Remote Sensing Monitoring Consultancy Service

REPORT

For

Knepp Castle Estate

Draft 1.0

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Specto Natura Limited.
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1 Introduction

The Knepp Castle Estate covers 1400 ha in West Sussex. Historically the area was managed as parkland and agriculture (arable and dairy farming). Since 2001, the focus has shifted to a re-wilding programme through a series of regeneration and restoration projects aimed primarily at nature conservation and less intensive meat production. These changes are having an impact on the landscape in terms of key features (e.g. hedgerows) and the distribution of habitats and species (e.g. scrub encroachment). To assess the success of the re-wilding programme it is necessary to monitor the landscape changes over time.

2 Requirements

To monitor complex, large-scale environmental changes an integrated approach is required to capture the landscape level patterns, the localised detail and the historical context. A key component of such an approach is remote sensing which allows rapid, synoptic, non-destructive and cost-effective image-based measurements to be made to support mapping activities. The comprehensive nature of the remote sensing images often provides a spatial framework for a site which can be used for the integration of disparate non-remote sensing data (e.g. field surveys).

Extensive and established ground data collection / field survey programmes are already in place at Knepp. Both these programmes and the overall monitoring of the site would benefit from a well designed and targeted remote sensing programme, especially as planning is made for major monitoring activities in the near future.

This reported is aimed at supporting the implementation of the remote sensing component of monitoring by providing technical advice and guidance, reviewing image data acquisitions, undertaking prototype product development and advising on the later analysis and reporting.

3 Technical report

This consultancy service has addressed a number of specific activities which are reported in separate sections below.

3.1 Support access to West Sussex County Council data

West Sussex County Council (WSCC) have a history of acquire remotely sensed data for their mapping activities. They are acquiring a county-wide true colour (blue, green, red, see Figure 1) aerial photography data set for 2012. True colour images are useful for visual interpretation by the general user as features look very similar to how they would appear when viewed directly. However, images that record information in the near infrared (NIR) region have an exaggerated response to vegetation properties (Figure 2) such as type, biomass, leaf area index and health.

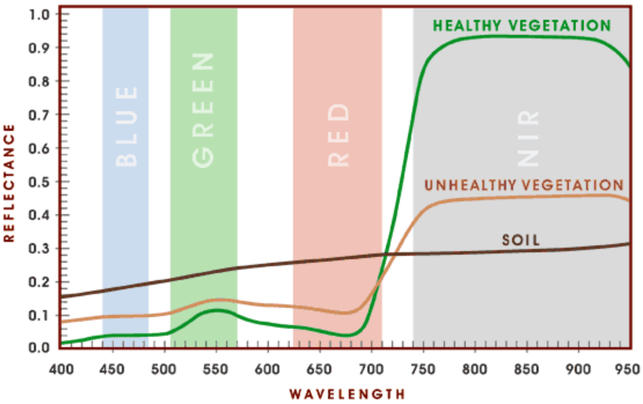

Figure 1 Generic reflectance spectra for basic surface types in visible and NIR regions. Water has a relatively low reflectance across the spectrum and thus clear appears black in FCIR AP.

Figure 2 A comparison of true colour (left) and false colour infrared (FCIR, right).

WSCC were contacted and confirmed that they had contracted GetMapping to do the aerial survey work for 2012. The WSCC specification was for 12.5 cm data in a true colour format to be flown early in the growing season. This specification would allow sufficient light levels while collecting data in leaf-off conditions. Even when collected near solar noon, images acquired this early in the year would contain significant amounts of shadow from hedges, trees and buildings. This type of specification is more suited to topographic mapping than vegetation / habitat assessment, but would record the perennial vegetation, the impacts of winter and possibly dead vegetation from the previous season.

Depending on the system used by GetMapping to acquire the WSCC aerial photography in 2012, it was hoped that there may have been a possibility of obtaining some false colour infrared (FCIR: green, red, NIR, see Figure 1, Figure 2 right) data at the same time over Knepp. Unfortunately, GetMapping are using a new camera system for the WSCC survey that currently only records true colour data. There are plans to upgrade the system with the NIR band required for FCIR data, but this seems unlikely to happen before the WSCC data is acquired.

