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The use of remote sensing for monitoring change in agriculture in the uplands and lowlands

B K WYATT
Institute of Terrestrial Ecology, Bangor Research Station

1 Introduction

In assessing the impacts of agriculture upon wildlife and semi-natural habitats, it is necessary to understand, first, the nature of these impacts, and, second, the location and extent of the areas where the effects are felt. The first requirement (how agricultural practices impact upon ecosystems) is considered elsewhere in this symposium volume. The questions of where such conflicts exist or may arise, their degree, extent and duration are equally important if effective measures are to be found for minimizing them, whether through statutory provisions or by voluntary means.

Specific questions which must be answered include the following.

- Where do vulnerable ecosystems and habitats occur?
- Where are agricultural methods being practised which result in conflict with ecological interests?
- Where are changes occurring in agriculture which may affect the situation?
- What is the extent of the effect, locally and nationally? For example, is there localized pressure on a commonly occurring habitat, or is the threat widespread and the habitat rare?
- What are the dynamics of the problem? For example, what is the rate of encroachment of arable farming on permanent grassland?

The range of information needed to answer these questions is considerable. Identification of habitat types demands a knowledge of the basic topography, vegetation cover, pedology, hydrology, etc. In order to evaluate specific agricultural impacts, it is necessary to distinguish patterns of cultivation, often on a field-by-field basis. Further, much of this information must be collected repetitively in order to provide a monitoring capability.

This information is needed at very local scales (eg in assessing potential impacts of agricultural development on a Site of Special Scientific Interest), at broad national scales to evaluate the overall effects of changes in agricultural practices, and at intermediate scales (eg to monitor agricultural impact in a National Park).

In practice, although elements of such an information base exist (eg Coppock 1976; Coleman 1961; Soil Survey of England and Wales 1983; Heath & Perring 1978) and a number of potentially useful sources is described elsewhere in this volume (Ball 1984; Bunce *et al.* 1984), the available information falls short of the requirements identified above.

On the face of it, remote sensing from satellites or aircraft offers an attractive means of collecting much of the necessary information on land cover that would otherwise be so time-consuming and costly to acquire. This paper is an attempt to evaluate its suitability as a technique for mapping and monitoring rural land cover in the UK, to identify inadequacies in existing techniques, and to suggest research needed to minimize these shortcomings.

2 Methodology for obtaining information

2.1 Terminology

Strictly, the term 'remote sensing' covers all methods of data acquisition in which the sensor is not in physical contact with the object under observation. This paper adopts the narrower, and more useful, definition of Reeves *et al.* (1975): 'Observation of the earth's surface in various parts of the electromagnetic spectrum by sensors carried on aerial or space platforms'. A further restriction has been introduced in that the paper covers only those systems which record in digital form. Aerial photography, whose use in agricultural and ecological survey is now routine, is not considered in this review.

2.2 Survey methods

Survey from aircraft in the UK, until recently, has been confined to photographic methods and to infra-red linescan, mainly because of the lack of suitable scanners. Experimental airborne remote sensing campaigns (Williams 1984) have demonstrated their potential for land cover survey applications, but have also highlighted a number of shortcomings. In particular, spatial correction and registration of airborne imagery presents problems, and radiometric correction for the effects of off-nadir viewing needs further study.

Satellite imagery has been more readily available, despite its high capital cost, because the cost of imagery per unit area is modest, and the techniques have been vigorously promoted by national space agencies. Table 1 summarizes the satellite systems from which environmental remotely sensed data are, or will shortly become, available.

Interactions between plants and radiation at visible and near infra-red wave lengths are distinctive (Figure 1). The multispectral scanner (MSS), carried by all the Landsat satellites, exploits this fact, and senses in the 4 bands in this region of the electromagnetic spectrum. Landsats 1-4 have achieved continuity of cover over much of the earth's surface from 1972 to the present time. Consequently, data from the Landsat programme have been easily the most widely used for vegetation mapping and in studies of vegetation change.

