Annals of Tropical Research 29(1): 1-8 (2007)

Spatial Technologies: What Use are They to Managers of Environmental Land?

Jack Baynes

School of Natural and Rural Systems Management, The University of Queensland, Gatton, 4343 Australia and Queensland Department of Primary Industries and Fisheries, Gympie 4570, Australia.

ABSTRACT

This paper reviews the potential use of three types of spatial technology to land managers, namely satellite imagery, satellite positioning systems and supporting computer software. Developments in remote sensing and the relative advantages of multispectral and hyperspectral images are discussed. The main challenge to the wider use of remote sensing as a land management tool is seen as uncertainty whether apparent relationships between biophysical variables and spectral reflectance are direct and causal, or artefacts of particular images. Developments in satellite positioning systems are presented in the context of land managers' need for position estimates in situations where absolute precision may or may not be required. The role of computer software in supporting developments in spatial technology is described. Spatial technologies are seen as having matured beyond empirical applications to the stage where they are useful and reliable land management tools. In addition, computer software has become more user-friendly and this has facilitated data collection and manipulation by semi-expert as well as specialist staff.

Keywords: satellite image, global positioning system, geographic information system

INTRODUCTION

Land managers have always wished for spatial technology which can routinely generate, store and display reliable information about points on the ground. This technology has only recently become available and as late as the 1970s the art of cartography and image analysis were still arcane sciences which were only understood and used by specialists. The research impetus in aerial photography, radar and rockets in World War 2 was continued in the space race between the USSR and the USA, one result of which was the development of satellites which could record images of the earth. Support for the satellite programs was supplied by developments in computer-aided radio-navigation systems and methods of transmitting data from satellites to receivers on the earth.

Although earlier rocket launches had a political and military focus, achievements in space became popular with the general public and this led to demands from industry to use the technology for civil applications. However, despite wide reporting in the literature, across the world there have been wide differences in the implementation of the technology by land managers (Curran 1985).

Even in developed countries, land managers who worked in field locations as late as the 1990s will remember that maps were usually supplied from a centralised office, computers had insufficient memory to run spatial software and internet connections were very slow, if available at all. By 2007, however, this gap has diminished with the global spread of high-speed internet connections.

Websites such as Google™ Earth promote remotely sensed images as a form of entertainment by offering viewers the opportunity to ‘fly from space to your neighbourhood’ or to ‘type in an address and zoom right in’ (Google Earth 2006). This website illustrates three recent changes to spatial technology which are useful to environmental land managers. In chronological order of development, these changes have been the proliferation of satellite imagery, improvements in geographic information system[1] (GIS) software and the commercial development of global positioning system[2] (GPS) receivers.

The Use of Satellite Imagery in the Environmental Sciences

Beginning with the launch of Landsat 1 in the USA in 1972, the use of satellite imagery for land management has become popular as a method of assessing changes in the earth’s surface. For the first time, the spectral reflectance[3] of various land-cover components could be used to assess land-cover variables such as canopy cover and biomass over wide areas of the earth’s surface without the expense of sensors carried in aircraft. The research background for these applications is well described in standard remote sensing texts e.g. De Boer (1991) and Lillesand and Kiefer (1994) and the internet. For example, the National Aeronautics and Space Administration remote sensing tutorial (available at http://rst.gsfc.nasa.gov/) describes the history and development of satellites as well as the theory of remote sensing.

The success of subsequent Landsat satellites in commercialising remotely sensed imagery has prompted launching of satellites in other countries, particularly Europe, China and India. Image resolution in more recent satellites has improved dramatically, with pixels[4] as small as 2.5 and 0.61 m for SPOT[5] and QuickBird[6] images,

---

[1] A geographic information system is a computer assisted system for acquisition, storage, analysis and display of geographic data.

[2] A global positioning system is an application of radio-navigation in which satellites are used to transmit a signal to a receiver on the earth’s surface, enabling the position of the receiver to be fixed.

[3] Spectral reflectance is defined as the ratio of incident to reflected energy irradiated onto a surface and then reflected back to a target e.g. a remote sensor for a particular wavelength.

[4] A square pixel or ‘picture element’ is the smallest unit of a remotely sensed image and is analogous to each ‘cell’ in cell-based modelling.

respectively. The small pixel size makes the images visually appealing, but they are expensive compared to Landsat images where small scenes (25 x 25 km) can be purchased for as little as 400 Australian dollars.

