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Satellite Imagery and GIS applications in Mediterranean Landscapes

1 Introduction

Following the early seventies, when satellite imagery first became readily available, a wide range of professionals, including archaeologists have attempted to utilize satellite images in environmental sciences. An early example of the use of satellite imagery includes that by Quann and Bevan (1977) which identified the Egyptian pyramids from such imagery. However, such examples emphasize the limits of such images — the spatial resolution of the image is usually far larger than the average archaeological site. Satellite images have therefore not been very useful for detecting the direct location of archaeological sites. Despite this, these images can be of enormous help. Archaeologists can use them to define physiographic regions, soil zones etc., and when this data is integrated within a GIS and combined with our knowledge of archaeological sites and distributions, a variety of analyses can be performed on the data (Limp 1987; Lyons/Scovill 1978: 9).

Within GISs, satellite images are treated as a data input source. Where cartographic information is not available or is not of high enough quality, the use of such images is frequently a useful alternative. Any individual can purchase a multi band image of the area of the earth they are interested in and, if used correctly, such images can provide an enormous amount of information about the environment.

The principal subject of this paper is to discuss the use of satellite imagery within archaeological landscape studies and to present some recent results of such work. One such study has been carried out in the central Adriatic where an international team of archaeologist, historians, geographers and other specialists has been studying the archaeology of the Central Dalmatian islands (Croatia) for more then a decade (fig. 1). This research has included the analysis of settlement patterns, colonization, contacts, land use and economy of the prehistoric, protohistoric, Greek and Roman communities who lived in the area. The archaeological data for this work was gathered through field surveys of the islands and extensive archive research. The natural environment data (when available), was largely supplied as thematic maps which were frequently unsuitable for detailed analysis. These contrasts are exemplified by the situation relating to detailed soil maps in the area. That for the island of Hvar (Gaffney/Stančič 1991) was extremely detailed with a refined classification and plotted at a scale of 1:25,000. Unfortunately no other island, with the exception of the island of Brač, possessed such maps. The situation clearly limited comparative analysis between the islands. Satellite imagery therefore suggested itself as an alternative source for such data.

2 Methodology and classification techniques

The classification of Landsat data for the purposes of defining soils and land use categories is invaluable for interpreting agricultural potential, a variable which is frequently used in archaeological landscape studies. The objective of image classification is to identify and portray the image in terms of the object or type of land cover under study. Image classification is probably the most important part of digital image analysis.

Basic to the understanding of multispectral classification is the concept of the spectral signature or spectral response of an object on the ground. The spectral response for a given object is a measure of the amount of electromagnetic radiation it reflects as a function of wavelength. The reflectance of each cover type behaves differently across the wavelength spectrum (Mather 1989). In fact, these spectral responses are often sufficiently variable to enable spectral discrimination of each cover type. It is the apparent uniqueness of the spectral response of each object from which the term 'spectral signature' is derived: as each signature is assumed to be a unique identifier of its owner.

Unfortunately, when performing classification, you do not have the entire spectral signature in an image. Rather, you have a set of signatures that consists of reflectance in a few discrete locations (the bands of the imagery acquired). These incomplete signatures provide only a partial description of an object. The fewer the observations in the spectral signatures with which you work, the less likely it will be to discern an object's signature.

In general, the greater the number of bands or channels, the better the ability to discriminate between objects and classify them correctly. However, simply adding more bands of information does not necessarily yield improved results. Improvement will be recognized only if the

