Abstract

This paper explores the advantages of using satellite remote sensing and GIS to identify ancient land divisions in the eastern Mediterranean by studying the organisation of modern agrarian landscapes. Since current land divisions sometimes retain the arrangement of an older system, either wholly or partially, remote sensing methodologies have been successful in distinguishing ancient demarcations, especially Roman centuriation. This study places emphasis on techniques to recover past landscapes around settlements where the correlation between modern agrarian divisions and a potential ancient system is not clear from visual interpretation. Within GIS the dominant orientations of modern agrarian fields are analysed and presented as histograms which show general trends in the organisation of land. These methodologies are applied in two case-studies where the evidence for an ancient urban or rural land division is not well-defined: Mantinea, a classical Greek city in the Peloponnese, and Aphrodisias, a Late Hellenistic foundation in western Anatolia. The histograms identify trends in the organisation of modern fields that might mark the presence of an ancient system of land demarcation. The data from Mantinea show that the majority of modern agricultural fields inside the fortification walls have dominant orientations identical to the alignments of excavated buildings and a series of streets revealed through geophysical survey. Likewise, there is evidence at Aphrodisias that rural land outside the fortification walls share orientations with urban features inside the city. Both examples show that an analysis of the dominant angle frequency of modern land divisions is useful for reconstructing the archaeomorphology of ancient landscapes in the eastern Mediterranean.

Keywords: Remote Sensing, GIS, Urban History, Land Division, Mediterranean Archaeology

Introduction

Remote sensing methodologies have been widely employed since the middle of the twentieth century to identify and study ancient land divisions around the Mediterranean and neighbouring regions. Aerial photography was a forerunner in targeting organised systems adopted by the Greeks and Romans, including orthogonal city streets and rural farmland (Castagnoli, 1956; Ward-Perkins, 1974). In certain conditions, vegetation stress caused by buried streets or other anthropogenic linear demarcations can potentially appear as vivid “crop marks” or “soil marks” on the surface. Although pioneered by standard aerial photography, this method of remote sensing has since expanded to include multispectral satellite sensors and Remotely Piloted Aircraft Systems (RPAS) fitted with infrared cameras that can identify linear surface anomalies in different spectral band combinations and specifically those invisible to the human eye (Donati & Sarris, in press). At the
same time, remote sensing has been successful in recognising ancient patterns of land demarca-
tion by studying the alignments and metrology of features in modern agrarian landscapes. Initially,
research focused on instances where modern land divisions were largely unaltered from Classical
Antiquity and therefore could be distinguished fairly easily with basic photo interpretation. Nu-
merous Roman centuriation systems in Western and Central Europe have been identified in this
way (Chouquer & Favory, 2000; Clavel-Lévêque, 1983; Montufo, 1997) as have a handful of Greek
systems in places such as South Italy and the Crimea (Carter, 2006; Smekalova & Smekalov,
2006). Beyond basic photo interpretation, methods to develop computer-based applications to study
the morphological dimensions of ancient agrarian landscapes from aerial images were first explored
by the Optics Laboratory of the University of Be-
sançon (France) in the 1970s and 1980s (Chouquer et al, 1987; Charraut, Favory & Raynaud, 1992;
Charraut & Favory, 1993). More recently, GIS has allowed researchers to expanded this line of study
and experiment with automated processes to de-
tect patterns not obvious from photo interpretation (Clavel-Lévêque, Vassilopoulos & Evelpidou, 2001;
Romano, 2003). This includes vector-based GIS
software that transforms features from aerial and
satellite imagery into vector data that can be ana-
lysed (Vassilopoulos, 1999; Clavel-Lévêque, Vassi-
lopoulos & Evelpidou, 2001). In addition, digital
archives with cadastral data in vector format are
available in many European countries and, used
in tandem with aerial and satellite data, they are
often valuable in targeting large areas in GIS (Gugl,
Doneus & Doneus, 2008). Nowadays, multidiscipli-
nary approaches are a common element of ancient
land division studies (Palet & Orengo, 2011). Field
survey and geophysical prospection offer archae-
ological evidence on the ground to supplement
and expand upon the findings of airborne remote
sensing. Epigraphy and documentary research can
be beneficial in contextualising the inherently dia-
chronic nature of these anthropogenic landscapes
from Classical Antiquity to today.