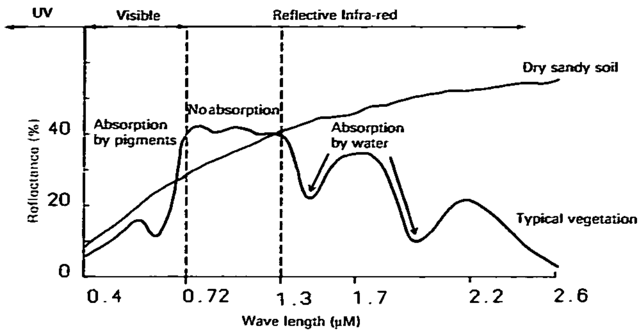

Figure 1. Reflectance and absorption of short-wave solar radiation by bare soil and vegetation (Source: Fenwick & Thompson 1976; Seddon 1976)

2.3 Image analysis

Remote sensing using conventional photography generates a physical image as the primary product. Although it is possible to analyse photographic images quantitatively, the processes entailed are laborious and inconvenient. A major attraction of data derived from

Table 1. Summary of satellite systems of importance for environmental remote sensing

SATELLITE	SPONSOR	STATUS	LAUNCH	MAIN SENSOR(S)
NIMBUS-7	NASA	IN ORBIT	1978	CZCS/SMMR
HCMM	NASA	NO LONGER OPERATIONAL	1978	HCMR
SEASAT	NASA	NO LONGER OPERATIONAL	1978	SAR SMMR
LANDSAT-1, -2, -3	NASA	NO LONGER OPERATIONAL	1972, 1975, 1978	RBV MSS
LANDSAT-4	NASA	MSS OPERATIONAL TM NOT YET COMMISSIONED	1982	MSS TM
LANDSAT-5	NASA	APPROVED	1984	MSS TM
SPOT-1	FRANCE	APPROVED	1984	MSS
MOS-1	JAPAN	APPROVED	1986	MSS
ERS-1	ESA	APPROVED	1987	RADAR
MAGSAT	NASA	IN ORBIT	1979	MAGNETIC FIELD STRENGTH AND DIRECTION
ERS-2	ESA	PROPOSED	1990	SAR ALTIMETER
SPOT-2	FRANCE	PROPOSED	1988	MSS
GRAVSAT	NASA	PROPOSED	1989	GRAVITY MAGNETIC FIELD
RADARSAT	CANADA	PROPOSED	1990	RADAR
FIREX	USA	PROPOSED	1990s	RADAR
NOAA-7	NOAA	IN ORBIT	1981	TIR
METEOSAT-2	ESA	IN ORBIT	1981	TIR
SHUTTLE EXPTS				
SIR-B	NASA	APPROVED	1984	RADAR

RBV = Return-beam vidicon
MSS = Multispectral scanner
TIR = Thermal infra-red
SAR = Synthetic aperture radar
CZCS = Coastal zone colour scanner
TM = Thematic mapper
HCMM = Heat capacity mapping mission
HCMR = Heat capacity mapping radiometer
SMMR = Scanning multichannel microwave radiometer

digital recording devices such as scanners and radars is the fact that they are directly available in digital form and readily amenable to analysis using digital computers. The physical image as observed by the sensor is only one (and by no means the most useful) form in which such data can be presented.

Imagery in digital form is readily manipulated by computer, and many software packages and integrated systems are now available for this purpose. Baker (1983) gives a comprehensive description of image analysis processes of relevance for ecological mapping applications, as implemented on one such system. Comparable systems provide similar facilities which differ mainly in the details of the implementation.

3 Monitoring change in land cover

Allan (1981) has given an authoritative review of the principles behind the use of remote sensing for monitoring land use change, and has discussed the needs of land cover monitoring programmes using remotely sensed data. He indicates that, in the case of large area survey, economic considerations dictate a choice between comprehensive coverage from satellite platforms at low resolution (typically 80 m^2) or survey from aircraft at relatively high resolution (perhaps 1 m^2) using sampling methods. These methods are increasingly being used in combination (eg Tomlins 1981; Williams 1984): an aircraft, 'underflying' the satellite, can provide high resolution coverage of selected areas which can then be used to aid interpretation of the satellite image. However, as indicated earlier, literature references to the use of multispectral data for land use survey describe predominantly satellite sources, by far the most common being Landsats 1-3.

