Satellite monitoring of cultural heritage sites

A Norwegian pilot project

The registration and monitoring of cultural heritage sites in the landscape

In order to protect cultural heritage sites in the landscape from damage and destruction, modern authorities maintain a record (database) of the known sites in the areas for which they are responsible. The better the record, the easier and cheaper it is to minimise conflict between planning and the construction of new roads, airports, bridges, golf courses etc. Cultural heritage sites can comprise burial mounds, old settlements, old roads and numerous other features. A good and well-organised cultural heritage database can therefore facilitate sustainable cultural heritage management.

The current problem is that our existing cultural heritage databases only contain a fraction of existing sites. Some types of settlements that are difficult to discern during the course of field survey will be under-represented among the registered sites. There is also a clear tendency towards more frequent registrations in zones with dense human activity than in thinly populated areas. The lack of a systematic cultural heritage survey of Norway has left large blank areas on the map.

Traditional archaeological field survey, which, when necessary, includes the digging of small test pits to gain insight into what lies hidden beneath the surface, costs around NOK 250,000 per square kilometre (with some variation due to different landscape and vegetation types). The survey of Norway's nearly 400,000 square kilometres using traditional field methods would cost in the order of NOK 100,000,000,000. In light of this, it seems logical to use modern satellite technology as a means of developing an essentially cheaper method for mapping and monitoring cultural heritage sites.

Multispectral satellite images

In principle, multispectral satellite images are digital photographs, but rather than storing all information in one layer of pixels, they separate light according to differences in wavelengths and so produce several 'layers' of information from different parts of the spectrum. Typically, they make separate recordings of blue, green, red, and near-infrared intervals, and the Landsat satellites also have a thermal channel that allows observation of features that lie slightly below the earth's surface.

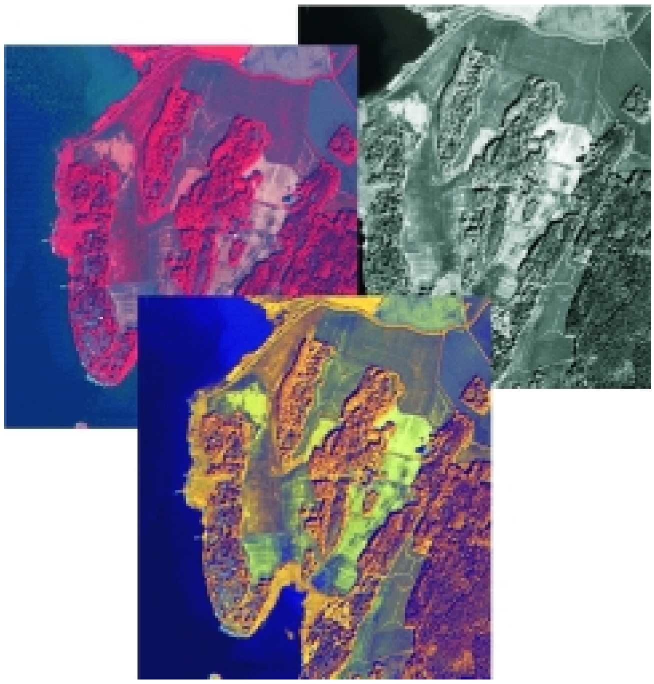

Fig.1 *Being different from aerial photos, multispectral satellite images provide access to 'layers' of information from different 'bands' in the visual spectrum. These layers of digital data can be combined in numerous different ways in order to yield information about vegetation and the ground surface (IKONOS - copyright: Space Imaging).*

The scale of resolution of the images is defined by the size of the pixels in the recordings. The first Landsat satellite was launched in 1972 and produced multispectral data with a resolution of 30 m, and panchromatic data (equivalent to a black & white photo) with a resolution of 10 m. This scale of resolution was only useful for observing large-scale archaeological features.

The IKONOS satellite was launched in 2000, providing a multispectral resolution of 4 m and a panchromatic resolution of 4 m. The Quickbird satellite, providing resolutions of respectively 2.5 m and 0.61 m, was launched in 2001. These satellites facilitate the development of methods for observing even the smallest features and thus promote a systematic utilisation of satellite data in the mapping and monitoring of cultural heritage sites.

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The advantage that multispectral images have over ordinary photos is that the combination and manipulation of the different layers allow more information to be extracted from the light reflected from the earth's surface. Variations in sediment surface and vegetation can be observed that are not visible in ordinary photos. Among other things, these can provide important information which reveals the presence of cultural heritage sites hidden below the surface; for example, information about differences in vegetation dynamics, differences in mineral composition, differences in ground moisture etc.