The present study identifies ancient land divi-
sions by utilising high-resolution satellite imagery
to study the orientations of modern agrarian field
divisions and generate histograms capable of
revealing patterns in the landscape. Like previous
studies that use digital applications to the same
effect, this method works on the basis that those
modern agricultural fields have the potential to re-
fect ancient land divisions. As others have noted,
there are indeed limitations on the reliance of ori-
entation and modulation analyses in the identifica-
tion of ancient land divisions without some degree
of ground truthing and archaeological and histor-
ical contextualisation (Leveau, 2000; Palet, 1997).
These shortcomings can be alleviated in part by
other methodologies, including ground-based
geophysical prospection, targeted excavations,
and field survey. Despite some striking examples
where the boundaries of modern agricultural
fields clearly follow an ancient system, in most in-
stances an obvious correlation is lacking because
land use has gradually changed over the centu-
ries. If there is a relationship to be found, satellite
remote sensing is well-suited as a starting point
of reference to extract this information regardless
of the level of site preservation and subsequent
occupation.

In order to demonstrate the advantages of
satellite remote sensing, this study investigates
two settlements in the eastern Mediterranean.
The first, Mantinea, was a Greek settlement in
the Peloponnese that was occupied more or less
continuously from the fifth century BC through the
Roman period. The other in Turkey, Aphrodisias
was a Greek foundation in the second century BC
that became an important regional centre in the
Roman Empire. For the purpose of better under-
standing and identifying ancient land divisions
using remote sensing and GIS applications, the
two settlements are ideal because
1)  the cities are largely surrounded by agricultur-

al fields,
2)  the evidence for an ancient system of urban or
rural land division remains inconclusive from
photo interpretation of aerial and satellite im-
agery, and
3)  previous archaeological fieldwork and espe-
cially geophysical prospection can be used as complimentary data.

It is worth emphasising that considerably fewer examples of ancient systems of rural land division are known from the eastern Mediterranean, and even rarer are pre-Roman examples. One reason for this circumstance is the greater emphasis on studying archaeolandscapes in Western and Central Europe, where, among other factors, aerial imagery and digital data are more readily available to the researcher. This obviously creates an imbalance in established perspectives on Greek and Roman land use patterns. The geographical focus of the case-studies presented here aims to partially alleviate this disparity in current scholarship.

Methodologies

High-resolution multispectral satellite imagery of submeter resolution, such as GeoEye-1, Quickbird, WorldView-2, and WorldView-3 are ideal datasets for analysing modern agrarian land divisions. The clarity of ground features is compromised with satellite sensors of inferior resolution quality, such as Landsat 8 with a resolution of 15 m panchromatic and 30 m multispectral. Compare this to WorldView-3 which has an optimal resolution of 0.31 m panchromatic and 1.24 m multispectral. From the satellite datasets, modern land divisions can be digitised and converted into vector data, either polylines or polygons. Regrettably there are no automated methods that seamlessly transform land divisions from raster datasets into reliable vector data, despite the progress made by some in this direction (Clavel-Lévêque et al, 2001; Vassilopoulos, 1999). This is primarily the result of an imperfect process with vector-based GIS software that cannot authentically represent the boundaries of agricultural fields in every instance. Various filters and classifications can be applied to the satellite imagery to enhance land divisions and reduce peripheral noise from modern features and vegetation (e.g. directional filtering, non-directional edge enhancement algorithms). However, one should expect a certain degree of artefact noise and inconsistencies in the ensuing vectorisation process when using vector-based GIS software. These issues vary from site to site and can be partly resolved with manual editing in GIS to eliminate excess data and to correct any errors. In sum, automated vector software is highly useful to create accurate field boundary divisions but they cannot (as of yet) be absolute replacements for visual assessment and manual editing.

