AERIAL PHOTOGRAPHS AS RECORDS OF CHANGING VEGETATION PATTERNS

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ABSTRACT

Aerial photographs provide baseline data on vegetation for monitoring subsequent changes, and may form a unique historical record of vegetation patterns. In using historical photographs to measure change, the ecologist has to be aware of the problems of interpretation and the difficulties caused by distortions, which may restrict the methodology used and the accuracy achieved; but, as long as the errors can be shown to be small in relation to the changes observed, valuable results can be obtained.

Some of the solutions to the problems are illustrated, by reference to a number of studies, with particular emphasis on techniques that can be applied by ecologists, often with limited resources, and with little training in photogrammetry.

INTRODUCTION

Plants establish, grow and die, so that even the most stable ecosystem is, in fact, dynamic, with measurable changes in time. In addition, man has continually reshaped the landscape, and a true climax vegetation is almost unknown in Britain. We can all tell of areas where the countryside of childhood memories has changed, almost beyond recognition. Yet can we give an accurate, let alone objective, account of what those changes have been? If ecologists are to advise on environmental management, to predict the results of developments, or assess the impacts of past activities, it is essential that they understand, and can communicate the nature, causes and extent of changing vegetation patterns.

Aerial photographs provide one of the most detailed and comprehensive records of changing vegetation cover, in Britain, over the last half century. They extend back to the 1920s (Howard 1970; St Joseph 1977) and cover, well, the period from about 1945 to the present. The quality of the early photographs, in terms of definition, is often as good as that of modern photographs, and the scales are usually compatible with mapping and measurement of plant communities. They may provide evidence of long term changes which can be studied within the duration of short term projects. Perhaps most importantly, the evidence is preserved for all to see and assess for themselves.

SOURCES OF PHOTOGRAPHS

Many of the early aerial photographs were taken by the Royal Air Force (RAF) but those taken before 1945 are relatively scarce and not fully catalogued. From 1945 onwards, the UK Town and County Planning Departments agreed free access to RAF aerial photographs with the Air Ministry. The Air Photographs Units of the Department of the Environment, the Welsh Office and the Scottish Development Department now maintain collections of early RAF material, Ordnance Survey (OS) material over 10 years old, and hold details of more recent OS, RAF and commercial sorties (Brotchie 1979). OS hold their recent cover at Southampton and other organizations, such as the Cambridge University Committee for Aerial Photography, maintain collections of their own prints. Keele University have a unique collection of prints covering western Europe, but not the UK, taken between 1939 and 1945. Local authorities may often commission, or know of the existence of aerial cover of their area. Unfortunately, systematic large scale coverage of the UK has apparently declined in recent years. In 1964 the Air Ministry decided that the RAF could no longer accept a planned flying programme (Brotchie 1979). Since then, OS has undertaken a programme of major revision involving photography, mainly in the early 1970s. But future large scale re-surveys seem likely to be piecemeal. RAF have covered the country at 1:50 000 in 1980/81. Landsat and other space imagery may fill some of the gaps. However, photography at scales between 1:2500 and 1:20 000 will remain an important source of data for ecologists.

TYPES OF PHOTOGRAPHY

The earliest prints generally available are oblique views, made by organizations such as Aerofilms. Most 1945-64 cover was taken by the RAF using the split-vertical, or split-pair format, where 2 parallel runs of photographs were taken simultaneously, using 2 cameras, one inclined to the left, one to the right of the flight run, at between 10° and 15° to the vertical: full stereoscopic cover gives the normal 3-dimensional model when overlapping prints are viewed with a stereoscope. Split-verticals can usually be recognized by the fact that they are 165 x 215 mm (6½ x 8½ inch) instead of the now more usual 230 x 230 mm (9 x 9 inch) (Sewell 1966); often F21 or F22 is marked in the margin indicating that a fan of 2 cameras was used and that a print is from camera 1 or 2 respectively. Sometimes a 5-camera system was used, as may be evident from the F41-44 classification, with a simultaneous V or Vertical run. From the mid 1960s, most 'vertical' aerial photographs in the UK were taken with the camera axis tilted by no more than 3°.