Fig.2 *The study area comprises a mosaic landscape, of which approximately one third is covered by forest and the remaining two thirds by cultivated fields (IKONOS - copyright: Space Imaging).*

Satellite observation of cultural heritage sites

Cultural heritage sites appeared originally as physical features which were often related to chemical features. For example, burial mounds were often constructed of material that differs from the soil on which they were placed. The building of ramparts led to compression of the subsoil that might alter drainage and thus create visible patterns. Ditches, pits, and old roads are often filled with material differing from the surrounding subsoil. Settlement sites where the remains of physical features are no longer visible on the surface can often be traced as areas with high concentrations of phosphates, heavy metals and other chemicals that can influence the dynamics of the vegetation.

In general, it seems reasonable to assume that there is a basis for detecting a large enough proportion of existing cultural heritage sites with methods based on multispectral satellite technology in order to be able to create a representative picture of their distribution. It is likely that this type of survey can be used to locate considerably more sites than traditional ground survey which tends to overlook a broad range of features. It is unlikely, however, that archaeological fieldwork will ever be totally replaced by high-technological methods, the potential of which lies in their ability to pinpoint locations with cultural heritage potential in a fast and cheap way, and to exclude large areas from survey.

Fig.3 *The study area is approximately 11 by 11 kilometres in area and covers part of Rygge municipality, Østfold County.*

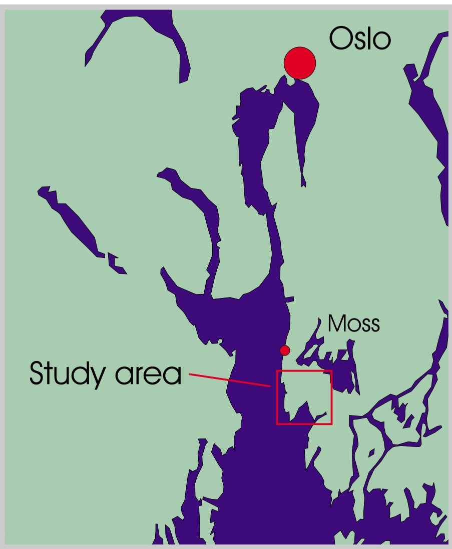


Fig.4 *The sites listed in the Norwegian cultural heritage registers are far from representative, both in terms of their real distribution within the landscape and in terms of the represented variety of site types. Sites located close to areas of dense human activity are over-represented, whereas sites in more remote areas are clearly under-represented. Settlement sites are significantly under-represented in comparison to burial mounds, for example. Black dots show registered cultural heritage sites. Yellow dots represent cultural heritage sites which are not registered.*

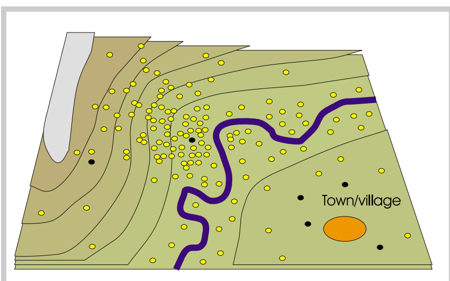
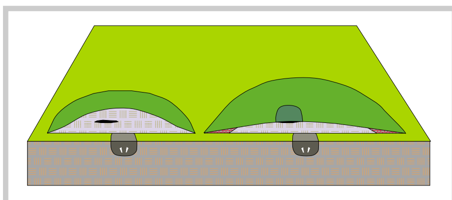


Fig.5 *Even though burial mounds are over-represented in relation to other types of cultural heritage sites, many of them are no longer visible as physical features in the landscape. Mounds subjected to ploughing lose some 3-8 millimetres of their height per year. In addition, mounds in fields have often been used as easily accessible sources of filling material used in connection with building and construction work from the 17th century on. In the study area, results indicate that less than 2% of mounds are preserved in cultivated fields. Because mounds are often composed of material that differs from the soil on which they were built, they can show up as anomalies in the satellite images even though they are invisible on the surface.*



