Visualising changes in historic landscapes

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Abstract

This paper describes the methods used to visualise landscapes in two study areas in the United Kingdom at multiple dates since 1946. The principal source of data was reconnaissance or air survey quality aerial photography with which high resolution digital elevation models and orthophotographic mosaics were derived. These enabled the creation of models for viewing in real time and for the creation of video fly-throughs to illustrate changes in landscape over the time period. In addition to visualising landscape, the effect of a change in landscape due to afforestation was evaluated using a predictive preference model for scenic landscapes. The results of the work show the potential for developing packages of educational and research material for exploring and communicating information about landscape and landscape changes.

1 Introduction

Appraisals of the type and extent of the natural resources of an area are required for effective decision making in environmental management from local to a national level. An appraisal for a single period in time provides valuable information, but only with information for additional years can assessments be made of natural or man-induced change in the landscape (Simmins and Hunsacker 1993, Hester et al. 1996) Such change may be historical or proposed and consideration of the nature and rate of change in landscapes is of importance to land managers and planning authorities. Typical uses of information on changes in landscape include its monitoring or surveillance to assess the effectiveness of policy decisions, such as changes within areas classed as priority natural habitats in the EC Habitats Directive (EEC 1992) or on the visual impact of afforestation and forest management (Haider 1994).

Methods for the identification, measurement and communication of changes in landscape may be grouped within five categories: textually descriptive, statistical, mapped, photographic (terrestrial and aerial), and modelled (usually, but not exclusively, with computing techniques). Often, it is a combination of different approaches which provides the most comprehensive impression of change and the principal issues, common to all, are: data capture (including census and sampling techniques); data processing for ensuring consistency in classification, geometry, reference system and level of detail; interpretation and measurement of features or classes; and presentation of the results. One limitation of many of the applications of these approaches to assessing landscape change is commutting a three-dimensional environment into two by the process of mapping and subsequently limiting the presentation and analysis of the results (Orland 1994, Berger et al. 1996).

The objective of this paper is to illustrate a combination of methodologies that enable the visualisation and evaluation of changes in the landscape. The methods are a coupling of geographic information systems (GIS) and a landscape preference model, for which digital photogrammetric techniques have been used to derive the input data for two areas which have undergone different types of land cover changes over time periods of approximately forty years. Therefore, the photographic data provides the basic data for the visualisation of the landscape at different dates and the input to the landscape preference model which enables an evaluation of the landscape at each date and thus a quantitative assessment of the change in the preference for the landscape over the time period.

2 Study areas

Examples of work in two study areas are presented: Glen Feshie in the Cairngorm Mountains of Scotland and Cwm Berwyn in mid-Wales (Figure 1). Both areas are rural and in the uplands but the landscape and landscape change is different in each area. The time periods between the earliest and latest datasets are approximately the same (forty-two years and thirty-eight years).

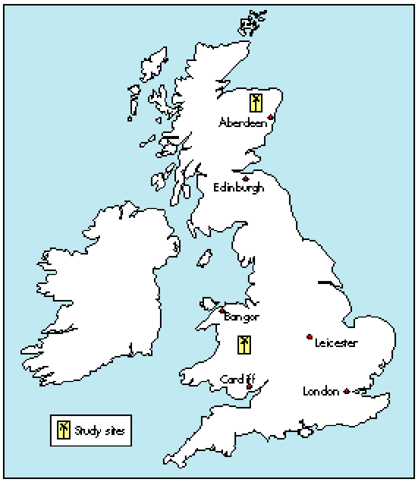

Figure 1. Location of the two study sites.

3 Methods

Aerial photographs were draped across Digital Elevation Models (DEMs) to provide input data for visualisation software with which:

1. single perspective views of the terrain were derived;
2. the model was manipulated in real-time to enable viewing at different resolutions, scales, perspectives and orientations; or
3. sequences of views compiled into video fly-throughs.

The aerial photographs used were for different dates for each area and thus comparisons could be made of the views of the landscape and change interpreted. The evaluation of the impact of afforestation on the preference of a view of the landscape used a landscape scenic preference model (Wherrett 1997) applied at times of pre- and post-afforestation.

3.1 Hardware and software

The digital photogrammetric software used was the ERDAS Imagine OrthoMAX product (ERDAS 1995) (licensed from Vision Inc. a subsidiary of Autometrics Inc), mounted on Sun Sparc stations 4/20 and 10/20, with 128 or 164 Mbytes of core memory. The processing times required for the production of the elevation models and orthophotographs are summarized in Tables 1 and 2. It was not possible to dedicate either of the machines to the and the principal impact of multi-users on the processing times will have been on the time taken to "swap" data in and out of memory. Consequently, the "user" time for the production of the datasets will have been greater than would be expected although the CPU time should be the same.

Table 1. Details of the data for the study site at Cwm Berwyn, Wales.