As later generations of satellite systems become operational, offering better spatial resolution (eg Landsat Thematic Mapper (30 m^2), SPOT Multispectral Scanner (30-10 m^2)), so the distinction between aircraft and satellite technologies are becoming blurred. Nevertheless, high resolution satellite detectors bring with them problems of analysis, due to the high volumes of data they generate, and in many cases it is likely that some sort of sampling strategy will be employed in routine applications of such imagery for large area survey and monitoring.

Because the spectral response of vegetation is partly a function of phenology, timing of data acquisition is an important consideration when using remotely sensed data for studies of change in land cover. Data should be selected in the first instance to maximize the ability to discriminate the land cover types of interest. For example, if the problem concerns the encroachment of arable farming on areas of permanent pasture, the optimum time of survey is immediately after ploughing, when the difference in spectral response between bare soil and growing vegetation can be exploited. Successive images should then be acquired so that the vegetation is at similar stages of maturity.

In the case of aircraft based surveys, the timing of the flights must be carefully planned. Time of day is important in order to minimize the effects of different sun angles. A number of images taken at regular intervals may be available, from satellite sources, and, in principle, it is a simple matter to select the most suitable ones.

In practice, cloud cover often seriously limits choice, particularly in temperate latitudes. For example, there were only 3 cloud-free images available for the area of mid-Wales depicted in Plate 8 in the entire period from 1972-83 during which Landsat has been operating. These images were all early summer scenes, so that it has been impossible to study seasonal change, or to use such changes as an aid in classifying ground cover. The problem is less acute in lowland areas of south-eastern Britain, but it seriously restricts the use of satellite methods for routinely monitoring land use change in upland areas (at least until RADAR systems are in regular service, and the use of microwave imagery for identifying vegetation types is better understood).

Given the wide availability of Landsat imagery at reasonable cost, the volume of literature describing its use in vegetation and crop inventory comes as no surprise. Although much of this material is of limited value in advancing understanding of the techniques and use of remote sensing, it does demonstrate collectively that remote sensing is capable of identifying many of the land cover types of interest to the strategic planner. A number of land cover classifications have been suggested for use with remotely sensed data (eg Anderson *et al.* 1972) (Table 2). These systems tend to be hierarchical in structure. Using the classification techniques already discussed, including multitemporal methods, it is possible to distinguish all Anderson's level 1 classes and most of the level 2 classes with some precision (typically 80-90% pixels are correctly classified for many groups).

It is therefore surprising to note the relative paucity of reports describing the use of multitemporal data for monitoring land cover change, particularly for strategic planning purposes. Now that Landsat imagery has been continuously available over a period of more than 10 years, it is reasonable to suppose the existence of a body of evidence concerning its suitability as a broad-brush aid to environmental monitoring. There are certainly examples of such applications in the literature. On the continental scale, the success of the Large Area Crop Inventory Experiment (MacDonald 1979) in monitoring crop growth and predicting yields has already been remarked. Satellite data have been used successfully to monitor arid land conditions in several regions (eg Maxwell *et al.* 1980; Robinove *et al.* 1981). Instances of the use of multitemporal

Table 2. Land use and land cover classification system for use with remote sensing data
(Source: Anderson *et al.* 1972)

LEVEL 1	LEVEL 2
1 Urban or built-up land	11 Residential
	12 Commercial and services
	13 Industrial
	14 Transportation, communications and utilities
	15 Industrial and commercial complexes
	16 Mixed
	17 Other
2 Agricultural land	21 Cropland and pasture
	22 Orchards, groves, vineyards, nurseries and ornamental horticultural areas
	23 Confined feeding operations
	24 Other
3 Rangeland	31 Herbaceous range
	32 Shrub-brushland range
	33 Mixed
4 Forest land	41 Deciduous
	42 Evergreen
	43 Mixed
5 Water	51 Streams and canals
	52 Lakes
	53 Reservoirs
	54 Bays and estuaries
6 Wetland	61 Forest
	62 Non-forested
7 Barren land	71 Dry salt flats
	72 Beaches
	73 Sandy areas other than beaches
	74 Bare exposed rock
	75 Strip mines, quarries, and gravel pits
	76 Transitional areas
	77 Mixed
8 Tundra	81 Shrub and brush tundra
	82 Herbaceous tundra
	83 Bare ground tundra
	84 Wet tundra
	85 Mixed
9 Perennial snow or ice	91 Perennial snowfields
	92 Glaciers

