MONITORING WOODLAND GAP DYNAMICS USING HIGH RESOLUTION IMAGERY: BUT WHEN IS A GAP IS NOT A GAP?

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Abstract
This paper uses aerial photographs and CASI imagery to consider the relationships between the ecological concept of gaps within woodland canopies and their remotely-sensed representation. The effects of the scale of investigation, complexities of spectral scene elements within gaps and difficulties of temporal change on a diurnal and seasonal basis are examined. A preliminary analysis of CASI imagery targeted at a more object-oriented approach aimed at "modelising" the canopy is presented.

INTRODUCTION

When trees die or are destroyed a gap is created in the overstorey canopy of a woodland and this has important consequences for the microenvironmental conditions at this locality. Changes in solar radiation receipt and airflow patterns cause surface and sub-surface variations in micro-climatic parameters. Such abiotic variations lead to biotic responses, making gaps important sites for regeneration and habitat and species diversity. While it has been recognised for some time that the spatial characteristics of gaps influence the magnitude and tragectories of such changes, relatively little evidence has been available on the spatio-temporal characteristics of gap creation and infilling. Individual-based models of gap regeneration dynamics are now able to simulate accurately demographic processes within forests and their interaction with environmental factors. Such models have the potential to predict the successional changes taking place within forests as a result of environmental or climatic change (Urban *et al.,* 1991). However, their predictive capabilities are limited by the accuracy with which the initial composition and structure of a forest is parameterised. Typically, detailed vegetation surveys are undertaken field in order to specify the initial conditions for a simulation model. However, such surveys are extremely time consuming and are therefore rather limited in their spatial coverage.

With improvements in their spatial and spectral resolution, remote sensing instruments are becoming capable of providing detailed information on the composition and structure of forests, with a comprehensive spatial coverage. Blackburn and Milton (1997) have shown that spectral classification techniques can be applied to imagery from the Compact Airborne Spectrographic Imager (CASI) in order to delineate forest canopy gaps. This has enabled the size, shape and spacing of gaps to be accurately quantified for a range of deciduous forest types. Some ecological information has been derived from a knowledge of gap spatial properties (Blackburn and Milton 1996) but this has largely been based on inference using established ecological principles. A more powerful approach would be to use remotely sensed data to drive a simulation model of forest regeneration dynamics. Indeed, considerable potential exists for marrying the two technologies because the information which can be derived from the CASI is at a spatial resolution (1-2m) which is similar to that of the grid cells on which some recent gap simulation models operate. However, in order to be able to fulfil this potential, advances need to be made in both the remote sensing and modelling domains. The material presented in this paper forms part of a larger project which to develop a numerical model of a woodland ecosystem which can be driven by inputs from remote sensing (i.e. derived from satellite and airborne sensors) together with information from existing maps. The model will be explicitly spatial and therefore it will be constructed within a geographical information system. The model will be used to evaluate the effects of different management scenarios on the ecological status of a woodland - this will be expressed using the concept of “ecological value” which we define as a function of the regeneration status, biodiversity and ecosystem stability. The objective of the first phase of the project is to investigate the potential of remotely sensed imagery for deriving information on the three-dimensional structure of a semi-natural deciduous woodland canopy, and the interior light regime and biophysical characteristics of vegetation within gaps, as well as the spatial properties of gaps.

STUDY SITE

The site used for this project is Frame Wood in the New Forest which contains several types of semi-natural deciduous woodlands. This array of woodland types, within close proximity to each other, present a wide range in all of the gap and canopy variables of interest. The site has been used by the authors for a number of field-based ecological studies and during NERC Airborne Remote Sensing campaigns in which a sequence of aerial photographs and images from digital remote sensing instruments (specifically the Compact Airborne Spectrographic Imager (CASI) and the Airborne Thematic Mapper (ATM)) have been acquired over the last two decades, allowing the possibility of change detection.