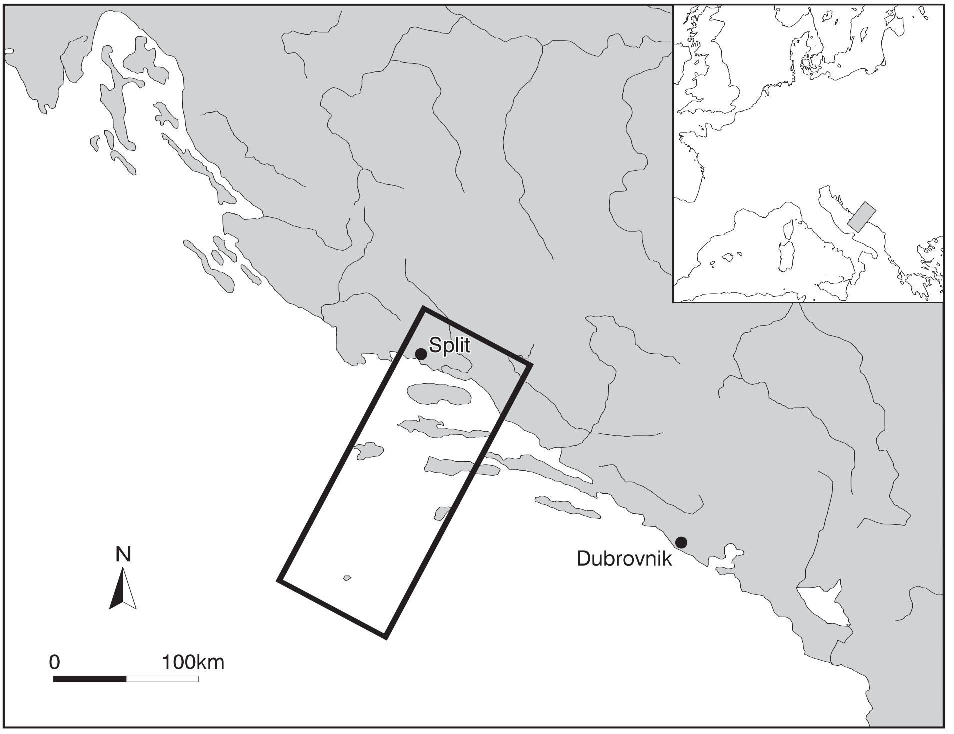

Figure 1. The study area.

additional bands represent new or different information. For this reason one should be wary of using spectral bands that are quite close in wavelength as it is unlikely that the spectral curve would be significantly different from adjacent band(s). Much of the time spent in performing a classification analysis is devoted to gaining an understanding of the spectral behaviour of features of interest in imagery and to determine the combination of bands that offers the greatest spectral separation between image features.

Automated image classification has traditionally been divided into supervised and unsupervised classification procedures. The primary distinction between these two approaches is the manner in which the spectral signatures are generated. In the supervised approach one locates samples of each cover type, in a number of bands, from which the computer can generate spectral signatures. In unsupervised classification, signatures are generated by mathematically grouping the n-dimensional spectral information (PCI 1994). Unsupervised classification is usually used to get an overview of data and provides quick results, for serious studies supervised classification must be implemented.

The process of image classification consists of three main parts:

1. signature generation and editing,
2. classification,
3. analysis and presentation of results.

The first task is done 'by hand' during supervised classification and automatically during unsupervised classification. There are several different algorithms for both classification techniques, which can be found in specialized literature on image processing, or in software manuals (see Mather 1989; PCI 1994). We shall not discuss the algorithms here, but it should be mentioned that these range from very simple, e.g. parallelepiped, to very sophisticated techniques which use neural networks and fuzzy logic. Even after classification it is likely that some further improvements can be made on the results and sometimes the procedure has to be repeated with different signatures, training areas or algorithms.

3 The Research

The project under discussion here needed data for the entire region of Central Dalmatia and it was decided to use Landsat TM images. Good quality thematic maps were available only for the island of Hvar and these data were used for a comparative study of the quality of traditional thematic data with that provided from satellite imagery. The Hvar data was compiled for the purposes of a local development plan (Bognar 1990) and included climatological, pedological and geological maps and settlement data. This data was prepared via traditional sampling procedures and was presented in paper format, but was converted to digital format by project staff.

It was intended that the work on Hvar would demonstrate the comparative value of using Landsat data for the purposes of environmental planning, whilst the work on Vis, Brač and other islands would demonstrate the application of new technologies where environmental data was absent. Land use and soil maps were not available for islands other then Hvar and Brač. The island Vis, for example, had been under Yugoslav military control and was closed to foreign visitors until 1991. Most information on the island, including environmental data, aerial photographs, detailed topographic and cadastral maps were classified as restricted. They are therefore not available. Archaeological field work was carried out during 1993 and 1994 to provide detailed archaeological data, and this information will be integrated with Landsat data as it becomes available. This should allow rapid evaluation of land use and the condition of cultural resources.

For purposes of analysis, the Landsat quarter scenes were split into subsets relating to individual island groups. These were:

1. Hvar and the Pakleni islands,
2. Vis, Biševo and Svetac,
3. Brač, and
4. Šolta.

Rectification and geo-referencing of each subset of the 1993 quarter scene was carried out in conjunction with available maps. Although a standard procedure, a number of specific problems was encountered. The only accessible maps available for transformation were produced at a scale of 1:50,000, larger scales being classified. Almost all the maps had been produced during the 1950s, with no major re-survey carried out after that date. It was therefore difficult to locate accurate ground control points that still existed and were not on the coastline (e.g., roads). Several map sheets also displayed a number of significant printing errors. The map sheet relating to the island of Vis was particularly inaccurate with respect to the southern coastline of the island. This latter problem was resolved by the use of ground control points on adjacent islands, i.e. on the island of Biševo. Although the results of such remedial action were adequate for the analysis, it would be desirable to acquire more accurate control points for registration.