Recent developments in hyperspectral[7] imagery have revived scientific interest in remote sensing. The general problem is that the main bands used for traditional multispectral[8] imaging are so broad that the surface material's characteristic spectral reflection and absorption peaks cannot be resolved (Spencer 1992; Short 2007). Hyperspectral imaging has been applied to tasks as diverse as determining the proportion of living and dead coral reef (Mumby *et al*. 2004) and delineating crown area of trees (Bunting and Lucas 2006) but costs are high because the sensors are only carried in aircraft. Consequently, many researchers still use the single bands, band ratios or combinations available in multispectral images.

Using these bands, simple classification of land-cover into grassland or forest presents little difficulty. However, the validity of many of the traditional image processing algorithms - e.g. band ratios or combinations - is often questionable in complex land-cover situations. The contribution of various scene components to overall spectral reflectance may vary across the landscape. This situation leads to questions whether reflectance changes are directly and causally related to land-cover changes or are an artefact of scene components of which the researcher is not aware. Consequently, land managers who are not trained in remote sensing techniques have been reluctant to use remote sensing to assess landscape variables[9], particularly when they cannot be confident of extrapolating apparent relationships between reflectance and scene components across landscapes.

Global Positioning Systems

The use of hand-held GPS units to provide ground location coordinates with positional errors often less than 10 m horizontally and 30 m vertically has greatly

---

[5] SPOT is the acronym for 'Systeme Probatoire d' Observation de la Terre', marketed as SPOT Image satellite imagery.

[6] Quickbird is the name of a high resolution satellite launched in 2001 and owned by the Digital Globe Company in the USA.

[7] In hyperspectral images, up to several hundred spectral bands may be imaged with consequent small band-widths. The small band widths enable the unique spectral signature of 'pure' land-cover types (i.e. monoculture plantations) to be imaged.

[8] Multispectral images are images in which reflectance is recorded in several broad bandwidths, e.g. Landsat band 5 is recorded with a bandwidth of 1550 – 1750 nm. In the Landsat 7 satellite, there are seven bands, namely visible blue, visible green, visible red, near infrared, two middle infrared bands and a thermal band.

[9] Typical landscape variables include grass cover, bare soil, trees, stand height and canopy density.

assisted surveying and cartography in situations where absolute precision is not required. It is also useful when existing maps are not reliable.

The GPS system is controlled by the US Department of Defence with hand-held or backpack GPS receivers used to decode signals from satellites, enabling the receiver to compute position, velocity and time. An alternative system is being developed by the European Space Agency (ESA), through its 'Galileo' satellite radio-navigation program in which it is planned to offer improved position location with a commercial 'extreme precision' system. With the use of ground stations, the system will reputedly reduce horizontal positioning error to 10 cm (Wikipedia 2006), although the ESA only asserts that positions will be located with an error of less than one metre (ESA 2005).

With the full complement of 30 Galileo satellites not intended to be in operation until 2010, land managers may still be attracted by the speed and convenience provided by current GPS units, provided that positional errors are acceptable. This brings into focus reasons for carrying out surveys and the precision which is required. Do the results of the survey have a temporary consequence, such as establishing progressive land clearance rates or do they have a permanent legacy, such as when ownership of land is established by a survey? In developing countries, GPS surveys have sometimes provided the first opportunity to reference older maps to modern map coordinate systems, and datums[10]. At the local level, this requires land mangers to re-examine their mapping system. Do they upgrade their old maps to comply with modern global mapping systems such as the widely accepted WGS84 geocentric datum[11]? Do they maintain parallel databases of new and old mapping systems? Would those changes cause problems transferring information between land management agencies? Also, what are the legal consequences of using GPS measurements if position estimates are not precise? The answers to these questions will be largely predicated by the value of the land, the intensity of land management and the timeframe for which the data will be used. Inevitably, with the budgetary and human resource constraints which are common to many land management agencies, GPS units will be used for surveys wherever possible.

[10] In surveying, a datum is a set of geometric and numeric constants from which other quantities such as coordinate systems can be defined. A datum defines a reference surface, e.g. the surface of the earth.

[11] The acronym WGS84 refers to the World Geodetic System of 1984. It is a geocentric datum and geographic coordinate system created by the United States military and used in many countries.