Date	1957	1975	1992	1995
Scale	1:20,000	1:26,000	1:10,000	1:10,000
Nomical Resolution (m)	0.6	0.82	0.31	0.31
DEM Resolution (m)	–	2	1	1
Orthophotograph Resolution (m)	1	1	1	1
Horizontal Accuracy (RMS, m)	+/-2.3	+/-1.3	+/-1.1	+/-0.9
Vertical Accuracy (RMS, m)	–	+/-1.1	+/-0.9	+/-0.7
Number of models	10	2	4	4
Total CPU time for DEMs (decimal hours)	–	36.4	24.9	27.3
Host Memory/Processor Speed	128 MB/ 120 MHz	128 MB/ 120 MHz	164 MB/ 200 MHz	164 MB/ 200 MHz

Table 2. Details of the data for the study site at Glen Feshie, Scotland.

Date	1946	1988
Scale	1:10,000	1:24,000
Nomical Resolution (m)	0.3	0.77
DEM Resolution (m)	–	2
Orthophotograph Resolution (m)	1	1
Horizontal Accuracy (RMS, m)	+/-3.9	+/-2.1
Vertical Accuracy (RMS, m)	–	+/-1.8
Number of models	9	4
Total CPU time for DEMs (decimal hours)	–	29.3
Host Memory/Processor Speed	128 MB/120 MHz	164 MB/200 MHz

3.2 Elevation models and orthophotographs

Aerial and terrestrial photographs provide a media for recording the content and patterns within a landscape at a level to which the scale and resolution of the photographs are capable. To ensure geometric registration of photographic imagery orthophotographic coverage has been derived for each set of aerial photography. Orthophotographs are photographic images which have been corrected to remove the effects of tilt and the topographic relief on the geometry of the photograph using photogrammetric software.

The photogrammetric software Erdas OrthoMax (Erdas 1995) was used to derive a model of the topography from the stereo photography to create a Digital Elevation Model (DEM). The DEM is subsequently used to correct the original digitized photographs to produce the orthophotographs. The output can then be processed to a specified scale and used as though it were a map, on which other map-based information, such as national topographic mapping data, soils or compartment maps may be overlaid. DEMs were derived for each date of photograph.

Figure 2 illustrates a DEM and associated orthophotograph for an extract from the Cwm Berwyn site. Features such as roads, rides, clear fellings and thinning lines can be identified from both the DEM and photograph. The value of deriving and using such large scale DEMs lies in resolving the detail of the changes in elevation sufficient to identify individual landscape features in the landscape in three dimensions (Miller, et al. 1996, Dralle 1997).

The photography available for Cwm Berwyn for 1975, 1992 and 1995 was near vertical, with focal lengths of approximately 152 mm, with two scales, 1:10 000 and 1:25 000. The 1957 photography was low oblique, 1:20 000 scale. For Glen

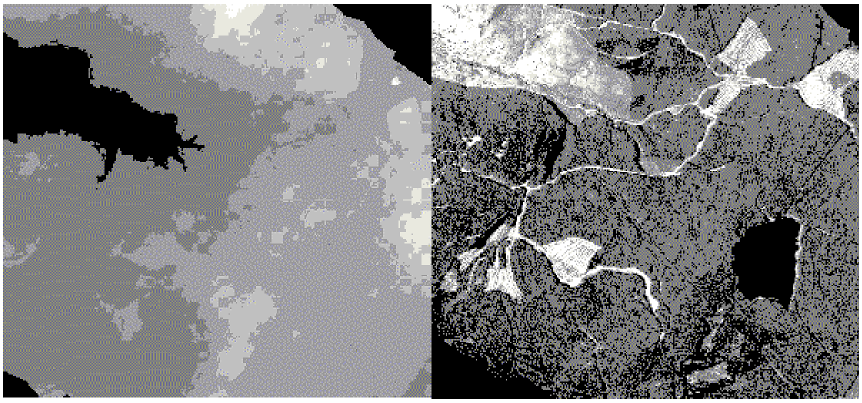

Figure 2. DEM and orthophotograph for an extract from the Cwm Berwyn study area (resolution 1 m vertical, 0.5 m horizontal).

Feshie, the 1988 photography was near vertical, at a scale of 1:24 000, and the 1946 photography was of the same low oblique, fan photography as that for 1957 for Cwm Berwyn. At least five fiducial marks on each photograph, for each of the three dates of vertical photography, were distinct and their locations easily measured and all four on the 1946 and 1957 photography. However, it was not possible to observe as many as eight fiducials on each photograph due to insufficient contrast between the mark and the background over which it was superimposed.

The photographs were scanned at 800 dpi, providing a ground resolutions of between 0.25 m and 0.8 m. The scanning resolution was selected to be higher than the spacing between the trees in the afforested sites, compatible with the accuracy of the ground observations and the manageability of size of the data files (Miller et al. 1994).