Once in digital format, modern land divisions can be analysed for trends in their dominant orientations. In the two examples here, all agricultural fields within a 2 km circular zone (12.56 m²) around Mantinea and Aphrodisias, and all agricultural fields inside the fortification walls at Mantinea, were included in the data analysis. This is a rather small target area compared to similar surveys elsewhere in Europe (Gugl, Doneus & Doneus, 2008) where digital cadastral maps and other large-scale vector maps are more widespread. The absence of parallel datasets from eastern Mediterranean lands, including Greece and Turkey, is but one reason why this region remains marginalised in the current direction of research. The aim at both settlements was to study the morphological characteristics of the urban and immediate rural hinterlands in light of known orthogonal street systems inside the cities. Geophysical survey carried out at Aphrodisias in the 1990s and at Mantinea in 2014 demonstrate that the two cities were planned settlements but a potential land division outside the fortification walls still remains a question mark. If a field was only partially inside the 2 km target zone, its entire extent was incorporated in the study. Two calculations were applied to each field represented as a polygon in ESRI ArcGIS:
1) total area was measured in hectares, and
2) the dominant angle was calculated and assigned specific values with the “Calculate Polygon Main Angle” tool.

The second step provided the input data for studying the dominant orientations of the agricultural fields and other manmade land use areas. Once processed, the data were exported into a spreadsheet for further statistical analysis and the creation of histograms.
Fig. 1. Mantinea from Quickbird 13 September 2003 © 2015 DigitalGlobe.
The histograms show the frequency percentage of each dominant angle from 0° to 180° as a weighted ratio of a field’s area divided by the total study area. In this way, the orientations of larger fields have higher weighted values than smaller fields. The dominant angles were also regrouped in bins spanning every five degrees. So, for example, angles from 18° to 22° were reclassified as 20°, those from 23° to 27° as 25°, and so on. The use of bins evens out the histograms to display general trends rather than absolute values.

Mantinea

Mantinea was an Arcadian settlement in the Peloponnese established sometime before the middle of the fifth century BC. The known archaeological features include the elliptical fortification walls, 4 km in circumference, and the agora and theatre at the centre (Hodkinson & Hodkinson, 1981). These were the focus of archaeological investigations by the French School at Athens from 1887-89 (Fougères, 1898). Very little of the remaining urban area inside the fortification walls (119 ha) has been excavated and today the site is predominantly covered by agricultural fields. Satellite remote sensing and geophysics, carried out by a research team including the present author from the Laboratory of Geophysical, Satellite Remote Sensing and Archaeoenvironment (IMS-FORTH), identified an extensive orthogonal street system inside the fortification walls (Donati & Sarris, in press; Moffat et al, 2015). The streets detected, with few exceptions, have orientations near the cardinal points. East-west streets have a median orientation of 89.5° and north-south streets have a median orientation of -0.5°. Before this work, no evidence existed for town planning at Mantinea. Satellite remote sensing was implemented to study the arrangement of agricultural fields inside the fortification walls and to see whether they correspond with the recent fieldwork data. Furthermore, the immediate rural territory outside the city walls was analysed for a possible rural land division.

The dataset used to calculate the dominant field orientations at Mantinea was a high-resolution (panchromatic 0.63 m; multispectral 2.50 m) multispectral Quickbird image from 13 September 2003 (fig. 1). The total number of fields digitised inside the fortification walls numbered 217, while 1,610 were included within a 2 km radius outside the fortification walls. Total coverage was approximately 105 ha or nearly 90% of the 119 ha area inside the city walls and 883 ha or nearly 78% of the 1,137 hectare area outside the city. Certain regions were not included, such as the fenced area that encloses the archaeological park, pockets of seasonal lakes and streams with curvilinear edges and the uncultivated foothills east of the settlement.