Having transformed the 1993 images to a UTM coordinate system, the remaining images were registered using image to image classification. After preparation and geo-referencing, preliminary classification was carried out using the July 1993 image of Hvar. Hvar was chosen for classification because of the relatively large amount of available data for supervised classification. This included: documentation relating to the agricultural development of the island, aerial photographs relating to the Starigrad plain and a development plan completed in 1990 (Bognar 1990; Carter 1990; Poduje 1975).

Although a variety of unsupervised classifications were carried out using the Hvar data, the results were not such that they could be used uncritically. Consequently, supervised classification was carried out using the aerial photographs for the Starigrad plain as a source of training samples. On this basis a total of 7 landuse types were defined. These were:

1. urban areas,
2. areas of bare rock,
3. vineyards,
4. maquis,
5. pine,
6. pasture, and
7. flysch arable zone.

After the classification on Hvar was completed, satellite images of other islands were then processed. Whilst the results from Hvar could be widely used for other islands where there was very little land use data, the results could not be verified without further ground truthing. Despite these problems, it seems worthwhile to compare the results of the Landsat land use analysis with earlier comparative data on land use on Hvar published by Poduje in 1975 and the soil survey published by Bognar as part of the 1990 Hvar Development Plan. For these purposes the Landsat data has been reclassed, as shown in table 1, to allow comparison with earlier quantifiable data.

Table 1. Comparative landuse data for Hvar (area in hectares).

Land Use classes after Poduje (1975)

Arable	Pasture	Forest	Infertile
4,491	9,199	22,630	1,921

Landsat derived landuse classes

Arable	Pasture	Maquis	Pine	Open/Urban
4,928	4,212	10,232	3,997	7,954

Soil classes after Bognar (1990)

Very Good	Good	Poor	Very Poor
6,568	5,924	9,655	9,176

Landsat landuse reclassed for comparison with soil data

Very Good	Good	Poor	Very Poor
4,928	4,212	10,232	11,951

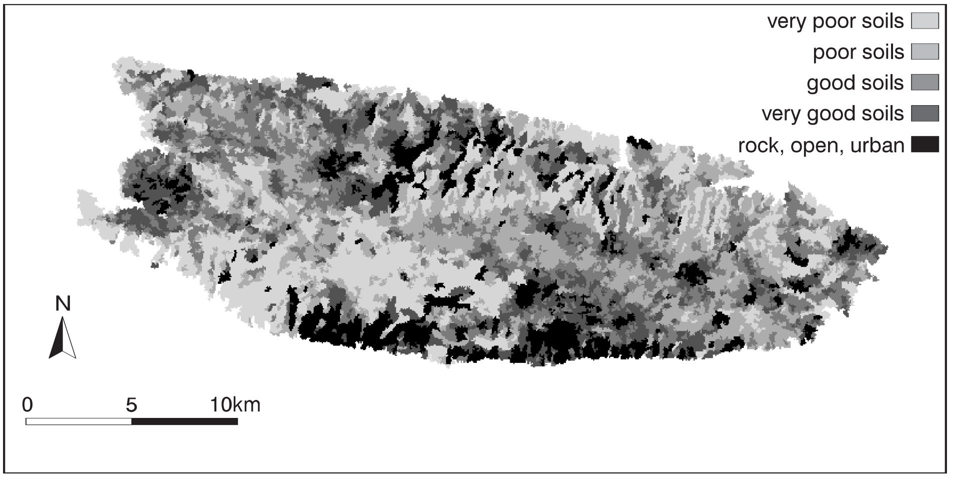

Figure 2. Classification results for July 1993 Landsat TM images of Brač.

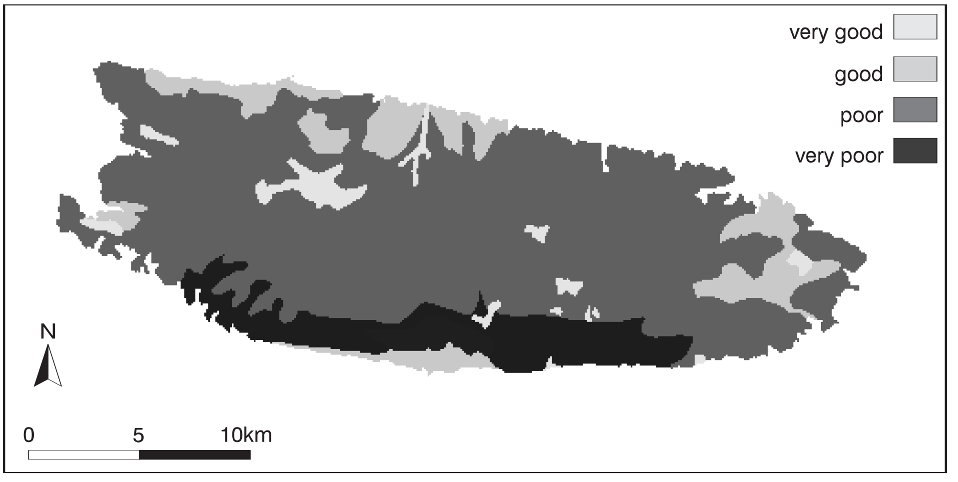

Figure 3. Soil map of Brač after Miloš, 1984.