Use of Geographic Information Systems for Vector and Raster Mapping and Modelling

The link between the seemingly disparate aspects of spatial technology such as remote sensing and GPS is the GIS software in which both raster[12] and vector[13] datasets are stored, displayed and manipulated. Colloquially, a GIS can be defined as a computer database which describes the world in geographic terms (ESRI 2001) with modules which allow for:

- database management and data support
- cartographic display and export
- raster and/or vector file geoprocessing and analysis
- statistical analysis.

In recent years, because commercial competition has forced GIS developers to establish their own market niche, there has been a proliferation of modules which allow users to undertake specialised querying and manipulation of datasets, i.e. to carry out network analysis and three dimensional modelling.

For simple tasks such as thematic mapping, the software has become more ‘user friendly’ and the distinction between raster and vector software systems has become blurred. For example, whereas older GIS software was often focussed on either raster or vector data, recent developments of the ESRI[14] suite of programs which specialises in cartography now incorporate cell-based modelling. Raster GIS software such as the IDRISI[15] and ENVI[16] systems offer extensive suites of modelling tools in either format. This is an advantage to land managers in applications such as georeferencing raster files of Shuttle Radar Topography Mission (SRTM) digital elevation data to vector datasets of towns or roads.

As computing power has increased in the last 10 years, so has the capacity of notebook computers to run GIS software. This has been essential because increased computer memory has been matched with file sizes that are huge by comparison with older datasets. One scanned aerial photograph may have a file size of 100 megabytes and most GIS software routinely crashes when presented with datasets that are very

---

[12] Raster’ datasets are composed of cells, or in the case of photographs or images, of ‘pixels’ or picture elements.

[13] Vector datasets are composed of points, lines and polygons and as with rasters, they are usually linked to an attribute table which contains information about them.

[14] ESRI is the acronym for the Earth Science Resources Institute a company which markets the ArcGIS suite of GIS software in the USA.

[15] IDRISI is a raster-based GIS software package marketed by Clarke University in the USA.

[16] ENVI is a raster-based GIS software package marketed by Research Systems Incorporated in the USA.

large. However, GIS software is now more amenable to importing and handling datasets with different file formats and the dominance of Microsoft Windows as a software operating platform facilitates file transfer between packages.

Despite the obvious uses to which GIS software can be put, GIS methods are still regarded in many organisations as requiring specialist expertise. Software licences are often highly expensive and are often purchased as 'stand alone' licenses for key staff or 'floating' licenses which can be used on one networked computer at a time within an organisation. While this arrangement is cost-effective, it can also inhibit proliferation of the technology. Fortunately, companies such as ESRI have made GIS data-viewers such as ArcExplorer available for free download from the Internet. ArcExplorer performs a variety of basic GIS functions, including display, query and data retrieval applications. This allows the development of two levels of expertise within an organisation, these being specialist key personnel who use the software and land mangers who are able to view and query the results.

For Australian land managers, the 'Aussie GRASS' and 'Northern Australian Fire Information' websites allow internet access to satellite-derived products which describe pasture growth and bushfire locations respectively. In each case, the maps have been developed from a number of datasets (e.g. satellite imagery and rainfall) into satellite derived products which can be viewed with a simple GIS 'viewer'.

The integration of GIS software with remote sensing and GPS is a common theme in five of the papers contributed for this issue. The underlying purpose of all of the technology described in the papers is to serve as a decision-support tool for land managers and it is hoped that this emphasis on practical applications of spatial technology may be of use to other land managers when faced with issues similar to those reported here.

OVERVIEW OF CONTRIBUTED PAPERS

Five of the six papers which follow, report various aspects of spatial technology which have been used as part of ACIAR project ASEM/2003/052 - *Improving Financial Returns to Smallholder Tree Farmers in the Philippines* or as part of a study commissioned by the Australian Department of Transport and Regional Services (DOTARS) into the feasibility of expanding timber planting in north Queensland, Australia. The articles describe research which was undertaken using commercial off-the-shelf spatial technology which has been released to the public.

Remote Sensing Studies

Two papers examine the use of remote sensing and the effect of tree canopies on the spectral reflectance of light. Baynes (this issue, a) reviews the use of the Forest Canopy Density Mapper to estimate the effect of breaks in the canopy on the reflectance of Landsat digital image data. Strong correlations between reflectance and stand height are seen as promising for detection of deforestation or differentiation between coconut plantation and native forest in the Philippines. This theme is explored further in research presented by Baynes (this issue, b) where the influence of breaks in a simple canopy complicates the derivation of spectral signatures which may be used to assess tree health.