PROBLEMS OF USING HISTORICAL AERIAL PHOTOGRAPHS

Firth (1973) points out that much of the work done with aerial photographs has been unsatisfactory, because the people who used them were unfamiliar with the nature of the material they were handling. Few ecologists have had formal instruction in the use of photographs, as part of their training in the methods of surveying vegetation. So, although nearly all British ecologists will have looked at photographs of their study sites, perhaps published sketch maps made from them to illustrate papers, or maybe used them to help stratify a sampling programme, in practice ecologists have made surprisingly little use of the detailed information that aerial photographs can provide (Goodier 1971); this would seem to remain the case in a recent survey of remote sensing users (Lindsay 1981). This is not because vegetation patterns show badly on aerial photographs, for photographs are frequently used in forestry, while soil scientists and archaeologists, for example, rely heavily upon differences in vegetation patterns to enhance the features that they seek to identify from aerial photographs (St Joseph 1977).

Too many published accounts of aerial mapping, in ecology textbooks, place emphasis on the advantages of different films and filters, of non-photographic sensing, of changing season and scale, without giving enough detail to allow ecologists to successfully use photographs already in existence. With financial constraints on research it is common to rely upon existing material rather than to commission new surveys. Furthermore, when commissioning a survey, such advice should be available from the survey company. One important textbook *Aerial photo-ecology* by Howard (1970) covers both theory and practice but needs updating with information on new equipment available. Also, the book makes little mention of the use of historical photographs and the special problems involved with them.

In using the perspective view provided by aerial photographs, allowance must be made for displacements, and the distortion of scale caused by tilts of the camera, or relief on the ground. The large scale foreground and small scale view into the distance, compressed into the frame of a high angle oblique photograph, is just an extreme example of the sort of distortions encountered with any tilted photograph. The way in which tall buildings and trees 'lean' away from the centre of a print just illustrates how high levels of relief can cause displacements on the photograph, as well as producing varying scales with points at varying distances from the camera. Maps made from uncorrected photographs are not likely to be accurate but people read maps as if they were without any error: yet, even OS maps are subject to errors (Harley 1975). Anyone using aerial photographs to map or measure a changing landscape should be confident that the changes observed are greater than the likely errors attributable to the methodology.

The large angles of tilt on some historical photographs, combined with the usual problems of relief displacement, may be further complicated by lens distortions and print shrinkage. Images may also have been lost or partially obscured by cloud cover, shadow, haze and reflected glare. Some photographs were taken with only minimal overlap and it is not possible to work in stereo; or the interval between frames was set wrongly and only perhaps 40% overlap was achieved giving runs of alternating stereo and mono blocks. The reaction might be to discard poor quality photographs; but, if they alone show the information required, then it should be possible to make use of them. Versatile methods of aerial photo-mapping may be needed to cope with such problems which arise all too frequently in historical studies.

In using historical aerial photographs it is not, of course, possible to verify the results of the subjective processes of photo-interpretation by conventional ground truth survey. But it is usually possible to find corroborative evidence in the field or in documents. And, of course, the photographs remain as, perhaps, the best check on the historical ecologist's interpretation.

THE GEOMETRY OF PERSPECTIVE VIEW PHOTOGRAPHS

Many accounts of the geometry of aerial photographs are available in photogrammetric textbooks (Born 1966; Tewinkel 1966; Howard 1970; Kilford 1973; Wolf 1974; Lo 1976), so it will suffice to mention only the conclusions here.