GPS (global positioning system) and large scale (1:2 500 or 1:10 000) map data was used for the ground control points, which were identified on the most recent aerial photography. The processing was in reverse chronological order. Therefore, for the Welsh site, once the data for 1995 was processed and checked additional points could be selected from the photography of that year to control and check the results for 1992. Similarly, the 1975 and 1957 data was processed and checked using the GPS observations and additional observations taken from the more recent years. The same approach was used for the Scottish site because of the relatively few control points identifiable on base maps of the area.

Creation of the orthophotographs for 1946 and 1957, using the RAF reconnaissance photography, required camera calibration information to be obtained from a museum but no details were available for tracking the specific camera that was used in the photographic sortie. This will inevitably lead to a lower geometric accuracy for the these orthophotographs. However, this, low oblique, photographic data covers over 95 % of the United Kingdom and it provides the most comprehensive source of data for interpreting land cover in the period 1945 to 1960.

Tests were conducted on the geometric accuracy obtained, in a regular pattern across the datasets, taking account of different slopes and aspects with respect to the principal point of the camera. Results of the test showed errors of up to 6 metres relative to the co-ordinates of the equivalent point at another date. The global accuracy for these datasets was an RMS of +/-2.3 m for Cwm Berwyn and +/-3.9 m for Glen Feshie, whereas the error for near vertical photography was between +/-0.9 m and +/-2.1 m.

Figures 3 and 4 show the sequences of orthophotographs, in plan view, for each site over the periods from 1957 to 1995 (Cwm Berwyn) and 1946 to 1988 (Glen Feshie). In each case, only panchromatic images have been produced, although some of the photography was taken in colour. Panchromatic output was selected due to the additional requirements for disk space of two dates of colour photography for a total of eight photographs.

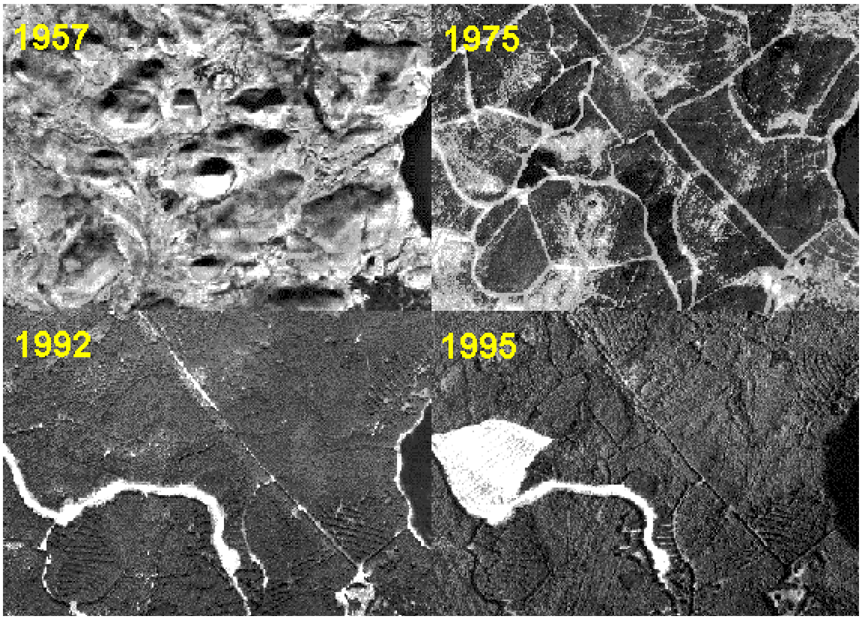

Figure 3. Orthophotographs of an extract of the Cwm Berwyn study area of each date: (a)1957; (b) 1975; (c) 1992; 1995.

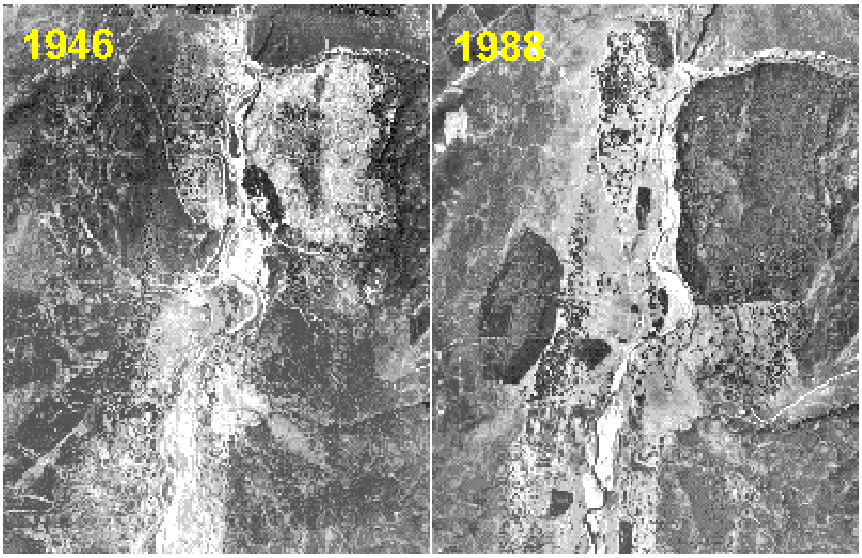

Figure 4. Orthophotographs of an extract of the Glen Feshie study area of each date: (a)1946; (b) 1988.