Global Positioning Systems and Compilation of a Database

Gordon and Cedamon (this issue) evaluate the precision of hand-held GPS units in open-air and closed-canopy situations. The acceptability of positional error in a GPS survey is seen to be dependent on the reasons for the survey and in some cases a compass and chain survey may be a logical alternative. Gordon and Bernaldez (this issue) also examine problems encountered in compiling a database of tree farms and highlight the problems of using electronic base maps with datums of old or uncertain lineage. This paper may serve as a guide to other researchers wishing to compile similar databases in developing countries.

Spatial Modelling

Baynes *et al.* (this issue) describe the process of spatial modelling using the ArcGIS® computer software suite to select a sample of municipalities as research sites. This paper also illustrates the usefulness of thematic mapping and information contained in the attribute files to justify decisions concerning research activities. Finally, Baynes (this issue, c) describes the process of selecting land suitable for growing hoop pine (*Araucaria cunninghamii*) in North Queensland. This investigation highlights the complexities and uncertainties involved in correlating spatial datasets which were developed for research uses and at different scales to that of the specific application.

IMPLICATIONS FOR THE USE OF SPATIAL TECHNOLOGY BY LAND MANAGERS

A common theme with these papers is that as spatial technology has improved, the speed and flexibility with which land management investigations can be undertaken has also improved. Both remotely-sensed image data and GPS coordinates were found to be transferable across software packages. Data downloaded from the internet (e.g. SRTM elevation data from the USA) could be overlaid with map layers describing the location of Australian towns. Concomitant with this increase in the flexibility of data transfer, however, is the likelihood of introducing various sources of error. Spectral reflectance is dependent on the architecture and composition of the scene components, GPS signals fail underneath tree canopies and datum differences may misalign maps. Also, restructuring vector data for analysis as raster data always involves the approximation of area calculations.

The six papers indicate that the challenge for land managers is to be sensitive to the limitations of the technology. One important change in GIS manuals and data release notes in the last 10 years has been the provision of comprehensive ‘help’ notes. The notes describe the uses to which the software may be put and often caution against inappropriate interpretations of the results. For example, the Spatial Analyst user manual warns that meaningless results will often occur when combining discrete and continuous data (ESRI 2001). Suppliers of data have followed the same trend, often indicating the limits to which the data may be representative of actual situations. Again, for example, SRTM (2005) data release notes warn that for elevation data, ‘water bodies may not appear flat’. When taken in context of the many positive results reported in the literature and by suppliers concerning these products, the warnings indicate increasing confidence in the application of the technology. Suppliers of spatial technology data and software are aware of the applications to which these products can and cannot be used. This signals a transition of spatial technology from empirical research to routine applications in land management.

REFERENCES

BUNTING, P. and LUCAS, R. 2006. The Delineation of Tree Crowns in Australian Mixed Species Forests Using Hyperspectral Compact Airborne Spectrographic Imager (CASI) Data. *Remote Sensing of Environment.* **101**(2): 230 – 248.

CURRAN, P.J. 1985. *Principles of Remote Sensing.* Longman Scientific & Technical, Essex.

ESA (EUROPEAN SPACE AGENCY). 2005. Navigation: What is Galileo? http://www.esa.int/esaNA/GGGMX650NDC_index_0.html. Accessed 14 June 2006.

ESRI (EARTH SCIENCE RESCOURCES INSTITUTE). 2001. *What is ArcGIS?* Redlands, California.

GOOGLE EARTH. 2006. A 3D Interface to the Planet. http://earth.google.com. Accessed 15 June 2006.

MUMBY, P.J., HEDLEY, J.D., CHISOLM, J.R.M., CLARK, C.D., RIPLEY, H. and JAUBERT, J. 2004. The Cover of Living and Dead Corals from Airborne Remote Sensing. *Coral Reefs*. **23**: 171 – 183.

SHORT, N. 2007. Remote Sensing Tutorial. National Aeronautics and Space Administration. http://rst.gsfc.nasa.gov/ Accessed 12 February 2007.

SPENCER, C. 1992. Remote Sensing with Hyperspectral Imaging Technology. http://www.Biogeorecon.com/rshyperspec.htm. Accessed 18 June 2006.

WIKIPEDIA, 2006. Galileo Positioning System. http://en.wikipedia.org/wiki/Galileo_Positioning_system. Accessed 14 June 2006.