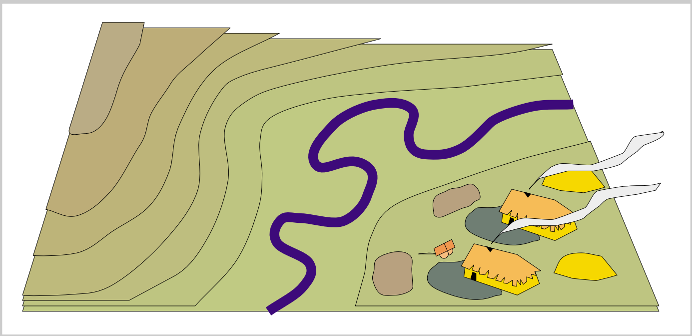


Fig.6 *The fact that humans have always been pigs is a stroke of luck in terms of increasing the potential for detecting ancient human settlements. Accumulations of trace elements, such as phosphates and various metals, are created wherever humans live. Even thousands of years after settlements were abandoned, trace elements can still cause discolouration of the vegetation which can be registered in the multispectral satellite images.*

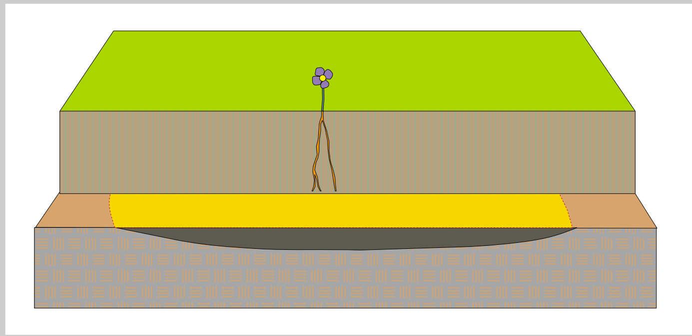


Fig.7 *Even though ancient settlement deposits may be covered by later layers of sediments, plants are able to 'lift' trace elements to the surface, making such 'invisible' cultural heritage sites visible in satellite images.*

The Norwegian pilot project

The Norwegian pilot project addresses these issues by initiating the development of a basis for a sustainable, up-to-date and cost-effective decision-support methodology which relies upon satellite remote-sensing for mapping and monitoring cultural heritage sites. With financial support from the Norwegian Space Centre, the Norwegian Directorate for Cultural Heritage and the Norwegian Institute for Cultural Heritage Research carried out a pilot project during 2001 and 2002 which had the following aims:

- To clarify what the current state-of-the-art is in terms of the location and monitoring of cultural heritage by satellite data.
- To evaluate the practical potential of multispectral satellite data with different resolutions.
- To look for relationships between anomalies visible in multispectral satellite data and ground features that can be distinguished by soil chemistry, ground spectrometry, and vegetation analysis.
- To suggest a strategy for further national initiatives in this field.

On the basis of the results obtained, it has been decided to continue the work begun in the pilot project in the form of a national project, running from 2003 to 2007.

The pilot project's study area comprised a large area of land measuring 11 by 11 km in Rygge municipality, Østfold County, covered by an IKONOS image taken on August 21st, 2000. This region has one of the highest densities of cultural heritage sites in Norway. It is a rich agricultural district with little topographical variation. As regards land use: a mosaic of small forested areas lie interspersed between intensively cultivated fields.

The missing mounds

The project has demonstrated that the density of cultural heritage sites in cultivated fields is less than 2% of that found in tree-covered areas. This indicates that about 98% of the sites of the types registered (mainly burial mounds in this area) seem to have disappeared from the fields. A rough estimate indicates that approximately 1000 cultural heritage sites - or on average at least 20 per square kilometre – are missing from the record in the study area's fields. In other words, the 458 registered sites represent less than a third of the total population.

This phenomenon may be a result of ploughing, which can reduce the height of visible cultural heritage features by 0.3-0.8 centimetres per year. However, another cause should also be considered. The systematic removal of even large mounds in Norway is documented as early as the 18th century, in some cases because they contained easily accessible material used for levelling-out building sites and other constructional purposes, in others simply as a result of attempts to find archaeological treasure.

That settlements are extremely under-represented in relation to burial mounds among the registered cultural heritage sites is probably due to the fact that they are difficult to locate, both in areas with tree-cover and in cultivated fields. It can be assumed that unregistered settlements add a significant number to the estimated total of 1000 missing cultural heritage sites in the study area.