Histograms

The histogram produced from the 13 September 2003 Quickbird show interesting trends in the organisation of modern agricultural fields (fig. 2). The vast majority of fields inside the city (black line) have dominant orientations very close to true north-south and east-west. More precisely, the data indicate that three-fourths (74%) of fields cluster in narrow ranges spanning 85°-90° E-W and 175°-180° N-S. Fields within the urban zone of Mantinea are unmistakably organised along the cardinal points with an emphasis on an axis slightly west of true north. There is a wider range of field orientations (red line) outside the city walls. Here, 36% of fields cluster in the same narrow range of 85°-90° E-W and 175°-180° N-S. Extra-urban field orientations appear to slant more frequently as much as ten degrees further to the west than those inside the city.

Interpretation

Do the above results bear any relationship to a potential system of ancient land division? This would certainly seem to be the case inside the city where dominant field orientations are concentrated in ranges that mirror the orthogonal grid of the an-
cient city. In this instance, the histogram comple-
ments quite well the results from satellite remote
sensing and geophysical prospection, serving as a
good example of how various remote sensing and
GIS based methodologies can be used in tandem to
identify patterns of ancient land organisation. The
histogram reinforces the conviction that Mantinea
was a planned settlement with streets arranged
slightly west of true north. One could still argue
that the resemblance between ancient and mod-
ern land use at Mantinea is a mere coincidence but
this does not explain why fields outside the forti-
fication walls diverge more from the urban street
system. Outside the city the evidence is not as
overwhelming since less fields as a percentage of
the total (36% compared to 74%) closely match the
urban grid (fig. 3). This does not necessarily mean
that the immediate rural territory of Mantinea
was not organised in Classical Antiquity, only that
there is less correspondence with the city plan. To
be sure, clusters of fields particularly to the east,
west, south, and southwest have dominant orientations
near the cardinal points (red) but they are inter-
mixed with fields having northwest to southeast
orientations (green) that account for 38% of the
total. Different factors seem to have influenced
two systems of orientations. One could plausibly
be related to the ancient city grid but rivers and
seasonal streams, pre-existing road systems in
the valley, post-antique land use or other environ-
mental factors could equally have played a role.
The exact nature of a rural land division at Mantin-
ea, if indeed it did exist, must be further addressed
with additional fieldwork.

**Aphrodisias**

A geophysical survey carried out from 1995 to 1998
showed that Aphrodisias in western Anatolia was
a grid-planned settlement where streets were
orientated slightly west of true north (Ratté &
Smith, 2000: 223-25; 2004: 146-47; Smith & Ratté
of urban space was closely followed, as shown by
archaeological excavations, by several monuments
within the city. Although literary sources indicate
that the foundation of Aphrodisias took place in the
second century BC, fieldwork dates the urban grid
to the second-half of the first century BC (Ratté,
2008; Ratté & Smith 2000: 221-22). The urban grid
remained unaltered until the abandonment of the
city in the seventh century AD. One significant
addition during this interval was the construction
of Late Antique fortification walls (De Staebler,
Fig. 3. Modern agricultural fields at Mantinea showing those that closely follow the ancient urban street system (red) and those that slant further west (green).
Outside the city walls, the rural territory of Aphrodisias was largely ignored until the Aphrodisias Regional Survey initiated a five year campaign from 2005-2009 to better understand the wider dynamics of occupation and land use in the region (Ratté & De Staebler, 2012). Among other features, the survey found evidence for fortified settlements that predated the foundation of Aphrodisias, Roman marble quarries, monumental tombs, farmsteads, and olive production sites. However, the evidence, either positive or negative, for a rural land division still remained unclear. An earlier attempt through photo interpretation of SPOT satellite imagery (resolution panchromatic 10 m; multispectral 20 m) also proved inconclusive (Guy, 1996). The target of remote sensing was to study the arrangement of agricultural fields in the immediate rural hinterlands of Aphrodisias. The urban area was not explored since the archaeological zone has relatively few agricultural fields.

