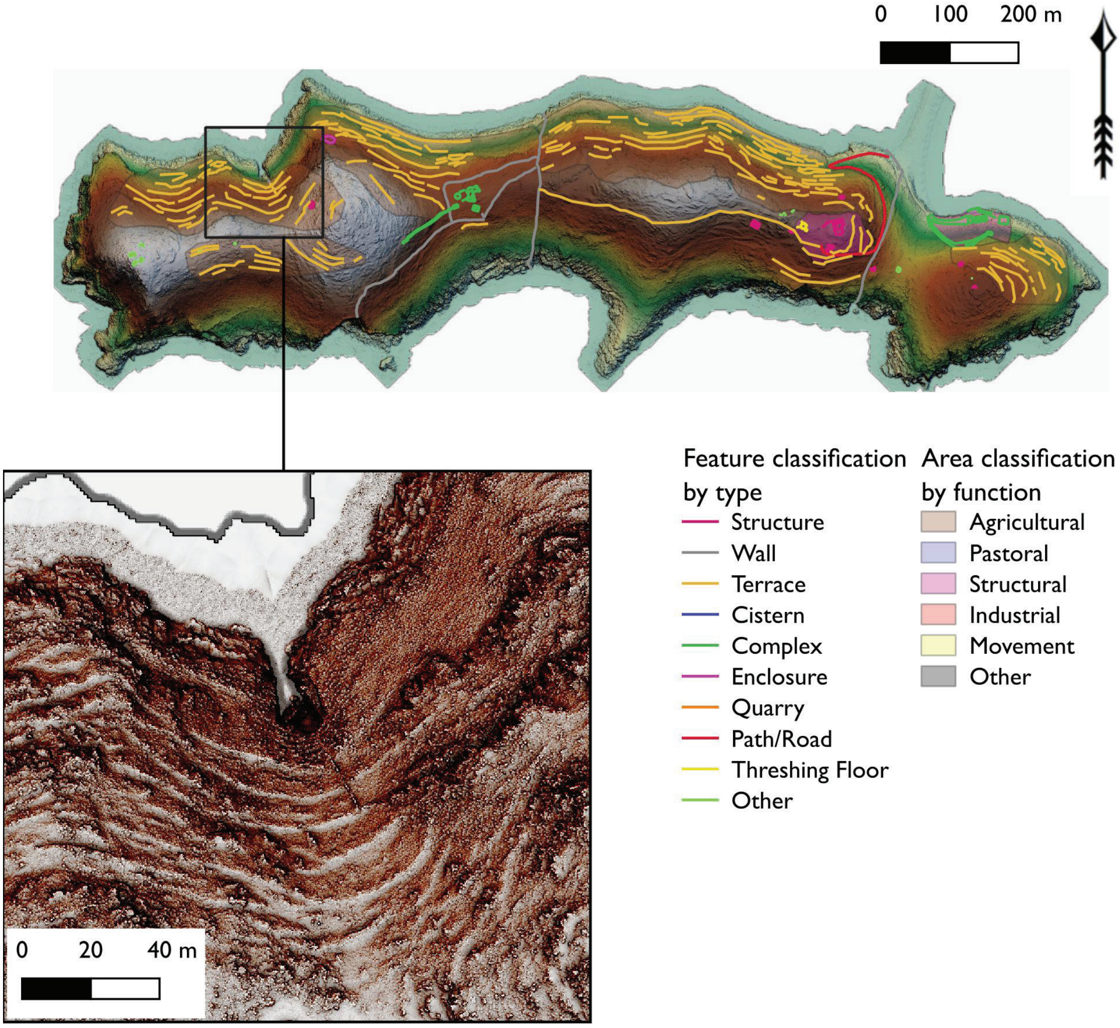

Figure 12. Aghios Loukas, showing the lidar classification, with an inset indicating possible phasing.

considerably, as lidar visualizations captured the topographic alterations caused by these terraces and facilitated the recognition of subterranean or otherwise obscured terraces. Fieldwork on the western part of the island revealed very little pottery, with only four diagnostic sherds collected across 20 survey units (prehistoric and early modern in date), as well as four of the island's 22 identified lithics. Likewise, few terraces were identified in the field. Lidar analysis, however, revealed widespread terraces throughout the area. In particular, we detected surface signatures of covered subterranean segments of terracing beneath visible, modern walls, suggesting that the terraces may predate the recent period in which the visible wall was constructed. Although precise chronologies cannot be established without excavation, the presence of prehistoric pottery, early modern pottery, and prehistoric lithics points to potential for a broadly diachronic system of terraces, perhaps constructed earlier than is typical for such features. Should this be the case, it invites reconsideration of the island as a whole. What were initially thought to be modern terraces may be in fact much older systems, actively maintained and reused in recent periods.