Identification of the character of anomalies

Almost 2000 anomalies that may represent cultural heritage sites were observed within the study area. Archival data and information from local informants made it clear that a number of these are modern features, such as power-line masts,

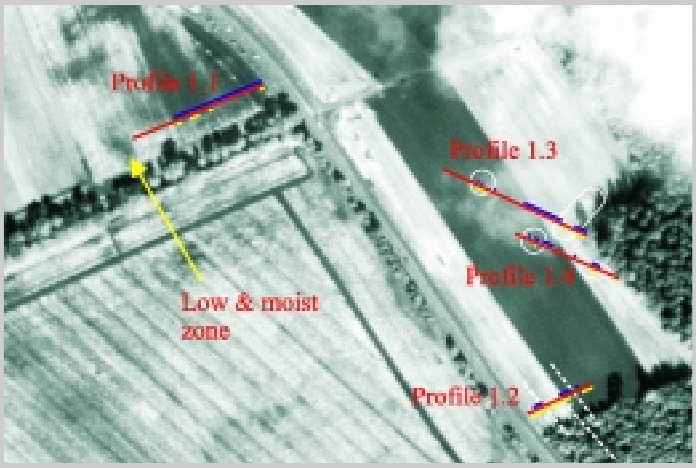


Fig.8 *Four analysed chemical profiles from Gibsund farm, shown as red lines. A correlation can be observed between features interpreted as cultural heritage sites and concentrations of trace elements. Yellow shows local maxima in the concentration of iron (Fe3+) and blue shows local maxima in the concentration of phosphate (P). Anomalies interpreted as mounds are shown as white circles, a possible Stone Age site as a small white oval, two phases of a track as broken lines, and a possible house as a large white oval (IKONOS - copyright: Space Imaging).*

recently removed hedges between fields, and former dirt tracks. However, it is nonetheless evident that a significant proportion may represent missing cultural heritage sites.

An increasingly important part of the project is the development of a methodology that facilitates the fast and efficient identification of the nature of anomalies observed in the multispectral images. The use of satellite data for cultural heritage management will be of little benefit if it only leads to statements such as the following: “there are 200 anomalies within the area to be investigated, of which approximately 30% are assumed to be cultural heritage sites”.

The development of chemical indicators for different types of sites has already yielded promising results within the pilot-study period. Phosphates and iron (Fe^{3+}) show an interesting relationship with the features studied. The value of heavy metals as indicators is being investigated.

Another approach that will be investigated is the development of an automated procedure for distinguishing cultural heritage sites among the anomalies observed. The collection of examples of anomalies that do not represent cultural heritage sites is as important to this development as the collection of anomalies which represent known site types.

Satellite Data Archive

Easy access to satellite data with sufficient quality and resolution is important for the development of cost-effective decision-support methodologies based on satellite imagery. Further development of the recently formed Satellite Data Archive within the framework of the Norwegian Mapping Authority is an important means of making the relevant types of satellite data accessible to the various sectors which can benefit from them.

Fig.9 *For each layer, the multispectral satellite images record the reflection from a certain band of light as one numeric value for each ‘pixel’. Here a tree in a fence is seen in an IKONOS image with a horizontal resolution of 4 metres (IKONOS - copyright: Space Imaging).*

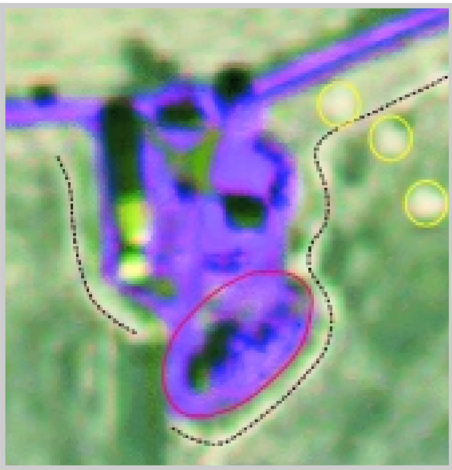


Fig.10 *A concentration of registered mounds, marked in red. A linear feature created by field-cultivation methods is shown as a broken black line. Three anomalies reflecting significant local changes in the soil, interpreted as the remains of mounds with no structural remains preserved above the surface, are marked with yellow circles (IKONOS - copyright: Space Imaging).*

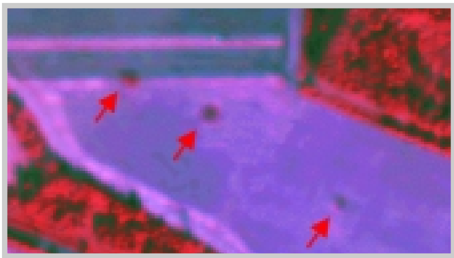


Fig.11 *Three anomalies representing the foundations of power-line masts (IKONOS - copyright: Space Imaging).*

Read more in the report «Development of methods for satellite monitoring of cultural heritage sites», available at: http://www.riksantikvaren.no/

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