remotely sensed imagery to monitor urban encroachment and urban change abound (eg Todd 1977; Angelici *et al.* 1977; Stauffer & McKinney 1978; Stove *et al.* 1980; Toll *et al.* 1980). Elsewhere, there are examples of monitoring programmes for agriculture (eg Loveland & Johnson 1983) and forestry (eg Smith 1979; Nelson 1982, 1983), but comparatively few instances in which the focus is on natural or semi-natural habitats. In the UK, there is remarkably little relevant published material. The Department of Agriculture and Fisheries for Scotland has commissioned a study to evaluate the use of remote sensing in compiling a national inventory of bracken (Grampian Regional Council 1982), and NERC is funding a number of programmes involving vegetation mapping, including an evaluation of the use of Landsat imagery for monitoring the drainage of wetlands and agricultural encroachment (J R Baker pers. comm.).

The reasons for the comparatively slow adoption of remote sensing as a tool for monitoring land use change are complex. There are a number of technical problems (see below). There have also been the educational and promotional difficulties which are often associated with the introduction of any new methodology, but which have, perhaps, been exacerbated by a tendency to 'over-sell' satellite remote sensing in its early days, earning for it the unjust reputation of a technique in search of an application.

An important consideration is that remote sensing alone can provide, at best, only a superficial analysis of the ecological consequences of changes in land use. In conjunction with other data sets recording topological, pedological, hydrological and biological variables, for example, the potentials of remotely sensed data are much enhanced. NERC is in a strong position to draw upon the resources of its Institutes, the university research it finances and its in-house cartographic expertise (Jackson 1981) to construct such geographic information systems.

ITE, at its Bangor Research Station, has recently embarked on a programme of work to assess the contribution of remote sensing, used in conjunction with such data sources, for ecological research and surveillance. The focus of the work is the characterization of vegetation cover in upland areas of Wales, using Landsat and supplementary information from NERC digital cartographic sources, from existing vegetation maps, from aerial photographs, airborne multispectral data and ground survey. After development of suitable land cover classification procedures, the programme will use Landsat imagery from 1975-83 to investigate changes in upland land use, and, in particular, changes due to the encroachment of forestry and agriculture upon natural and semi-natural habitats. The methodology is being developed in a test area, 20 km x 20 km, east of Dolgellau, with the ultimate aim of extending the system to give a comprehensive land cover monitoring capability for the whole of Wales.

The programme is still at a relatively early stage, but already a number of general principles are becoming apparent. The importance of access to accurate ground truth records cannot be over-emphasized. They are required for training purposes and to evaluate the results of the classifications. They should include examples of the entire range of cover types of interest, and should be, as far as possible, contemporary with the scenes being used to develop the classification procedures. In the case of the ITE project, with its emphasis on monitoring potential, it is important to be able to establish and verify a base-line. We have been fortunate in establishing this base-line as long ago as 1973, when extensive aerial photographic cover, together with some ground survey results, was available to assist interpretation of an early cloud-free Landsat scene.

Areas of natural vegetation are much less easy to characterize unambiguously from satellite imagery than is the case with agricultural land. Natural vegetation is less homogeneous than crops or agricultural grassland; physical boundaries are usually less distinct; spectral response tends to be more variable; and topographic variables such as slope and aspect tend to be more extreme, at least in upland areas, leading to areas of apparent contrast which may have little to do with the vegetation cover.

It has been possible to construct maps of broad structural vegetation types, such as those depicted in Plate 8a. The vegetation classes in this map appear to match well with ground observations, and a detailed evaluation against aerial photographic evidence is now in progress. While such a map providing synoptic cover over the whole of a region such as Wales would certainly be better than anything presently available, its ability to distinguish land cover types is too crude for most ecological and conservation applications. It is therefore clear that considerably more work is required on improving our ability to recognize and distinguish important natural vegetation communities from remotely sensed data.