3.3 Photographic mosaics

The illustrative quality of the orthophotographic mosaics was maintained by minimizing the possible disjunction in appearance between adjacent photographs. This is achieved by either, using the same photograph for two adjacent models, thus ensuring that the common boundary of the models is 'seamless' or, where a choice exists, selecting those photographs which have the most consistent tonal, colour and reflective appearance. No processing of the digital photographs has been undertaken to reduce or remove the effects of shadowing whether due to the topography, at the edges of the canopy or in the wider spacings of the thinning racks.

In those cases where two different, adjacent, photographs are required, two steps are taken in the orthophotographic production: (1) matching the contrast levels of the two photographs; and (2) clipping the line of intersection between photographs to follow, so far as is possible, linear surface features which can be used to camouflage any mismatch at the boundaries. In an afforested landscape, there is considerable scope for following the edge of tree lines at ride, tracks, thinning and compartment boundaries.

One aspect of mosaicing aerial photograph which is independent of the reflective appearance is that of the geometry of the photograph with respect to the tree canopy. The pattern of the tree canopy, in a location which has been viewed from two directions, may result in an apparent mis-match. This has been mitigated by attempting to mosaic the photographs along a line, approximately bisecting the area of overlap.

3.4 Landscape preference model

The landscape preference model is a psychophysical predictive preference model for natural scenic landscapes. It uses objective measures of landscapes to predict how the general public would, on average, rank a number of landscape images. In summary, these models establish precise quantitative relationships between physical features of environmental stimuli and human perceptual responses (Daniel and Vining 1983). The creation of such a model is detailed in Wherrett (1998).

The particular model to be used in this research requires the measurement of eight variables, all of which are either the area or perimeter of a landscape component. The landscape image is divided up into seven landform types: flat land, low hill, steep hill, mountain, obscuring vegetation, water and sky. Unlike some other models created by Wherrett (1998) this model does not use variables related to colour or complexity in the landscape, and may therefore be used on models which are abstractions of reality, rather than direct photographic representations of landscape.

This model scores images between approximately +/- 2, with 2 being a high preference score and -2 being a low preference score. The model has an R^2 of 0.724, therefore explaining roughly 72 % of the variance in preference scores of the sample used to create the model.

4 Landscape change

4.1 Area 1: Changes in a Scottish Glen

The study site lies within the Glenfeshie Estate and an aspect of particular interest in this area is that it forms part of the east-coast (Speyside) native pinewood area described by Steven and Carlisle (1959). The area forms the high-lying hinterland south-west of the Cairngorm mountain range (Pimm 1979) and pinewoods are located on gentle to steep slopes from about 360 m to 500 m in altitude. Steven and Carlisle (1959)

The landscape preference model has the following form:

$$
\begin{aligned}
Y = const - a\cdot\left(\frac{1}{perimeter\_mountain\_landform + 1}\right) \\
+ b\cdot(areas\_of\_steep\_land + mountain\_land) \\
- c\cdot\left(\frac{1}{perimeter\_low\_hill + 1}\right) - d\cdot\left(\frac{1}{area\_flat\_landform + 1}\right) \\
- e\cdot area\_of\_flat\_land^2 + f\cdot area\_of\_obscuring\_vegetation \\
+ g\cdot \ln(area\_of\_sky) - h\cdot(area\_of\_sky) \\
- j\cdot\left(\frac{1}{area\_of\_water + 1}\right) + k\cdot perimeter\_of\_still\_water \\
+ \frac{m\cdot area\_of\_sea\_water}{perimeter\_of\_sea\_water + 1} - n\cdot perimeter\_of\_sea\_water^2
\end{aligned}
$$

recorded few trees under 130 years old with the oldest being around 200 years old. Very little regeneration was noted at the time. The study area was fixed by the limits of the aerial photographs used and covers 256 hectares of the estimated 445 hectares of the Glenfeshie native pinewood area.

The study area was segmented into sub-areas using a regular, square, grid and individual trees, or clusters of trees, were identified on the most recent photograph and the positions recorded as points, with two attributes: 1. identifying if the point was an individual tree, grouping of 2 to 5 trees or clusters of greater than 5 trees; 2. a subjective assessment of the degree of confidence in the interpretation. The point data was used as an overlay, draped across the orthophotographs for each of the other years and changes in tree presence (or absence) were added to the dataset. Gross areal changes were interpreted as polygon features.