The scale of an aerial photograph is determined basically by the focal length of the camera lens and the flying height of the aircraft. If a feature is higher or lower than the datum set for determining flying height, then it will be at a larger or smaller scale than the surrounding land (Figure 1). The scale of a vertical photograph is given by:-

$$S = \frac{f}{H - h}$$

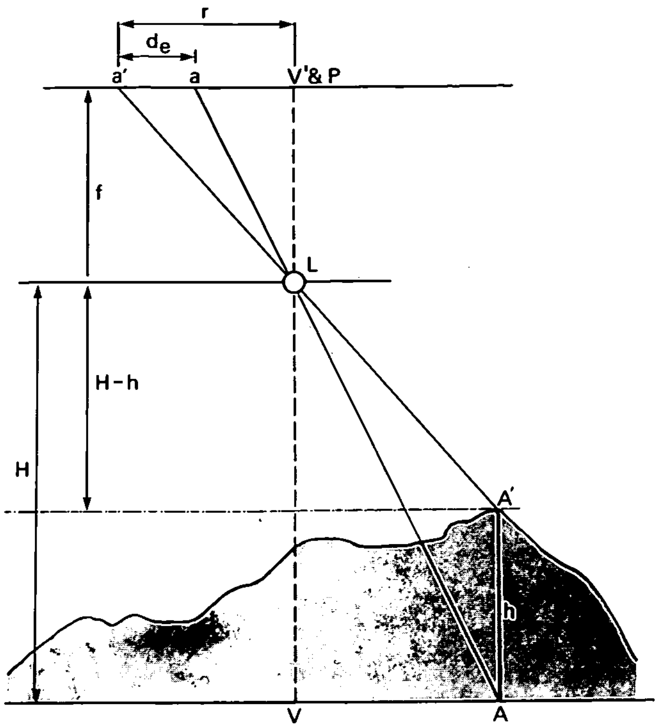
where:

S = scale

f = focal length

H = flying height

h = height of an object above datum



f - *focal length of camera*

H - *flying height*

h - *height of A' above datum*

A - *vertical projection of 'A' onto the datum plane*

L - *camera lens*

P - *principal point*

V - *nadir point*

V' - *image of V on negative*

d_e - *displacement of a' (image of A') from a (its planimetrically correct position)*

Figure 1 *Photographic image displacement caused by relief variation*

An object above the datum will also appear to be displaced from the centre of the photograph; in fact, it is displaced from the nadir point, which is the point where a plumb line through the perspective centre would meet the photograph (Figure 1). The amount of displacement is given by:-

$$d_e = \frac{rh}{H} \quad \text{(for a vertical photograph)}$$

where:

d_e = displacement

r = distance from the nadir point

This displacement may be used profitably in calculating heights, for example of topographic features, buildings or trees.

Tilt also causes scale distortions and displacements, in this case from the isocentre, a point midway between the nadir point and the principal point or centre of the photograph (Figure 2).

Tilt displacement is given by:-

$$d_t = \frac{y^2}{(f/\sin t)-y}$$

where:

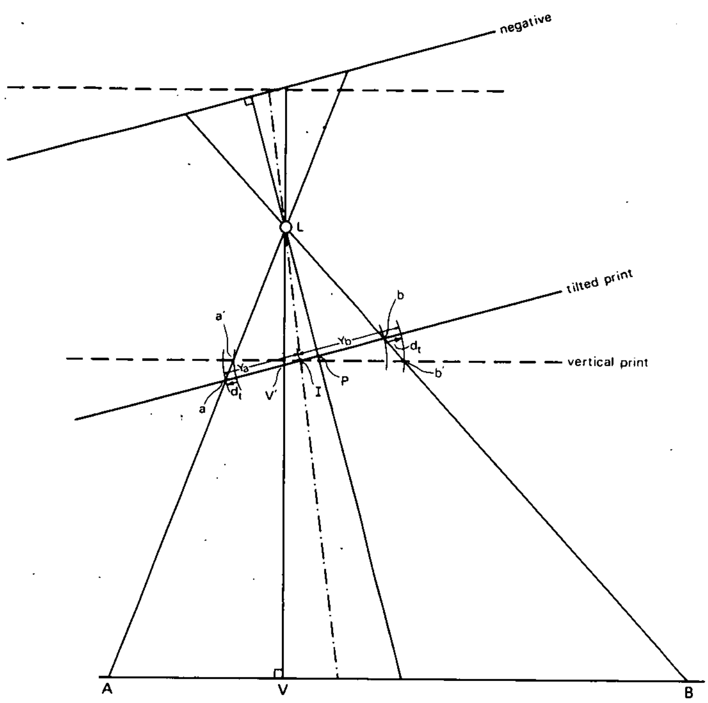
d_t = displacement of point due to tilt

y = distance from isocentre to the point

t^{o} = angle of tilt

The scale of an image on a tilted photograph is given by:-

$$S = \frac{f - (y \sin t)}{H - h}$$



L - *camera lens*

P - *principal point*

V - *nadir point*

V' - *image of V*

I - *isocentre*

a', b' - *images of ground features A and B*

d_t - *displacement due to tilt of a and b (tilted images of A and B) from their planimetrically correct position*

Figure 2 *Photographic image displacement caused by a tilted camera axis*

Lens distortions and print shrinkage are small sources of error where metric aerial cameras have been used; so from a knowledge of the flying height, lens focal length, relief variation, maximum likely tilt and extent of the photographic area to be mapped, it is possible to calculate, approximately, the maximum likely levels of error involved, firstly, in placing features and, secondly, in scaling features, if maps are produced from photographs without applying correction for distortion.

RAF split verticals were generally taken with 508 mm (20 inch) lenses, long compared with the 152 mm (6 inch) lenses more commonly used now on metric mapping cameras (Sewell 1966). This means that the flying height is greater, for any given scale, making relief variation a smaller problem than it would be with a shorter lens; also,the tilt required to achieve 5-10% side lap is reduced. However, 10-15° of tilt is still needed at typical scales of around 1:10 000. High flight also means that the stereomodel, seen when adjacent pairs of photographs are viewed stereoscopically, is less exaggerated than that of modern photographs, making textural patterns a little less distinct in stereo and relief a little less obvious. In practice, though, this is rarely a problem. The need to correct for distortions caused by tilt, relief variation, film or print shrinkage and lens distortions depends upon the uses to which photographs are put.

THE PRACTICAL USE OF AERIAL PHOTOGRAPHS

Aerial photographs may be used simply for qualitative purposes, for inventory and for linear, areal or volumetric measurements.

Inventory

A search for signs of plant disease (Risbeth 1977) may involve no measurement on the photographs, and,therefore, no correction for distortion. Counting trees or animals can be done from oblique photographs without correction, just as long as the oblique view does not allow the objects of interest to 'hide' behind taller features. Peterken and Hubbard (1972) used photographs taken in 1939, 1942, 1962 and 1967 to follow changes in the populations of holly trees growing on shingle at Dungeness, Kent. Aerial photographs have commonly been used for forest inventories (Howard 1970) and census of large animals (Perkins 1971; Vaughan 1971; Milton & Darling 1977).

Linear measurements

Linear measurements over short distances on photographs can be made just with local correction to scale; width of ditches, diameters of bushes are examples. Over long distances, the image of a linear feature may significantly change in scale along its length and allowances must be made for this. Pollard *et al.* (1974) measured hedgerow losses using 1946 and 1962/63 aerial photographs, plus ground survey. As hedges appear as boundaries on OS maps, presence-or-absence information was transferred from photographs to existing maps, later to be measured accurately from those maps (Hooper personal communication).

Simple areal measurements

Measurements of area, if made without correction, will be subject to a greater proportional error than linear measurements. So more careful corrections may need to be made where areas are to be calculated. The equations given earlier allow a user to make an assessment of the potential errors. Again, a distinction can be made between small features, where scale distortions within may be considered uniform, and larger areas where they vary across a feature. Where errors require correction, various methods are available.