In the case of land used for agriculture and forestry, classification problems are less acute. Plate 8b demonstrates the use of multitemporal imagery to identify areas of forest change in the 20 km x 20 km survey area. Further field work is necessary to identify the precise nature of the changes that are recorded. For example, an apparent increase in forest cover may be the result of canopy closure, rather than new planting. Similarly, reduction in cover may be the result of either thinning or felling. By counting pixels in various classes, it is possible to make a quantitative estimate of the rate of change. For example, in the case of this particular scene, there was an apparent increase of 1072 ha (2.7%) of mature forest canopy during the period 1975-82. This estimate is currently being compared with Forestry Commission records and with the evidence of field survey and aerial photography.

4 Summary of future research needs

4.1 Spatial resolution

Early generation Landsat imagery has often been criticized for its relatively poor spatial resolution. Leaving aside the question of how to measure the spatial resolution of a digital sensor, it is, of course, self-evident that Landsat MSS imagery is much inferior in this respect to conventional aerial photographs.

However, for purposes of large area survey, the ability to record an integrated synoptic picture is important and, except when individual vegetation stands are of interest, poor spatial resolution may well be less of a constraint than has been suggested in the past. Sensors with improved spatial resolution are already available. Few people can fail to be impressed with the quality of the published imagery from the Landsat Thematic Mapper (Townshend *et al.* 1983), and the French SPOT satellite offers the prospect of even better spatial resolution. Nevertheless, as Forshaw *et al.* (1983) point out, for purposes of ground cover classification, improved spatial resolution can be a mixed blessing as within-class variability is substantially increased. The imagery records real physical differences which are superimposed on the variation due to differences in cover type. For synoptic mapping purposes, the smoothing effect of low resolution sensors may prove, in retrospect, to have been no bad thing! If Thematic Mapper data and other high resolution sources are to be used for these applications (as inevitably they will be), then it is imperative that more sophisticated classification algorithms are developed to allow the data to be fully exploited.

4.2 Radiometric resolution

Much of the work on distinguishing and classifying land cover types has hitherto been based on empirical analysis and manipulation of multispectral imagery. The powers of discrimination of existing sensors have largely been limited by the choice of bands. New sensors such as the Thematic Mapper, which records in 7 bands, promise considerable improvement in species discrimination and in vegetation health studies. There is an urgent need for a programme of work using ground-based radiometers, under carefully controlled conditions, (i) to investigate the detailed reflectance characteristics of the various vegetation canopies of interest for wide area mapping, and (ii) to monitor these characteristics under various conditions of illumination. This programme is required in order to understand better the relationships between vegetation community composition and spectral response. Such a programme will also furnish useful information for the design of future sensors.

4.3 Another area where information is sparse, and potential benefits are great, is in the use of RADAR imagery for vegetation mapping. RADAR remote sensing offers the prospect of an all-weather monitoring system, capable of returning detailed information on surface texture which, allied with multispectral imagery, could greatly enhance our ability to classify land cover types.

4.4 Extrapolation in space and time

Large area mapping and multitemporal analysis make the basic assumption that it is possible to apply statistics from training sets in one scene or in one portion of a scene to other images. This assumption is not entirely valid. Large area mosaics composed of several Landsat scenes inevitably exhibit perceptible differences in contrast across the composite image (Merson 1983). Neighbouring scenes are not necessarily imaged on the same day; the problem is even more acute in multitemporal studies. The effects of different sun angle on plane surfaces are easily corrected. The effect of topography, and, in particular, differences in slope, can only be dealt with satisfactorily if terrain data are available in digital form. This is rarely the case. Atmospheric conditions also affect image quality and, until procedures have been devised which are capable of routine systematic correction for these variables, it is not possible to envisage the regular use of automatic classification of remotely sensed imagery for land cover monitoring. However, remote sensing, in combination with other relevant data sources and in the hands of informed and experienced operators, does offer the prospect of a cost-effective surveillance and monitoring capability that could not be satisfied by other means.

5 Summary

The paper reviews the use of digital remotely sensed data from air and space for land cover survey and for monitoring change in land cover. In particular, interactions between agriculture and areas of importance for wildlife and conservation are considered.