A final point on chronology concerns combining artifact collections from archaeological survey with lidar interpretation. On Kitriani, modern features also have extensive artifact scatters from the modern period; these are depicted as the purple dots in the area of the Byzantine to modern church complex (Figure 13). Modern material is also present amidst the terrace systems of the island, though earlier ceramics from the Classical, Hellenistic, and medieval periods are much more common, suggesting long-term use of a significant form of landed capital.

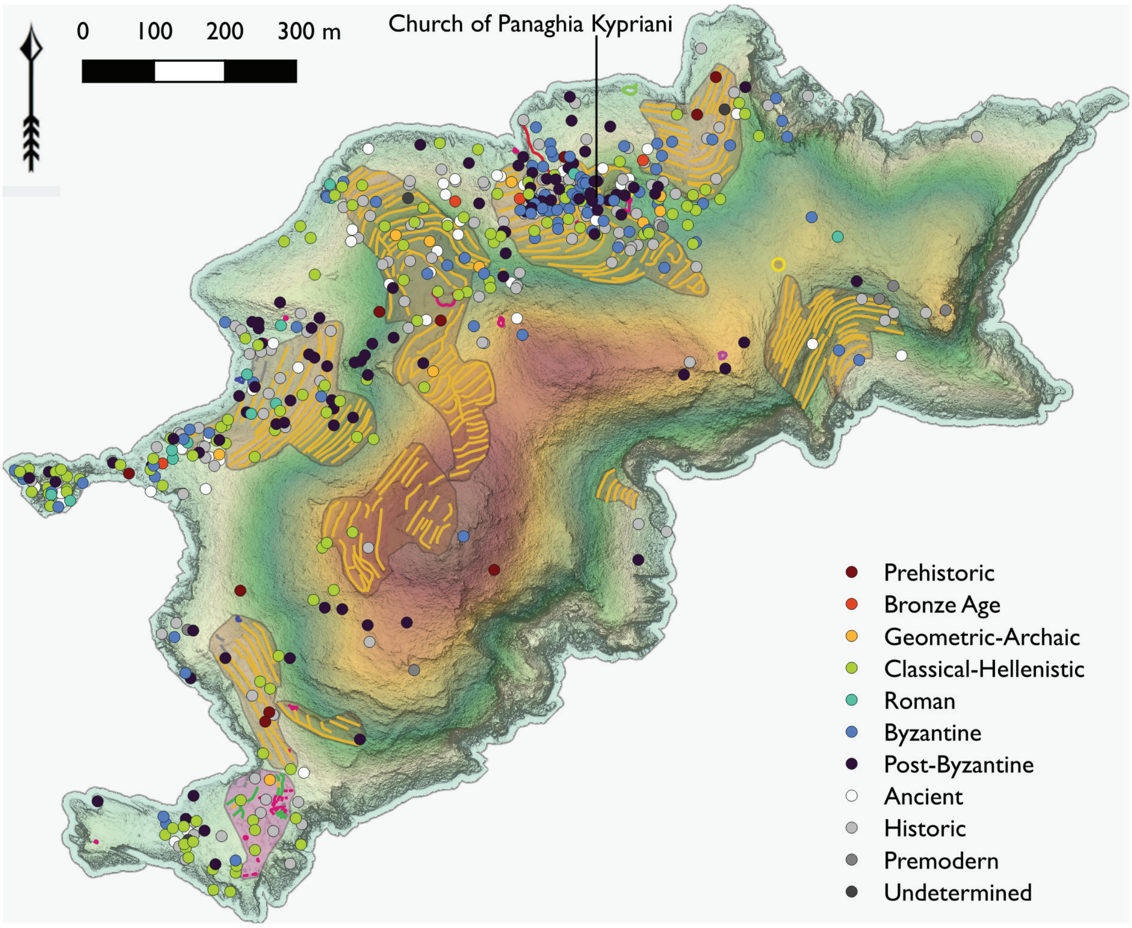

Figure 13. Kitriani pottery chronology and features.