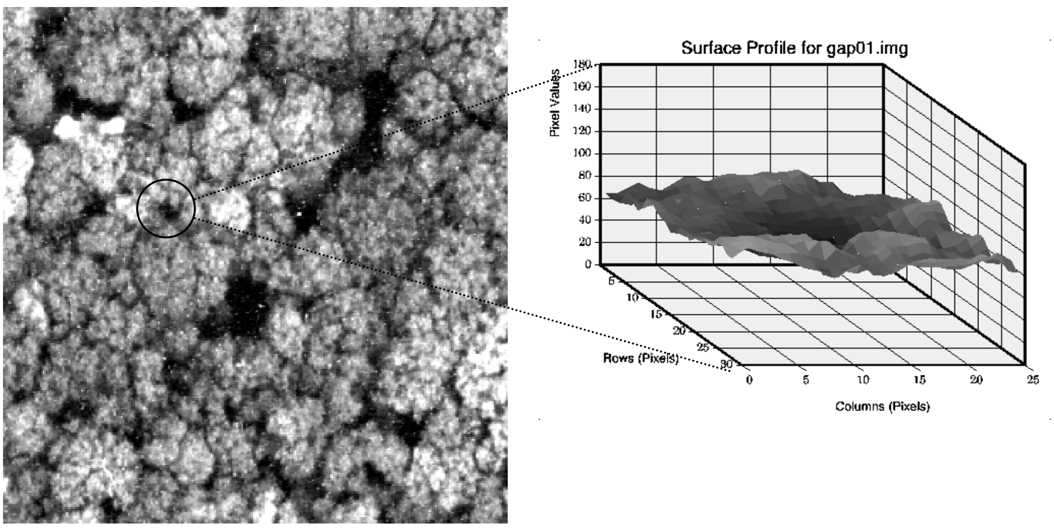
GAP CONCEPTUALISATION

On starting work with the various data sources available for the field site it became obvious that the methodology required to fulfil the objectives of the study and the desired outputs from the analysis of remotely sensed data largely depend upon our conceptualisation of gap and canopy features. We must first address the concepts of gap features as understood in an ecological sense then how we may define gaps from a remotely-sensed point of view. If our aim is to detect gaps using remote sensing and derive ecological information we need to identify links between the two concepts. One factor which does link the two concepts is radiation. A major effect of a disturbance in a woodland which creates a gap is to drastically alter the light regime within the canopy and at the forest floor this in turn leads to biotic responses. This implies that the creation of gap is also likely to have a significant effect on the reflected radiation from the woodland, in that locality. This physical link between the gap as an ecological feature/phenomenon and its reflectance characteristics immediately gives us the potential for applying remotely sensed data for monitoring such features. However, once we progress beyond this first level link between the two concepts we discover a much greater degree of complexity in the relationship.

Within a remotely sensed image gap features result from a combination of the reflectance properties of large number scene elements, including illuminated tree canopy, shaded canopy, illuminated understaory, shaded understorey. Moreover, the gap as a spectral feature is transient and varies on a number of time scales. Throughout the day, the varying solar illumination angle causes the shaded and illuminated components of canopy and gaps to constantly change. Throughout the year, particularly with deciduous woodlands, the spactral reflectance charactersitics of the tree canopy changes dramatically (see Blackburn and Milton, 1995) which leads to variations in the spectral quality of the shadows cast by the canopy within the gaps. In addition as the understorey develops, senesces and dies, the spectral reflectance properties of the contenst of a gap can vary widely from a litter/soil dominated response to that of a vigorous vegetation canopy. In the case of dense understorey species, such as bracken (*Pteridium aquilinum*) the spectral reflectance properties can actually be very similar to those of a mature tree canopy.

In addition to such difficulties one important problem which needs to be addressed is that of scale. Within remotely sensed data of low spatial resolution (tens of metres) it is difficuult to distinguish different woodland sub-compartments. With data of higher spatial resolution, some differences can be distinguished, depending on the reflectance characteristics of the compartments. At finer resolution still the differences becoming more clear implying different ecosystem functionality and energy flows. An important question is to consider the optimal spatial resolution required to simulate ecosystem functionality. Starting with the simplest concept, a gap can be considered to be a hole in the tree canopy, or in terms of remotely sensed response, the area in which the low value pixels are surrounded by those of higher value in the bands in which the vegetation reflectance is high such as the infrared. But is it always so simple? The answer is no. The response of a gap actually depends on factors such as the tree density, the overlapping of the neighbouring tree canopies, the understorey vegetation, the microtopography , the dominace tree species and the solar angle defining the gap light regime.