The paper outlines the techniques involved, including the characteristics of the more commonly encountered sensors and platforms, and reviews existing and future sources of remotely sensed imagery. Data analysis procedures, including methods of correction, enhancement and examination of digital imagery, are described.

The preparation of land cover maps from remotely sensed data is reviewed, and examples of the use of remote sensing to monitor the change in type and extent of cultivated areas are presented. The suitability of the method for deriving quantitative estimates of land cover and rates of change at synoptic scales is demonstrated, and the value of these techniques for assessing the ecological impacts of agriculture is indicated.

Limitations in the data and in existing analytical techniques for these purposes are noted, and the need for further research in the following areas is suggested.

i. Understanding the mechanisms which determine the characteristics of integrated radiance signals derived from a wide range of land cover types and, in particular, from complex natural vegetation communities.

ii. Investigating the effects of seasonal change on the reflectance characteristics of various land cover types to improve powers of discrimination.

iii. Solution of the problem of classifying structural vegetation types with non-uniform reflectance characteristics. This problem is exacerbated with increasing spatial resolution.

iv. Development of procedures to correct imagery for variation in experimental conditions (eg differences in irradiance levels, look angle, sensor characteristics) to facilitate extrapolation of the results of image classification both in space and time.

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Wildlife as disease carriers

H V THOMPSON
Cantab Group Ltd, Rose Cottage, Lower Farm Road, Effingham, Leatherhead

1 Introduction

Wild mammals and birds, to which this paper is confined, have many diseases and provide reservoirs of infection which may be passed on to domestic animals and man. Since I reviewed the subject some years ago (Thompson 1961), there have been major agricultural changes, even in our stable and settled conditions, and a quickening interest in epizootics. Because of its geographic isolation, Britain is relatively free from disease, even compared with mainland Europe, and this situation can lead to a complacent attitude that is all too easily shattered when an infected animal slips through quarantine and an alarm is raised.

2 Viruses

Rabies provided alarm in 1969, when a rabid dog was at liberty on a common in the Camberley area of Surrey for some 50 minutes, after it had bitten its owner. The dog had been imported from Germany and there were fears (fortunately groundless) that British wild mammals might have become infected. Starting from Poland in the 1940s, rabies in wildlife, especially foxes, has spread across central and western European states and eastwards into the USSR (Steck 1982). Other wild mammals and domestic mammals, particularly cats, have become infected, but there have been few human cases. In the USSR, wolves and wolf-dog hybrids may be rabid and cause concern, as in Kazakhstan, because of attacks on man (Cherkasskiy 1983). The 1969 incident led to increased research on fox biology, both in state laboratories and in universities, to an official Inquiry (MAFF 1971) and a tightening-up of quarantine regulations, with severe penalties for offenders.

Myxomatosis is a disease limited almost entirely to rabbits, and occasionally hares, but is mentioned here because of the immense effect of rabbits on habitats and on agriculture and forestry. The introduction of the disease to Britain in 1953 and its subsequent spread in 1954-55 greatly affected the natural scene and encouraged the cultivation of downland and some former upland grazings. It also led to an expansion of research on the disease, the effects of rabbits on vegetation, rabbit biology, behaviour and control (Fenner & Ratcliffe 1965; Fenner & Myers 1978; Ross 1982).

Foot-and-mouth disease poses problems in many parts of the world, and the involvement of wild animals in its epizootiology is little understood. Wild birds are often suspected of carrying this and other diseases and the subject has been reviewed by Keymer (1958), and by McDiarmid (1962). Starlings, for example, have often been suspected, on circumstantial grounds, of being mechanical carriers of foot-and-mouth disease, but Murton (1964), Thearle (1968), Snow (1968), and Feare (1980) were unable to find convincing evidence.

Newcastle disease, or fowl pest, puts the national poultry flock at risk, and there is a need for more research on wild birds in this context and, especially, on the hazard posed by the trade in captive birds which come from all over the world, but particularly alarmingly from some African countries and the Far East. Ashton (in press) has drawn attention to the dangers of spreading this disease, and also psittacosis, influenza viruses and others. On 6 February 1984, the UK Government banned the import of all cage birds because of an outbreak of Newcastle disease at quarantine stations in north London and Essex.