In order to account for chronological uncertainty in the surface assemblages of the island, we divided ceramics into broad groups, according to the level of chronological resolution possible (Figure 13). Associated pottery and feature morphology were then used assign the following chronological categories to archaeological features: Prehistoric (7000 BC–700 BC), Ancient (700 BC–AD 650), Medieval (AD 650–AD 1800), and Early Modern (AD 1800–AD 2000) (Figure 14).[21] On Kitriani, initial fieldwork revealed only one terraced area, measuring approximately 1.8 ha. Collected pottery in that zone suggested activity across several earlier periods, while more recent material is largely absent. Lidar analysis allowed us to map eight additional terrace systems. When combined with the one field-identified area, these nine areas of terracing total approximately 19ha (Figure 4). While Early Modern to Modern pottery is attested in most of these zones, earlier periods are much more prevalent. The retroactive application of lidar analysis, combined with ceramic data, extends the potential duration of anthropogenic activity in agricultural areas and raises new questions concerning diachronic use and reuse of agricultural spaces.

Finally, and perhaps not surprisingly, there is a positive correlation between chronological recency and visibility in lidar data. Rates of particularly high relocation (when features first found in the field are also recognized in the lidar) begin in the medieval period; of the previously identified medieval, modern, and contemporary features, almost 90% are relocated (Figure 14). For older features, relocation rate drops considerably. Just more than half – about 52% – of ancient features are relocated, while fewer than 42% of prehistoric features are relocated. Note that this does not include features with ambiguous or multiple chronologies, such as the extensive terrace systems we have discussed.

[21] Cloke *et al* 2023.

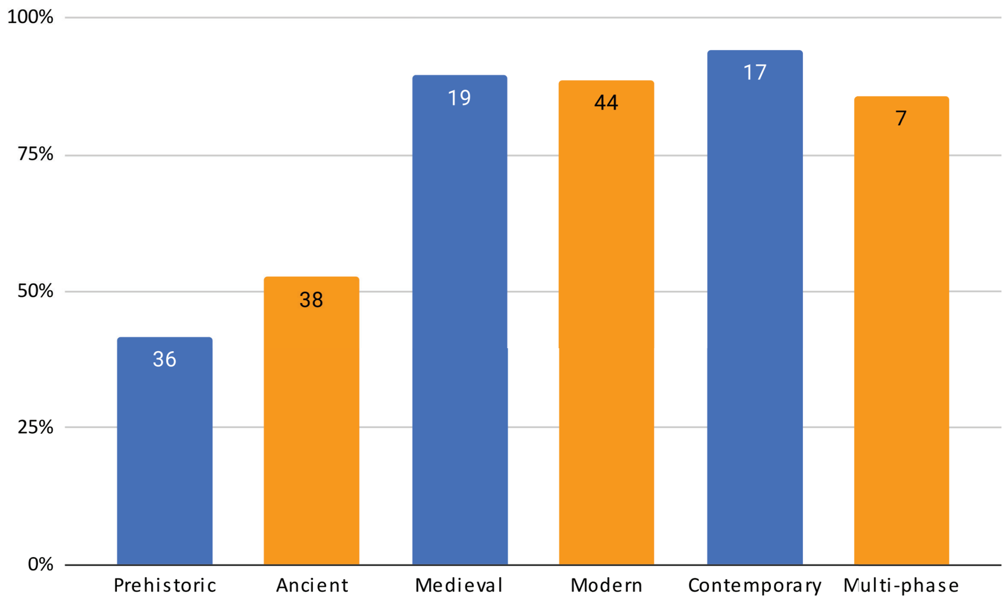

Figure 14. Relocation rate (whether a feature documented in the field was recognized in the lidar data) for archaeological features that could be assigned a chronological period; rate is expressed as a percentage, with the total number of features in each category given as an integer.

Conclusions

We can conclude that lidar provides significant 'value-added' benefits to archaeological surveys, even after the fact, but that pedestrian survey remains essential for the identification and description of many types of features. At the same time, regional-scale lidar coverage allows us to carry out new types of quantitative and qualitative geospatial analyses, especially with respect to large-scale landscape modifications and inter-island comparison. These comparisons look considerably different than they would if they were made using data derived from fieldwork only or even from other types of remote sensing. The high-resolution elevation data provided by ALS can also provide chronological insights, especially concerning the phasing of palimpsest-like archaeological landscapes. As we look ahead, there is much more work to be done in parsing some of the finer elements of analysis, concerning both phasing and signatures that can be tied to certain chronological periods.

Obvious benefits aside, lidar is not a cure-all and does not replace other forms of remote sensing, especially at a small scale. We have found aerial lidar to be particularly useful at a meso-scale or landscape-scale – somewhere between identifying big sites across regions and detailed architectural documentation – where it offers data-rich opportunities for analysis. In closing we note that all of the places we have presented in this paper are quite small – in aggregate they offer a unique perspective on a particular type of marginal environment across the Cycladic archipelago. This type of analysis has not been applied in the larger, inhabited islands of the Cyclades, which would offer new questions and new opportunities for comparison.

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