Woodland was identified and mapped, with reference to the Forestry Commission definition of a pinewood as having at least 200 trees that are capable of inter-pollination and cone production (Forestry Commission 1991), and as points for individual trees, for each date, recording the confidence level with which they were interpreted. General land cover classes were also mapped and the boundaries compared with an analysis of the variability in the model by image processing techniques. A comparison of the datasets together reveals:

1. The loss and regeneration of native pine trees in each area;
2. The change in both spatial distribution of woodland and its density;
3. Identification of areas in which the (predominant) loss or (small) gain in woodland is most visible and a measure of the relative visibility of each land cover class.

Results of the interpretation show that about 18 % of the mature tree cover died between 1946 and 1988 with recruitment into the canopy over the same period of just over 2 % giving an overall loss over the period of the study of 16 %, equating to about 0.4 % per annum. The main losses appeared to have occurred between the 300–400 m although this may be the result of unrecorded fellings on the more accessible lower slopes. While recruitment was found to be greater on the lower elevation sites, it was not sufficient to balance the overall loss. The imbalance between losses and recruitment has been put down to the intensification of management within the study area during the period of the study and particularly in the 1980s.

Other features which are interpretable from the historical photography include:

1. The areas of clear-felling which occurred during World War II (WWII) by Canadian workers, which were replanted in subsequent years; replanting which took place around the individual pine trees that were not felled. Indeed the logging camps which were inhabited by the Canadian workers, and the current pattern of shelter woodland which since have been planted around the camps are also visible, one of

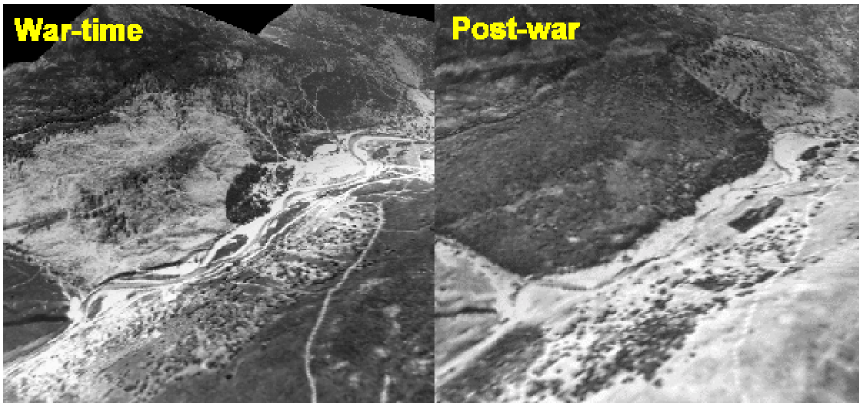

Figure 5. War-time / post-war replanting.

which remains in use as a farm in 1988. Figure 5 illustrates an area of clearfell in 1946 in which individual pine trees have been left on the hillside. In 1988 the woodland has been replanted with the new woodland surrounding, but leaving, the existing trees.

2. The pattern of muirburn on the hills, which would have been undertaken pre-WWII and with which comparisons can be made with more recent burning patterns (indicating almost no change in the rate of burning). Changes in the patterns of muirburn between each date can be related to changes in activity in land management such as grazing levels (Hester et al. 1996).
3. Comparison between the patterns of erosion and scree on the hillsides in the higher parts of the Glen for each date show where increased levels of erosion have occurred.
4. The vegetation patterns that occur on the geomorphological features such as moraines, kettle holes and alluvial fans.
5. The braiding of the river and changes in the route of its main channel between each date. This Glen is frequently subjected to flooding and changes in the route of the river will have occurred on many occasions over the forty year time period. Therefore, the routes identified at each date of photograph will be snapshots of a feature which experiences high frequency change.

4.2 Area 2: Growth of a plantation forest

Aerial photographic coverage of the study area for four different dates was used for a period of 38 years (Figure 4), which spanned the dates during which the land use was converted from upland grazing to forestry. Figure 6 shows perspective views of the area at each of three dates, created by draping the orthophotographs over the DEMs. The