In a study that the Institute of Terrestrial Ecology (ITE) has just started, on drainage and land use on the Romney marshes, field types can be discerned on 1946 aerial photographs. The field boundaries, as shown on the OS 1:10 560 map (revised 1930-45), remained largely unchanged in 1946. In order to map land use it was generally only necessary to add the information on field types to the map, before measurements were made. Essentially the photo-interpretation was qualitative, with only occasional need to record the position of new boundaries.

Monoscopic transfer methods

Usually the ecologist will wish to add vegetation boundaries, of his own interpretation, to the boundaries and other features shown on existing OS maps. If this is the case, more sophisticated techniques are needed. But as Maling (1971) states, this is still really a revision of existing maps, in a rather specialized way. OS maps will usually form a suitable base of known accuracy. Built-up areas are mapped at 1:1250; most others are 1:2500, with mountain and moorland covered at 1:10 000 or 1:10 560 (Harley 1975).

A very simple method of transferring photographic detail on to OS maps is to project the image of the photograph, or a tracing of information made from it, on to the OS map; the image is enlarged or reduced to match the scales of the map. Hubbard (1965) mapped cord grass (*Spartina* spp.) invasion in Poole Harbour, Dorset, from 1924 and 1952 photographs fitted to the 1925 OS 1:10 560 map, using fixed points along the shore and photographic reduction to match the scales.

I have used a *Grant Projector* on various occasions to transfer details, which were traced under the stereoscope, of vegetation on flat coastal and wetland areas. This instrument allows the projected image to be reduced down to ¼x or enlarged up to 4x, but makes no correction for tilt. By fitting small areas of detail to local OS map features, it is possible for the operator to vary the enlargement factor as he works across a print, so compensating for scale changes caused by tilt. Using this method, paths were surveyed on the dunes at Winterton, the study backed up with ground surveys of the path networks (Boorman & Fuller 1977). The spread of *Rhododendron ponticum* on this site was studied using 1946, 1953 and 1973 aerial photographs at 1:12 00C, 1:5000 and 1:2500 respectively, and a ground survey made in 1972 (Fuller & Boorman 1977). Although no estimates of error were made, the 1946 dune photographs clearly showed very few bushes; by 1953 they covered 0.6 ha of dune, and by 1972 had spread to occupy *c*. 5.6 ha. Such changes could clearly not be explained in terms of mapping errors.

Reedswamp die-back in the Norfolk Broads was studied, under contract, for the Nature Conservancy Council (Boorman *et al*. 1979). Reed species, growing in water, were interpreted from aerial photographs viewed under the mirror stereoscope, and the outlines traced on to clear acetate overlays using a 0.15 mm pen with etching ink. Control points were also marked on to the acetate tracings; the same points were taken from OS 1:2500 sheets and marked on to a matt tracing film. The Grant Projector was then used to correct the scales of the acetate tracings, by projecting the information on to the film. By fitting detail locally, tilted images were corrected and transferred with reasonably accuracy. Eighteen Broads were mapped, representing 82% of the total water area of *c*. 35 Broads shown on OS 1:50 000 maps (excluding Breydon Water). For every site at least 4 sorties of vertical photographs were found, with 8 available at one. A total of 80 maps was produced from prints representing 47 films of vertical photographs. Also, 19 oblique flights provided checks on interpretation. It was possible to check some results against published data on Broadland vegetation.

The consistency of values for the total area (water plus reedswamp) of each Broad over the years 1945-1977 gave an indication of mapping accuracy. These values may have fluctuated because of real changes or because of errors (or a combination of both). In no case was the fluctuation greater than ±4% of the mean area. In the 6 Broads, where 6 or more maps were made. the differences in total area never exceeded ±1.5% ($P < 0.05$). As the reedswamp-to-water boundary was more clearly discernible than the land-to-reedswamp boundary, the values calculated for reedswamp are believed to be as accurate as those for total water area.