Focusing at the first factor, and looking the sections of the aerial photographs in fig.1 and fig.3 it becomes clear that for this level of spatial resolution (1:4000 scale), that in the first photo it is quite clear what gap is - a hole in the tree canopy. Looking at the second aerial photo (fig.3) it is really questionable whether we can talk about gaps as 'holes' in the tree canopy, or whether the scene is dominated by background with sparse trees which represent the 'holes' in the matrix. The objects of interest here may be the trees in contrast with the first photo where the objects are the 'holes' - gaps. However a more careful examination of the first photo reveals the enormous heterogeneity in tree species composition, tree age and therefore in the tree height. So, a further question is at what level of vegetation height can a gap be specified and quantified? Looking at the spectral profile, shown in 3-D space the reflectance of the trees surrounding a gap (outlined by a circle on the original photo) in the visible wavelengths, we find that this kind of hole can not be described as a cylinder with the same perimeter and area at the top as at the bottom, but rather like a cone with the perimeter decreasing smoothly from the top to bottom. This illustrates the difficulty in deciding the correct height level to slice the cone and define the gap.



Gaps in Aerial Photo JUL 96 (Gray Sc)

Figure 1.

Furthermore, if we examine a negative image of the aerial photograph (fig. 2) the connectivity and contiguity of gaps becomes more clear, consisting a network of gaps and corridors between them. We could ask whether a corridor is a gap. Clearly, the analysis of these corridors is determined by the scale and the spatial resolution of remotely-sensed data.

The choice of the correct scale or resolution depends on the ecological phenomena we wish to investigate. For simulating biodiversity these corridors are extremely important as they are the ‘edges’ where we expect the bigest change of this ecosystem variable, as microenvironmental factors change. In addition, there is increasing evidence of the important role of small-scale gaps (therefore the gap-corridors) in regeneration dynamics (Kuuluvainen, 1994).

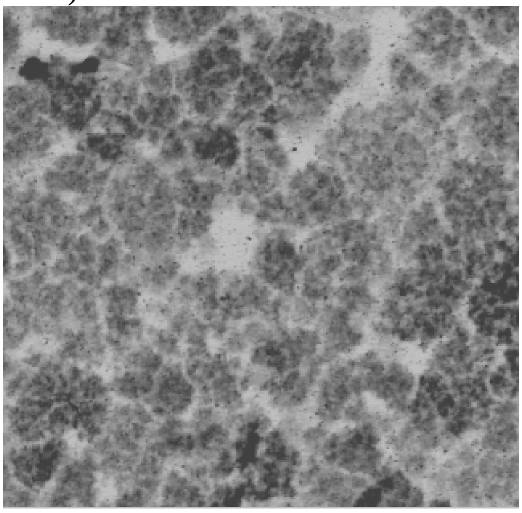


Figure 2 (Negative Image)

Examining the infrared aerial photo (fig. 4), some other aspects of gap conceptualisation can be analysed, such as the solar angle. Considering that is difficult to always obtain vertical (ortho) aerial photos or remotely sensed imagery with a low solar zenith, we need to deal with the problem of canopy shading. It may be possible for a gap to be entirely or partially in shade. It is difficult to apply classification techniques in such situations because of the spatial variation in spectral response within a gap. Looking at the surface profile of the small test area (square marked on figure 4) on the upper left corner we have the spectral response of a tree canopy, and the rest of the area covers non - tree cover. While the non-tree area all represents the same surface types (bracken understorey) the spectral response varies widely. The lower right corner of the understorey is shaded by a neighbouring tree canopy, while the upper right corner is illuminated. The authors currently investigating possible solutions to this problem.