A high-resolution (panchromatic 0.60 m; multispectral 2.40 m) multispectral Quickbird image from 29 September 2003 formed the main dataset for analysis. Apart from small farming villages, modern land use is predominantly agricultural with a scattering of roads and farmsteads. The number of polygons extracted from Quickbird numbered 1,412. The area was further subdivided into four separate regions (southeast, southwest, northwest, northeast) so that distinct areas of Aphrodisias could be examined more closely. The total coverage area of the polygons came to 989 ha, or almost 80% of the 1,256 ha zone. Land inside the fortification walls was not included in the study, as well as the village of Geyre (built in the 1950s), an uncultivated hilly region to the northeast and pockets of rivers and streams with curvilinear edges.

Histograms

A series of histograms produced from the 29 September 2003 Quickbird image show remarkable trends in the organisation of modern fields (fig. 4). One clear tendency is that the rate of dominant orientations of all fields (black line) in the target area steadily increases toward the cardinal points, peaking at 160°-180°/0°-10° N-S and 70°-100° E-W. These ranges account for two-thirds of all fields at Aphrodisias inside the 2 km target zone. The highest concentration of dominant angles falls between 160°-180° N-S (32%) and 70-90 E-W [16%]. The data indicate that the majority of modern fields have more or less north-south and east-west alignments with an emphasis on orientations slightly west of true north.

The orientations of fields in the southeast region (green line, bottom) are consistent with the general trends noted above. Yet in this instance, the range of dominant angles clusters more closely around the cardinal points and there is a conspicuous drop off in the frequency of angles beyond true north-south and east-west. More than two-thirds of the dominant angles in the southeast region range between 170°-180°/0°-10° N-S and 80°-100° E-W. The numbers peak at 175°-180° N-S and 85°-95° E-W, which account for 50% of the total. Like the data from all field boundaries, the majority of southeast fields have north-south and east-west alignments with an emphasis on orientations just west of true north.

The southwest region (red line, bottom) produces somewhat different results. Instead of two upturns along the cardinal points, the data indicate that just over half of the dominant angles fall between a narrow range of 160°-175° N-S. There is a considerable decrease in the frequency of angles beyond this scope. To a certain extent, these readings are comparable with the data from all field boundaries and the southeast region, where high frequency ranges of 160°-180° and 175°-180° respectively demonstrate the abundance of orientations slightly west of true north. In the southwest region, the dominant angles cluster a bit further to the west and there is a sharp drop in the percentage of field boundaries aligned at true north-south. This implies that different factors influenced the arrangement of southwest fields at Aphrodisias.

There is no clear orientation or groups of orientations that predominate in the northwest region.
In fact, if the data collected elsewhere denote groups of specific alignments, quite the opposite is true in the northwest. The region serves as a useful contrast, since it shows that the orientation of fields adjacent to one another potentially can show great variation. In this instance, the precipitous topography around the local foothills north of Aphrodisias and a river flowing through a narrow gorge appear to have influenced the morphological dimensions of fields. The landscape rises steadily only 500 m north of the city and the contours become steep beyond 1 km. If an organised system of rural land did exist at Aphrodisias in Classical Antiquity, it probably did not extend very far into the rural territory northwest of the city.

Data from the northeast region (green line, top) reveal a sequence of fields with diagonal orientations approximately 10°-30° N-S and 95°-120° E-W. These ranges account for 60% of the total. The north-south and east-west alignments in the southern region of the Aphrodisias valley are completely lacking here. Instead, the northeast fields maintain a peculiar diagonal alignment that slants downward from the northwest to the southeast.