Photographic data were supplemented with OS map data; the results showed that losses, by die-back to open water, had been greatest at some time in the period between 1946 and 1963, minimal between 1963 and 1970, and had increased again from 1970-1977. This seemed to be related to periods of high coypu numbers (Boorman & Fuller 1981). Coypus, large South American rodents of wetland areas, had been released from fur farms in the 1930s, and populations had apparently grown exponentially in Broadland (Figure 3). However, the cold winters of 1946-47 and 1962-63 had reduced numbers drastically, and through the period 1963-70 a combination of trapping and cold winters had kept numbers down. From population and food intake figures supplied by L M Gosling of the Ministry of Agriculture, Fisheries and Food's Coypu Research Laboratory (personal communication), we were able to calculate the likely food intake of the animals during the period from 1930 to 1977. The total biomass of reed lost represented about 27% of the coypu food intake in that time. By modelling the effect of coypu taking reed as 27% of their diet, values being calculated year by year, a predicted decline curve was calculated (Boorman & Fuller 1981). This compared closely to actual values measured from aerial photographs (Figure 3).

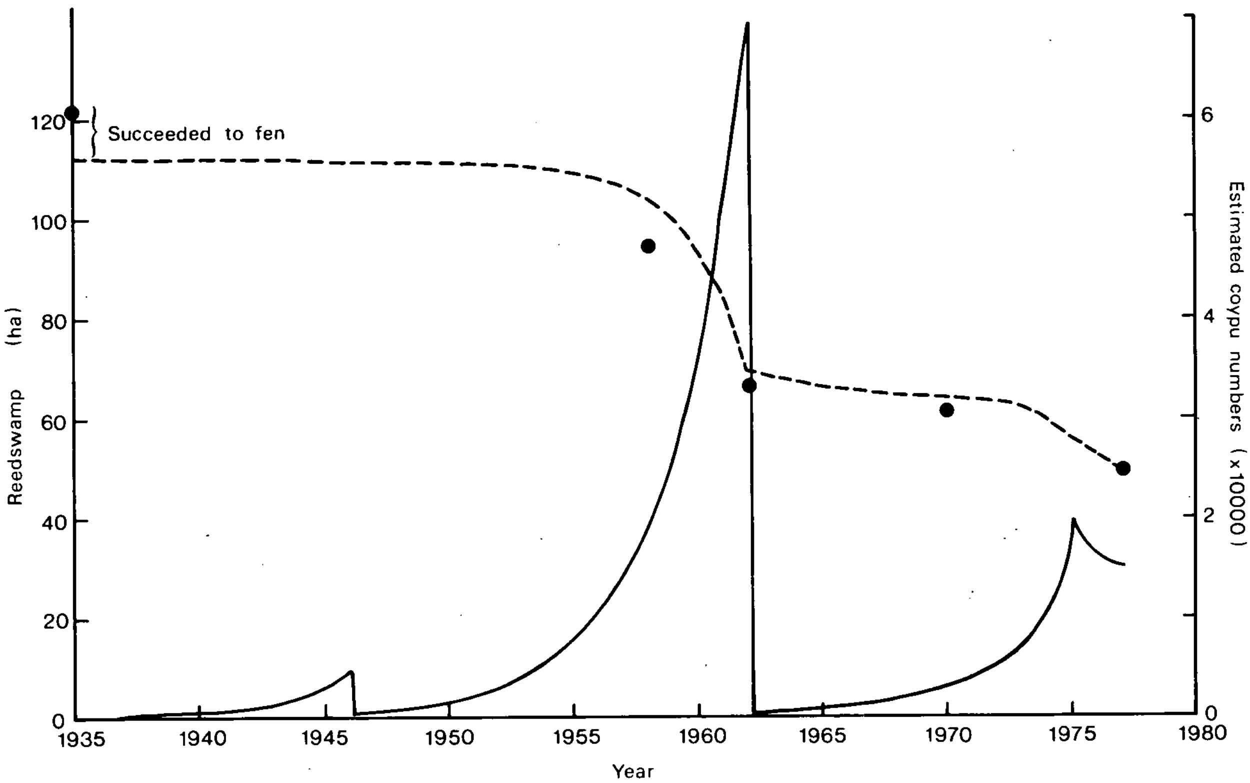


Figure 3 *Changing coypu population (——) and reedswamp areas (1935–1977) as measured from aerial photographs (●) and as predicted with coypu taking reedswamp as 27% of their diet (- - -)*