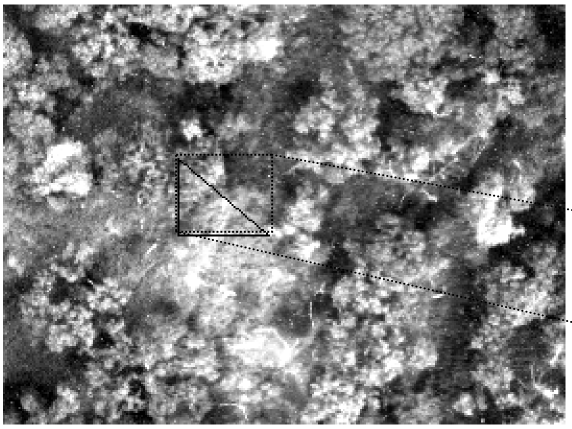
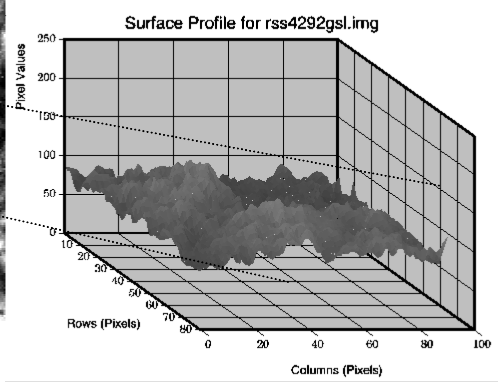
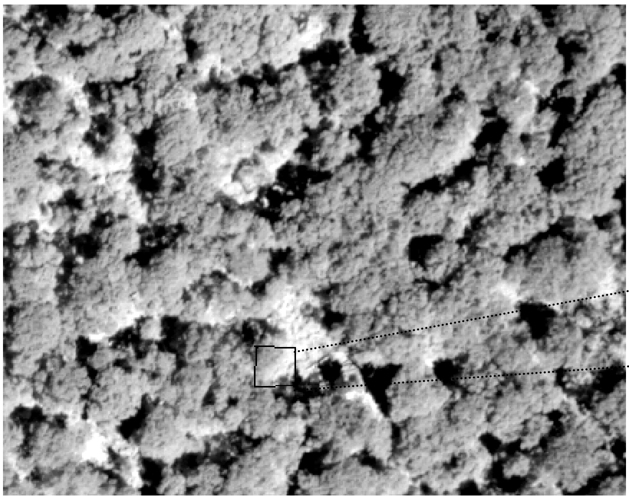


Figure 3



One possible positive application of the shading problem will be undertaken in the analysis of multi-temporal CASI Imagery of the study site acquired at various times throughout one day. This will mean that in successive images, the site will be illuminated at different solar zenith and azimuth angles and therefore the positions of shadows which are cast by the tree canopies will vary between images. Hence, different portions of gaps and sections of the tree canopy will be illuminated in successive images. The aim is to combine the information contained within successive images in order to construct a model of the three-dimensional structure of the forest canopy and quantify the light regime (spatio-temporal distribution of irradiance) and biophysical characteristics of vegetation within gaps, as well as the spatial



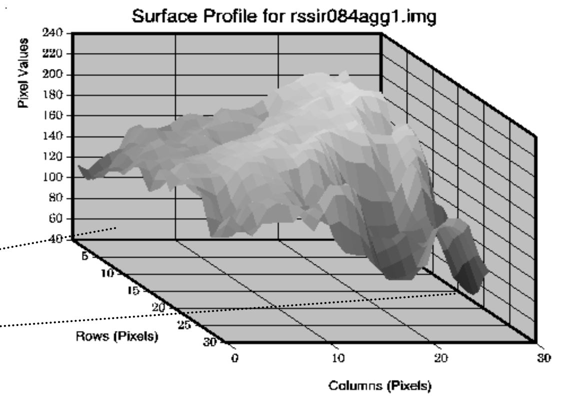


Figure 4

properties of gaps. The accuracy of these derived parameters will be tested against detailed field survey data.

In order to start to address some of the issues outlined above, CASI data of nominal spatial resolution of 2m, was analysed. Fig.5 shows an unprocessed CASI image where a composite of bands 8, 2 and 4 have been converted to grey scale (to meet the specifications of the current paper). In fig.6 is an NDVI image of the same area calculated from near-infared and red CASI bands. A low pass 3x3 filtering was applied to all CASI bands and the NDVI image.
A 3x3 kernel focal maximum (4 - neighbours in a cross configuration) was then applied to the imagery. The results are illustrated in the lower left image in figure 5. The image processing techniques were found to give a more object specific view of the area, enhancing differences between canopy and gap features. Isodata clustering was then applied to extract gaps features. The lower right image shows the results of this and illustrates that gap, canopy and intermediate classes can be identified. The black areas are gaps (the understorey veg or just a bare ground), white areas represent tree canopies and the grey area surrounding the black is the edge between the two first levels.

This type of approach leads to a 'modelisation' of the canopy and gap features as extracted from the remotely sensed imagery. While this may mean a loss of spatial information, this object-oriented approach provides a ready means of summarising the gap and canopy information within the scene in such a way as to be meaningful ecologically. Even in the field situation ecologists apply models for characterising gap features and for measurement purposes often assume that gaps are circular features (Barbour *et al.*, 1980). Clearly, before any evaluation of image processing techniques is possible, using field sampling techniques, the relationships between the ecological concepts of gaps and their remotely-sensed representation needs to be explored further. This paper begins to address such problems and but has also unearthed a range of associated issues.