Interpretation

Three of the four regions at Aphrodisias (southeast, southwest, northeast) indicate that modern agricultural fields were by and large arranged according to a system of shared orientations. Whether this is evidence for a prearranged scheme, such as a rural land division in Classical Antiquity, or a coincidental occurrence is an issue that is open to debate. Another noticeable trend is a contrast between regions that have dominant angles close to the cardinal points (southeast, southwest),
and those that do not (northwest, northeast). The ancient urban grid, oriented a few degrees west of true north, bears relationship to the orientation of agricultural land in the southeast and southwest regions (fig. 5). While this evidence does not provide definitive conclusions, it does raise the prospect that modern agricultural fields south of Aphrodisias preserve certain structural characteristics of the ancient landscape that were influenced by the urban grid. To be sure, the lack of uniform groupings of rectilinear agricultural plots forestalls the identification of a conventional rural land division at Aphrodisias. It would be useful to explore alternative models of Greek rural land organisation that display variable forms for comparable purposes but the archaeological evidence is still limited in this respect.

The most surprising data from the histograms were the range of diagonal orientations in the northeast region. Here, alignments contrast starkly with other regions in the target area and bear no relationship to the urban grid. One possible explanation is that the local topography is different here. The northeast region is divided into two parts by the southern extension of the local foothills. Therefore, it is likely that the diagonal orientations were dictated by topographical factors. On the other hand, the diagonal orientations share similarities to features inside the city. The Sebasteion, an early Roman imperial complex dating to the first century AD, and a series of roads and structures have similar diagonal orientations of approximately 10° N-S and 100° E-W. Urban features with these diagonal orientations are so far exclusive to the eastern region of Aphrodisias. The reasons for this discrepancy are still unclear. More clearly, however, is that the histograms identify a potential relationship between urban and rural land east of the city. The seemingly unusual diagonal orientations in the northeast region stand adjacent to where the same orientations exist inside the city.

In many ways, the data at Aphrodisias raise more questions than they answer. If the histograms do suggest the presence of a system of rural land division, then clearly not all regions of the Aphrodisias valley were neatly aligned to the ancient urban grid. The notion of a master grid extending into the countryside and laid out according to the dimensions of city-blocks finds little support in the present study. However, the data show that regional variation was perhaps a factor at Aphrodisias. Future archaeological fieldwork will hopefully shed further light on this matter.

Conclusion

The evidence presented here highlights the advantages of integrated remote sensing and GIS applications to uncover patterns in ancient land usage. The histograms produced from these case-studies offer some evidence, where little existed before, that urban and rural land was planned. In particular, geophysical prospection within the urban quarters at Aphrodisias and Mantinea help clarify and support the data from satellite remote sensing. At Mantinea, the correspondence of modern field boundary alignments inside the fortification walls and the buried orthogonal street system is unambiguous. Field alignments were clearly adopted from the earlier system of land organisation. Beyond the urban zones at Mantinea and Aphrodisias, the histograms reveal interesting regional trends in the organisation of rural land that are both similar to and divergent from urban features. Such variation should be expected, since rural land divisions in Classical Antiquity did not inevitably follow the established urban system. Both topographical conditions (e.g. terrain, hydrological features) and anthropogenic factors (e.g. pre-existing road networks, tombs) could have had an impact on the structure of these archaeolandscapes. Nevertheless, there is still little supporting evidence from fieldwork at both settlements to fully grasp the precise morphology and chronology of the rural field systems. In many ways, the integrated satellite remote sensing and GIS applications used and recommended here should only be considered as starting points for further research, in both traditional fieldwork and digital methodologies. At the very least, the data can and should assist the direction and findings of any future archaeological undertakings.
Fig. 5. Modern agricultural fields at Aphrodisias showing those that closely follow the ancient urban street system (red) and those that slant further west (pink).
References


Donati JC & A Sarris (in press): Evidence for two planned Greek settlements in the Peloponnese from satellite remote sensing, American Journal of Archaeology, 120(3).


Montufo AM, 1997. The use of satellite imagery and digital image processing in landscape archaeology. A case study from the island of Mallorca, Spain, Geoarchaeology, 12, 71-85.