The use of this very simple method for mapping reedswamp had been very successful. However, we were only identifying 2 basic habitats, open water and reedswamp; and reedswamp only consisted of 2 major species *Phragmites australis* and *Typha augustifolia*. Being marginal vegetation, relief was non-existent, and the degree of change observed was so marked that great accuracy was unnecessary. But it should be realized that the Grant Projector has inherently bad optical qualities and that the method of correction is unsophisticated, and dependent very much on the skill of the operator. Other similar instruments such as the *Rost Plant Variograph* are optically better but expensive for the level of correction they offer.

Most transfer instruments allow some correction for tilt, and details are provided by Pennington (1966) with further and more recent detail given by Wolf (1974) and Lo (1976). Instruments based on the *camera lucida* principle are common. The *Vertical Sketchmaster* (by Aero Service Corporation) and the *Aero-Sketchmaster* (by Zeiss Aero-topograph) are examples of such instruments. When using a Sketchmaster, the operator sees the map to be revised through a double prism, superimposed on the aerial photograph. Map and/or photograph magnifications can be altered to match scales, and the photo-holder can be angled and rotated to eliminate some of the effects of tilt. But Maling (1971) suggests that it is a difficult instrument to use.

Another far more sophisticated example of a mono-scopic transfer instrument is the *Bausch and Lomb Zoom Transfer Scope (ZTS)*. Working on a similar principle, it provides a zoom control to magnify or reduce the photograph to match the base map. An optical stretch facility can be used to provide an equal and opposite distortion of the photograph to that caused by tilt and relief variation. McGivern *et al.* (1972) state that "..... the accuracy obtainable with the ZTS can meet (US) National Map Accuracy Standards".

Stereoscopic transfer methods

Photographs viewed under the stereoscope are much more easily interpreted; textures are enhanced, shadow penetration is improved, and clues to interpretation are more numerous. Furthermore, the effects of relief are readily appreciated, so that corrections can be applied more easily. Where an inadequate supply of control points exists, features of relief can be fitted to map contours.

Where stereoscopic viewing is needed to assist during interpretation, it is necessary, with monoscopic transfer instruments, to annotate the photographs using a conventional mirror stereoscope and, subsequently, transfer the details in a second stage of mapping; but stereoscopic transfer instruments are available.

The *Hilger and Watts Stereosketch* is a subjective projection instrument (Lo 1976) which provides stereo-viewing of paired photographs, together with a third image of the base map seen in one eye. Tilts of up to 5^{o} (x and/or y) can be corrected, and photographic scale can be altered to accommodate 1:0.45 to 1:1.25, photo-to-drawing scale differences. Unfortunately, this is not a sufficient range to match all standard photographic scales with available OS maps. A new zoom version gives a range of 1:0.8 to 1:4.5 which overcomes this problem. However, the tilt correction range will not cope with split-vertical photographs.

The *Ottica-Meccanica Italiana (OMI) Stereo Facet Plotter* offers the range of corrections needed for most mapping tasks. It allows the user to see a pair of stereo photographs superimposed over a base map of known scale. By means of a mirror system, the map may be distorted to fit the photograph, a method which may lead to problems during the transfer. But the biggest problem is that enlargement of photographs is achieved by mounting the photographs on glass stages at varying heights above the upward facing viewing head, the result being that, on lower enlargements, the prints are so high above his head that the operator cannot reach them, to manoeuvre them whilst looking through the optical system to achieve stereoscopic registration. However, the Royal Commission on Historical Monuments have used the instrument successfully in archaeological studies (Hampton & Palmer 1977).