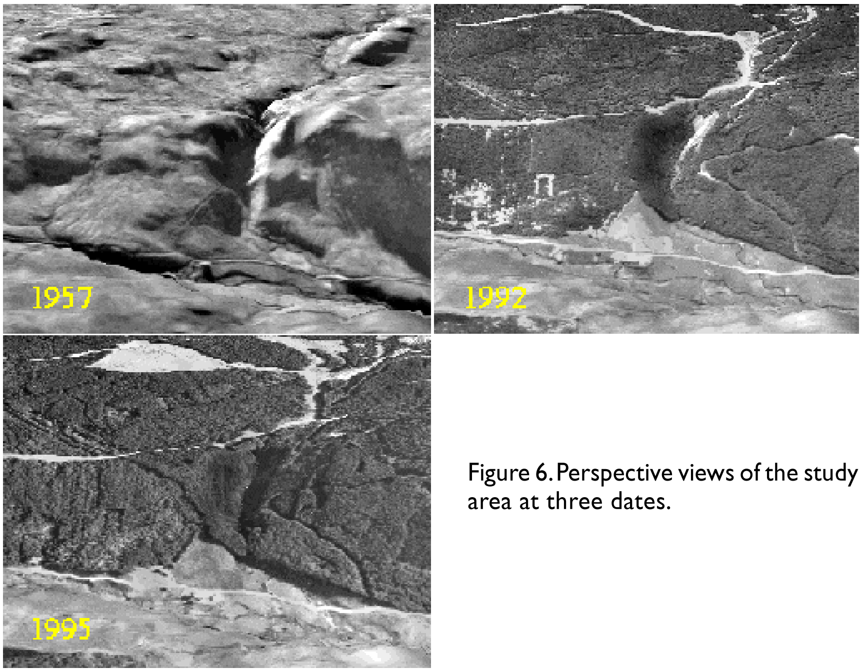

Figure 6. Perspective views of the study area at three dates.

embedding of the surface relief and height of the forest stand within the DEM provides a greater degree of foreground detail. The combination of the resolution of the photograph and the DEM enables the viewer to identify the patterns in the forest canopy due to thinning, clear-felling and wind-damage.

The changes in land cover and use over the time period are summarized below.

1957: Pre-planting, the land use was predominantly one of agriculture. The land around the Cwm and on the hill tops was used for sheep grazing and there were no trees in the area. An area of peat bog is interpretable to the south of the Cwm. On the lower slopes, in the valley which runs towards the west the land is enclosed and used for improved pasture and certain foraging crops.

1975: Planting or ploughing has taken place across almost all of the area since 1959, concentrating upon the hill tops and the land around the Cwm. However, some valley sides, previously below the head-dyke (the upper area of enclosed land) on the northern side of the valley has also been obtained for planting. The northern part of the peat bog has been planted but the southern half has been left untouched. The principal stocking species are also present as mixtures (Sitka Spruce/Lodgepole Pine and Sitka Spruce/Japanese Larch) across large areas of the forest with tree heights expected to be a maximum of approximately 8m. The stocking density across most of the forest is 2500 per ha (a spacing of approximately 2 m).

1992: By 1992 the trees were up to 33 years old and were measured in the field as being up to 20 m. The management of some areas has included selective thinning but no large areas of clearfelling. The canopy has closed across much of the forest, but some areas remain more open. Some areas can be identified as having a sparse canopy cover and are interpreted as under-performing. There is evidence of some wind induced damage, especially towards the north-east of the Cwm.

1995: By 1995 (36 years since first planting) the majority of the canopy was closed. Three large areas were felled between the dates of photography in 1992 and 1995 and the number, and extent, of the management units which have been thinned has increased substantially. Tree growth on the peat bog has been unproductive, with shrubs predominating. The areas damaged by the wind increased both in areal extent and in number.

5 Presentation of landscape changes

To aid in the presentation and communication of the changes in landscape over the forty years fly-through and video sequences were created for replay on either a Silicon Graphics video format or a PC (using QuickTime format and player). The use of a Silicon Graphics workstation (Onyx Reality Engine) provided a high quality, large format, visualisation facility, however, the portability of the PC format enables a wider dissemination and use of the videos sequences and so both outputs were produced. Movie sequences of flights across the landscape at different dates was created, visiting certain locations where either, change was dramatic over the time period or, key landscape features were highlighted.

The software used for the creation of the video sequences was the ERDAS Imagine VGIS package, housed on a Silicon Graphics workstation. Flight paths were defined and viewing parameters selected to highlight the occurrence of landscape features and changes within the study areas. The movie sequences, recorded by the software were in SGI video format allowing the editing and compilation of combinations of sequences using the SGI ‘Video Edit’ package. This package is rudimentary and it is not possible to significantly modify the files. Therefore, editing requires to be kept to a minimum and thus the onus is on the preparation and recording phases of the video creation using VGIS. Conversion into a PC video format used an RLE animation compression to reduce the size of the files when creating the QuickTime movies.

The value of such an output is in the communication of issues associated with landscape management and natural processes and man-induced processes in the uplands. This provides materials which can be used in, research, education and dissemination of information to a wider public. An example of a fly-through for the Cwm Berwyn area using photography for 1995 is **accessible here**.