ACKNOWLEDGEMENTS
Many thanks to the NERC Aiborne Remote Sensing Facility for data provision and to Dr E.J. Milton for loan of aerial photographs.

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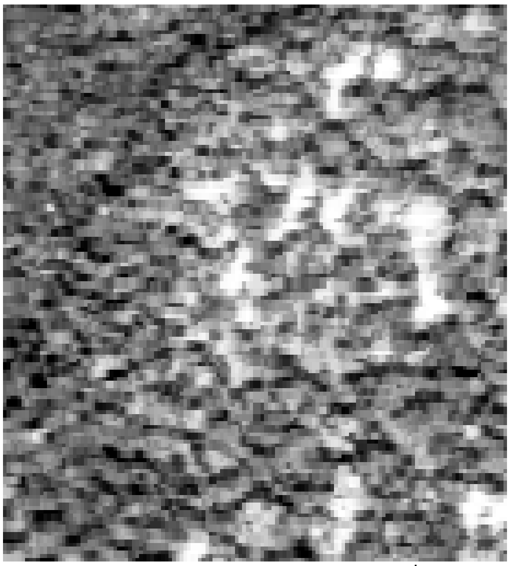
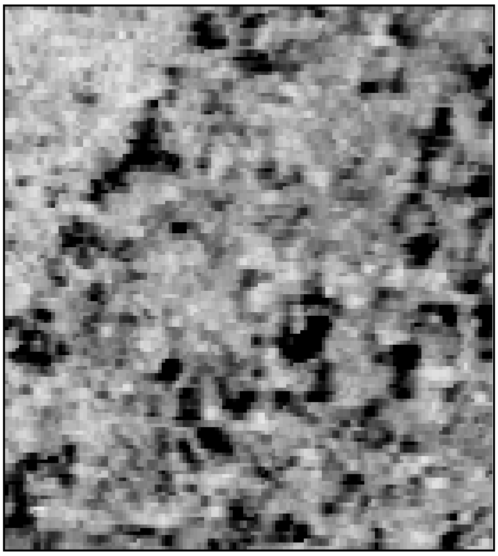
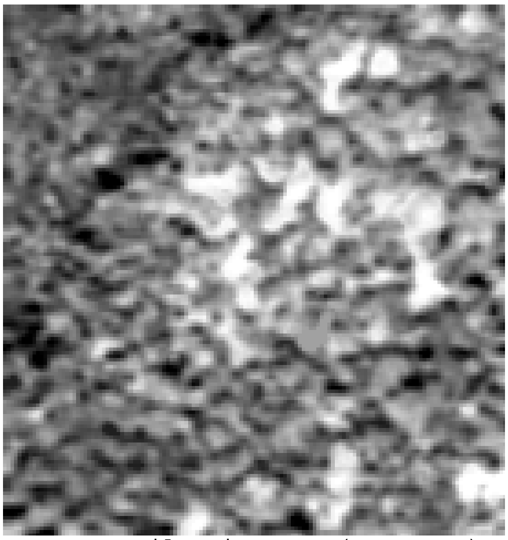


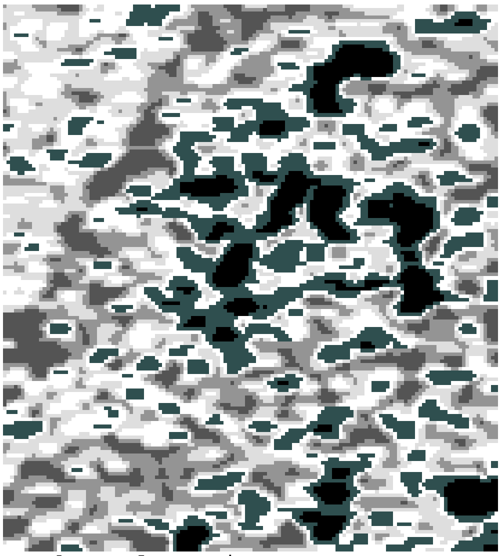
CASI Imagery -Jun 95, 8,2,4 in g-s



NDVI created from 8 & 4 CASI bands



Low Pass Filtering 3x3 (NDVI,2,4) g-s



Isodata Clustering - BL=gap, WH=veg

Figure 5