The *Bausch and Lomb Stereo-Zoom Transfer Scope (S-ZTS)* is an instrument with all the other features of the monoscopic ZTS, but with increased magnification and stereoscopic viewing. It is probably the most sophisticated of the pure transfer instruments available at present. The S-ZTS consists, basically, of a mirror stereoscope with a zoom magnifying head. Independent zoom adjustments for each print mean that differences in scale, arising from altitude changes between exposures, can be accommodated by independent adjustments. Photographs can be enlarged from 0.6x to 16x actual size and the map to 1x, 2x and 4x actual size, giving an excellent range of working scales.

Distortions of the photographic images, caused by tilt and relief variation, can be corrected locally by providing equal and opposite distortion, on the S-ZTS, using the stretch facility. Initial adjustments are made with the instrument set in mono-mode but stereo can be selected and adjustments made to zoom and stretch of the second image, to match it to the first.

The S-ZTS is being used to map 300 km^2 of Broadland vegetation under a contract with the Broads Authority (BA), with Grant Aid from the Countryside Commission. Sixteen natural and semi-natural habitats are mapped plus 15 other land use classes, to provide 1:10 000 scale maps of the BA Executive Area. Accuracy of interpretation is being checked using 1:2000 stereo colour transparencies of sample quadrats in Broadland. The maps are being digitized at the Natural Environment Research Council (NERC)'s Experimental Cartography Unit (ECU) (Fuller & Drummond 1981) to provide data files that are then used to produce output maps, data on lengths and areas of features; finally, we have a versatile data set that can be used for analysis of change, to test for relationships between the distributions of different vegetation types and factors such as soil types, water quality, boat traffic densities or coypu populations.

The data are being made compatible with ECOBASE. This is a series of data files of environmental variables generated by NERC at ECU. It consists of digitized cartographic information on British hydrological and communication networks, urban and forested areas. The data will also form an example of high resolution data within the Terrestrial Environment Information System (TEIS) being developed at ITE Bangor as a result of projects on ecological mapping and described in this symposium (Ball *et al.;* Bunce *et al.*; Sargent). Parry (in press) has used the S-ZTS in studies of historical changes in the extent of moorland in the National Parks of England and Wales. They used, for example, 1953, 1966 and 1968 photographs and OS maps to follow the history of land reclamation and reversion in the Peak District, successfully coping with the problems of relief variation and large tilts, simultaneously.

Photogrammetric plotting

So far in this paper I have mentioned approximate techniques of transfer for subjective correction of the distortions of the aerial photograph. Conventional photogrammetry and analytical plotting both have an important place in ecological mapping. Other papers in this symposium, by R Fenton and I Dowman, make more mention of these techniques so I will not go into any detail on them. But I will make several points. First, some of these techniques will not cope with the large tilts found on split-vertical and oblique photographs. Secondly, few instruments will take prints, so new transparencies may have to be made. Thirdly, most rely upon the presence of full stereo coverage to make their transformations. Fourthly, they are techniques which are not suitable for use by untrained personnel. So ecologists wishing to use photogrammetric plotting techniques will either have to put in a large amount of effort in learning the methodology, or will be contracting the work out to another organization. This may often be the most appropriate way of making maps of unsurveyed areas, where transfer techniques cannot be applied, or for making maps at higher levels of accuracy. And although topographic maps can theoretically be made on a number of transfer instruments using floating spot lighting devices, the plotting machine or analytical plotter is more appropriate for this work.

CONCLUSION

The most important thing for the ecologist to remember is that, whatever method is used to map and measure from aerial photographs, an assessment of potential errors must be made if a sound analysis is to result from their use as records of changing vegetation patterns.

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