Several points may be made concerning this data. The first relates to Poduje's data. Comparison of Poduje's data with that derived from the Landsat image illustrates the noted trend within Croatia towards the increasing abandonment of agricultural land. The decline in second class land (pasture) and the concomitant increase in maquis is particularly notable. Poduje's published data provides very detailed information on agricultural production that cannot be replicated with the Landsat data for the reasons given above. However, his data is very poor for non-productive land. The ability of the Landsat data to provide information on the spread of maquis is particularly useful in assessing the move towards climax population following desertion of agricultural land. We must presume that Poduje's data on forests actually contains information on maquis, although this is not indicated in the original publication. One suspects that his forest data was actually derived from a simple subtraction of the area of agricultural land from the total area of the island. The benefit of using a Landsat-based analysis over Poduje's semi-quantitative approach is clear, even at this stage of analysis.

It is more difficult to assess the relationship between the Landsat TM data and that from the Hvar Development Plan, particularly in the absence of an adequate vegetation map. However, there is a relationship between Bognar's qualitative soil data, which we may assume indicates the maximum area of soils of various fertilities, and that derived from the Landsat analysis. Differences probably result from the interpolative methods used to assess soil zones by Bognar and the disappearance of a variety of soil zones within maquis following abandonment. It is expected that the provision of more accurate training areas for Landsat data will ultimately provide a better assessment of areas of land use classes.

However, these results enabled us to develop an appropriate methodology for classification of Landsat TM images on other islands. Classification of the TM subscene covering the island of Brač was then performed and the results were much better then the original soil map which was published with a scale 1:200,000 (Miloš 1984). The results of the classification of Landsat TM image from July 1993 can be compared with the original thematic map in figures 2 and 3.

4 Conclusion and further work

The supporting digital environmental and cultural data has been made ready for rapid incorporation with the Landsat data and this should be reviewed. Digital elevation models for Vis, Brač and Hvar are available. The archaeological data for these islands is also available. The ability to rapidly integrate these data with that from the Landsat images can be illustrated through the interactive analysis of site locations with the spatial data on soil types. Although the project is still not finished and final results are not available at the moment, preliminary results are very encouraging.

1. The Landsat analysis, even at this stage, provides better quantitative data than Poduje's 1975 data for Hvar.
2. The study has already provided data related to one of the major aims in the exercises — quantification of the decline in agriculture on the island (e.g., for Hvar island a fall from *c*. 13,680 hectares in 1975 to 9,138 in 1993).
3. The 1990 development plan did not produce a vegetation plan to a standard that can be compared with the Landsat data. Final classification should therefore be a major contribution to available data for environmental planning on the islands.

Finally, several problems were noted during this analysis. Analysis of the training areas suggested that the signals derived were not homogenous. This probably has a number of causes. The most important are probably the following.

1. The agriculture of the islands is characterized by extreme polyculture. A wide variety of crops may be grown together on the same plot along with subsidiary tree crops. This prevents fine classification of crop types.
2. Arable areas on the islands are typified by the use of very small fields. Nearly 45% of the fields on the Starigrad plain on Hvar island for example are smaller than 30 meters (Fludder/Lister 1966) i.e. less than the size of a Landsat TM pixel.
3. Field boundaries are composed of masses of cleared stones and stone terraces that may be several meters wide and up to 3 meters high. Consequently, even good arable land may be characterized by a mixed signal.

A further complication was indicated by visual inspection of the distribution of land classes within the reclassified 1993 image. This suggested that land classification was less accurate in the mountainous spine of the islands than on the plain. This situation probably results from the necessity to use the available aerial photographic data relating to the Starigrad plain as the sole source of training areas. The plain should, perhaps, be considered an anomalous area. Signals for land use classes from this area may not transfer to similar land use categories situated high on the mountainous spine or on the bevelled upland plain that contains much of the agricultural land in the eastern part of the island. Although many of the problems associated with the data may be relatively minor, consideration of the data suggested that more accurate training areas should be sought. Despite these problems it is hoped that these results have demonstrated the advantage of using satellite imagery for providing natural environment data in archaeological GIS based research.

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