6 Evaluating the change in landscape

The landscape preference model was applied to views derived from two dates of photography, pre-and post-afforestation. The viewpoint was selected for the Cwm Berwyn study site in the vicinity of a newly created visitor information point. A height of 2 m above ground level was selected and a westward direction of view. Figures 7 and 8 show the derived views for each date, with the growth of trees producing an obscuring ef-

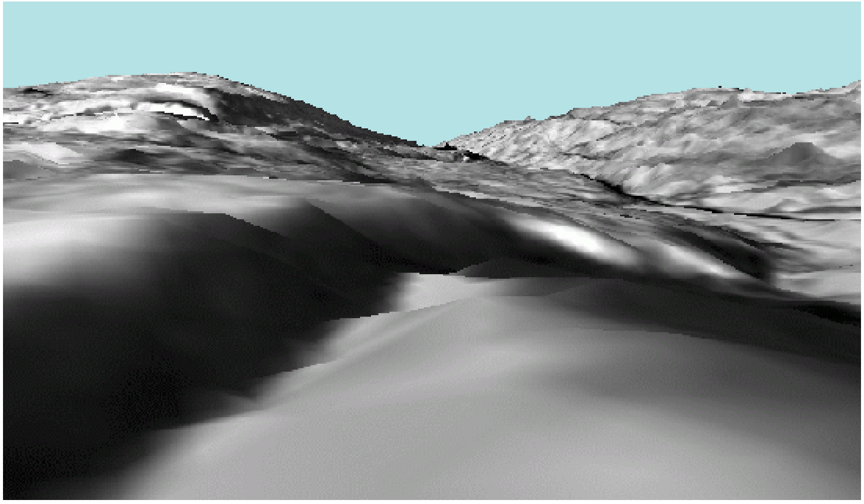

Figure 7. Cwm Berwyn, 1957.

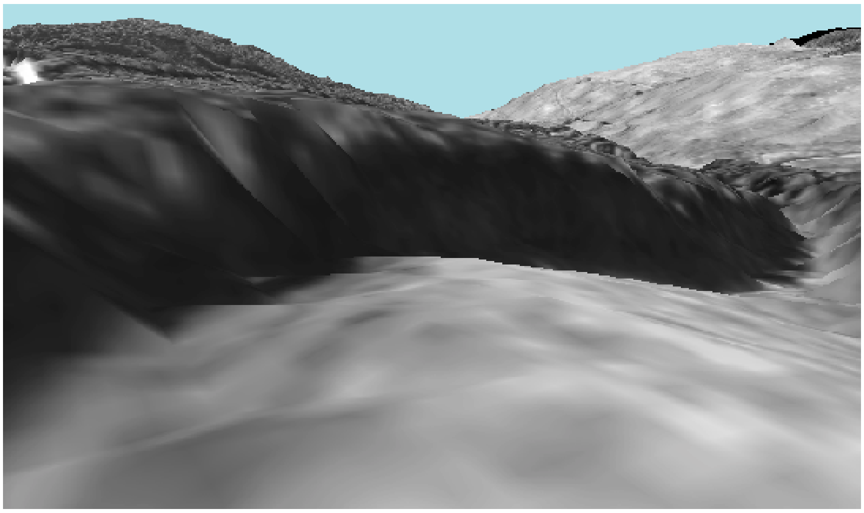

Figure 8. Cwm Berwyn, 1988.

Table 3. Landscape Component Measurements: Cwm Berwyn, 1957 and 1988.

Variable*	1957		1988	
	area	perimeter	area	perimeter
Low Hill	718	120	451	112
Steep Hill	207	101	156	102
Sky	162	95	124	94
Obscuring Vegetation	0	0	352	102
Scores	-0.4894		-0.3415	

* All variables are measured in WLC Units, of which there are 1080 in an image.

fect in the foreground of the 1995 view. Analysing each picture, the only variables from the model described in section 3.4 which are non-zero are low and steep hill, sky and obscuring vegetation (Table 3).

The results from the model show that the 1957 image has a lower score than the 1988 image, by around 0.15. In terms of the range of possible scores, this is a relatively small increase in score for the 1988 image, and implies that the preference for this landscape may have marginally increased.

7 Discussion

The visualisation and landscape preference modelling presented in this paper requires further development to produce a robust system for use in supporting decision making in issues of landscape management. However, there are several specific areas in which improvements are required and limitations may be significant for prospective future use.

7.1 Digital elevation models

The time taken to produce a DEM for the entire model varies by 15–20 % according to the power of the processor available. These figures will vary further where access is to a remote, rather than a local, disk. It would seem inevitable that the time taken for deriving a DEM will reduce with increased in computing power and sophistication of computer hardware and the processing times experienced are likely to be towards the maximum of the timescale required. Indeed a lower spatial resolution could be tolerated for some applications. However, the images used in testing the evaluation of the landscape required a level of detail sufficient to incorporate the shape and size of the forest stand and thus the obscuring effects in the view that it provided. Therefore, processing DEM data and associated orthophotographs would appear to be a practical exercise for individual forest stands.

7.2 Orthophotography

The quality of the original aerial photography, both in terms of geometry and reproduction quality, impacts on the quality of the output. The issue of quality is most significant when selecting a study site for which aerial photographic cover is required. A balance is required to be struck between the issues associated with the photography (geographic extent of the coverage, the temporal sequence available, the geometry of the photographs including scale and flying height and the quality of the photographic copy) and the requirements of the user.

The experience from the visualisation of afforestation described in this paper suggests that the low oblique, reconnaissance photography taken in the United Kingdom until the late 1950s can be used successfully for the creation of orthophotographs, however, their value for deriving DEMs has been lower due to the lack of detailed information on camera calibration. A more significant problem for applications in visualisation is that of the consistency and contrasts within the photographic copy when constructing mosaics. Fortunately, the quality of the photographs used within this study posed few such problems. However, photographs which are forty or fifty years old, for which the original negative may be missing or deteriorated over time may not prove to be useable.

Maintaining sequences of photographs for areas of particular interest would allow comparisons to be made between landscape views taken at different times. Information interpreted from one year's photography may be compared to that of another year. Areas of planting and clear-fell, for example, can be viewed with respect to the underlying topography and, interpretations of the land cover, from a historic perspective. Naturally, such views may be derived for locations and in directions selected by the user; these may include points that are currently inaccessible on the ground but which are of potential future importance. If the focus of interest changes, the landscape study is not restricted as it has been using conventional methods, by views selected for historic terrestrial photographs.

The cost of obtaining extensive aerial photographic coverage necessitates their use for multiple purposes, such as forest inventory, land cover mapping and impact assessments. The trade-offs that may be involved in satisfying multiple objectives of data capture could limit the value of the data for any one use. A cost-benefit assessment is required on the use of photographic and DEM data as described in this paper to contribute to the specifications of the data capture. The experience gained in the studies reported in this paper would suggest that scales of aerial photography in the range of 1:10 000 to 1:25 000 are suitable for visualisation of the landscape, but to obtain a sufficiently high resolution of DEM, scales of 1:10 000 and larger will yield the better results.

7.3 Visualisation

It is unclear what level of detail and realism is required for a user to recognize what is being presented and the key differences between competing options for a plan for the landscape. Therefore, gross changes, such as patterns of clear-fell, maybe presented in relatively simple illustrations. However, the landscape impression left by patterns of line thinning may be more subtle and require a greater degree of content and detail. An increase in detail in an image may require an increase in the associated degree of realism. For some applications, an increase in content, realism and detail may result in undue clutter and noise which may have one of two consequences: either, improving the information on the context within which any change in land management is taking place, or confusing the overall picture and complicating a decision making process.

7.4 Videos

There are several limitations associated with the creation of the video sequences. These include data quality (both geometric and visual), processing time, editing of frame sequences, disk space and configuration of the presentation media. Most of these issues are essentially hardware and software related and they can be overcome with suitable improvements. As an example of the files produced, a nine minute sequence, at 15 frames per second, for viewing on a Silicon Graphics workstation, using panchromatic imagery a video compression of 75 % of the original imagery, occupies 1.1 Gbytes of disk space.

The strength of this means of presenting the changes in land cover, use and thus landscape over time is the ability to create a tour of the landscape, viewing it from different locations and the opportunity to view the same pathway across the area at different dates. Thus it is possible to aid in the communication of the essential differences in the landscape.

However, its principal limitation is the lack of flexibility in viewing offered to the user. Except for moving through scene views at different speeds and directions, there is no opportunity for the viewer to modify the area in view and thus they are entirely dependent upon the choice of views presented by the movie maker. The extent to which this is a significant limitation will be dependent upon the use intended. For education and public dissemination of information, the constraint will be minor. However, for research into the directions and forces of landscape change, the constraint may be significant and the video merely an introduction to the area to be replaced by access to a modelling package and data.

7.5 Landscape evaluation

The use of a predictive preference model for landscape preference allows changes in relative preference to be calculated. However, it must be remembered that the figures obtained from such models represent only an average of the general population and that the models explain only around

70 % of the variance in the preference scoring of a sample population. However, such models are still a useful indicator of preference changes and may provide constructive input to decision support in the landscape planning arena.

8 Conclusions

The work presented in this paper demonstrates one approach to visualising and evaluating the landscape at different dates, when there is suitable aerial photographic coverage of the area. An ability to orthocorrect and register multiple dates of photographic imagery, including reconnaissance imagery with little or no camera details, to accuracies of approximately 2 m is a significant step towards realising additional value from the collections of historical photography available for many places.

The hardware and software configurations and processing requirements for creating models that may be viewed interactively or as video sequences are increasingly common and available on low cost PCs. Therefore, there is considerable scope for compiling a package to permit the throughput production of products similar to those presented in this paper as part of a larger package for exploring the effects of changes in landscape.

Applications have been explored in the area of education and there appears to be an opportunity to develop demonstration packages, targeting specific areas and time periods of interest. Future availability of high resolution satellite imagery may add greater opportunities to the options available for input data. The next challenge will be to derive interactive models of each date of imagery using technology such as that offered by the Virtual Reality Modelling Language (VRML) which would enable a significantly more flexible output for the user to explore.

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