Elaine Munns at WSCC was very supportive of what was being proposed at Knepp. As of mid-May WSCC were not aware that the images for 2012 have been acquired and recent weather conditions would support this. However improving weather conditions at the end of May would suggest the likelihood of acquiring the data has increased. Knepp will be kept informed of progress and when the 2012 data will be available, but is unlikely to be until September.

As data had previously been supplied to Knepp and that there have been no changes to the terms and conditions from 2007, it has been confirmed that it will be possible to supply the 2012 images also.

The 2007 data will be described later in this report, but it represents a useful record of the situation on the estate at that time, although it appears to be again be slightly early in season (end of April). Even if the specification of the 2012 data is again less than optimal, access is also valuable. The delays incurred in the acquisition of the WSCC 2012 aerial photographs will be an advantage to Knepp as there will be more vegetation development and it is likely that most trees will be reaching full leaf.

3.2 Review archive aerial photography data

The aerial photography available through archives is acquired during individual campaigns for a specific purpose. Historical aerial photography is available for the UK back to the 1920s, but these earlier collection can be spatially specific, difficult to access or of poor quality. When aerial photography became more established, county administrations and agencies began regularly acquiring data sets for their regions. Over recent decades regular campaigns have been undertaken to address national issues such as the updating of Ordnance Survey mapping and support for various government agencies.

Satellite systems pass over the same location on the surface at regular intervals controlled by their orbital characteristics. Unfortunately, this regular revisit does not, always transfer into regular useful image acquisitions. Depending on the imaging capabilities of the system concerned the revisit frequency may be as little as two times per month. Satellite systems are also at the mercy of weather conditions, with cloud cover a major problem in temperate regions such as the UK. Finally, the systems with the best spatial resolutions tend to have a small image footprint and operate in a selective mode where only targets of known interest are acquired.

The result of these constraints means that the archive data available for a rural location such as Knepp may be quite limited with little if any choice over the image specification. For this review, all aerial photography and satellite images with a spatial resolution of less than 10 m were considered (Table 1) to identified which datasets could be suitable for monitoring at Knepp.

There were some other satellite datasets identified, but due to cloud, haze or the amount of coverage of the site they would not be worth obtaining. Even so, Table 1 shows a good temporal spread, particularly since 2006, of sub 1 m data. Surprisingly the satellite systems seem to have a bias toward the winter months, which could be due to tasking to capture leaf off conditions or an indication of the poor summers we have been experiencing in the UK recently. All the recent datasets have at least true colour and false colour infrared capabilities.

Some of the datasets given in Table 1 are represented in the online image resources. GoogleEarth (GE) contains a time function and may hold a multi-date sequences for a particular location. For the Knepp area GE appears to contain the 2001 and 2004 data from Geoperspectives, GetMapping data from 2005, 2007 and 2009. Bing Maps has another dataset, but it is difficult to identify and there is no indication of date. There are a number of developments around the castle which could date it.

Table 1 Summary of available archive data

Date	Type	System	Spatial res. (m)	Spectral	Supplier	Comments
29/08/99	AP		0.25	TC	GetMapping	
01/11/00	Sat	Ikonos	1 (4)	TC / FCIR	e-GEOS	Slight cloud / shadow pollution
28/07/01	AP				GeoPerspectives	Terrain model (5 m), in GE
12/10/01	AP				GeoPerspectives	Terrain model (5 m), in GE
17/04/05	AP			TC / FCIR	GetMapping	
24/01/06	Sat	Quickbird	0.6 (2.4)	TC / FCIR	e-GEOS	Hazy
30/04/07	AP	ADS-40 Vexcel	0.25 / 0.5 0.125	TC / FCIR	GeoPerspectives	Surface model (2 m) WSCC data
17/12/07	Sat	Quickbird	0.6 (2.4)	TC / FCIR	e-GEOS	Missing western edge
22/08/09	AP	Vexcel	0.125	TC / FCIR	GetMapping	Partial coverage only
10/12/09	Sat	GeoEye-1	0.41 (1.65)	TC / FCIR	e-GEOS	
03/06/11	Sat	RapidEye	6	TC / FCIR / red-edge	RapidEye AG	
27/11/11	Sat	Quickbird	0.6 (2.4)	TC / FCIR	e-GEOS	Hazy, missing the northern part.
26/03/12	Sat	RapidEye	6	TC / FCIR / red-edge	RapidEye AG	

It was suggested that the key periods for historical monitoring at Knepp were pre-2001, 2005, 2007 and 2011. Based on the above results of the archive search the following data may be suitable for purchase:

- **Pre-2001:** The IKONOS satellite data from November 2000 would a suitable time point and give the opportunity for FCIR results with a 1 m spatial resolution. However, the seasonal timing is not optimal and may need to be used in a visual sense rather than with automated processing. Depending on what was happening on the site during 2001, the IKONOS data could be complemented by the GeoPerspectives aerial photography from July 2001 to give a summer and winter composite[1]. However, if there were lots of changes on the site during 2001 then the summer winter composite may not be representative of the true pre-2001 conditions.
- **2005:** Get mapping acquired an early season dataset in 2005 which would be similar to the WSSC 2007 data. The mid-April acquisition date is likely to mean that the tress may not be in full leaf and the various habitat patches may be less easy to distinguish.

[1] Summer winter composites capture the phenology of vegetation and are useful for identifying different habitats, tree species and crops.

- **2007:** Knepp already has access to the WSCC data which was acquired at the end of April. The Quickbird satellite data from mid-December would complement the WSCC to give a summer winter composite.
- **2011:** There are two well timed satellite acquisitions in 2011 from the RapidEye and Quickbird systems in June and November respectively which could form a summer winter composite. However, the RapidEye data only has a spatial resolution of 6 m and the Quickbird data is a little hazy and is missing northern part of the site.

When dealing with archive data in temperate conditions it is unlikely to have a complete set of optimal acquisitions available. The table and the suggestions above should be considered in the context of the important changes occurring at the site. Also, the bespoke specification developed in section 3.3 below should also be considered. The associated issues can then be discussed to arrive at a decision as to whether to pursue archive data purchases at this time. The likely cost of each type of dataset are variable depending on the system, the amount of processing required and the minimum extent that can be purchased. As a ball park figure, each dataset is likely to be in the range £500 - £1000 plus VAT.

3.3 Prepare a specification for bespoke acquisitions

To make optimal use of remotely sensed data it is necessary to prepare a detailed acquisition specification (Table 2) to either undertake a bespoke survey programme or evaluate archive datasets prior to purchase. The monitoring programme at Knepp and the specification below could be used for obtaining quotes and tendering for a possible bespoke survey in 2012 or 2013.

Table 2 Proposed survey attributes, specification and support comments.

Attribute	Specification	Comment
Type	Aerial imagery - frame camera or scanner	Aerial data sets have marginally better spatial resolution and can be acquired around uncertain weather conditions in comparison with satellite observations.
Spatial resolution (Figure 3)	25 / 50 cm pixels	Even though aerial data can be more spatial detailed than this, it is not required for the identified monitoring at Knepp. Also, more spatial detail means larger data volumes and higher purchase and processing costs.
Spectral information (Figure 1 & Figure 2)	Blue, green, red, near infrared bands as a minimum	The number of the spectral bands controls the ways in which the image can be visualised and the amount of discriminating power available for mapping.
Timing	As close to solar noon as possible	At solar noon the impact of shadows will be minimised on any given day.
Season	Summer	By mid-summer virtually all vegetation will be approaching full development. A more specific time period may be selected if the species of interest have particular flowering or visually distinct phases.
Image quality	Cloud cover and shadow less than 5%	Cloud free imagine would be best, but this is rarely the case. Haze should be avoided.
Overlaps	Forward and lateral for stereo imaging	Depends on the specific system and processing, but standard overlaps are 60% forward and 20 – 40 % lateral. Allows stereo / 3D viewing and the production of ortho-images.

Attribute	Specification	Comment
Coverage	Complete survey area in a single sortie.	To have a single snap-shot of the conditions on the site the whole area should be covered in a single sorte over as short a period of time as possible. This makes the illumination conditions as uniform as possible across the site and prevents phenology and other changes affecting the results.
Radiometry	No saturation, maximum dynamic range.	Each pixel is a set of digital numbers, one for each band. As when setting the aperture in conventional photography the sensor systems are set so that they can measure all the brightness difference in the image.
Metadata	All necessary	For the data to be used effectively information is required on the how, when, why and where the images were acquired. This is vitally important in monitoring programmes as future users will need as much information as possible to use the data.
Geometric processing	Ortho-correction to British National Grid	Ortho-correction creates an image with uniform scale with the affects of varying terrain height and view angle removed. These images can be directly compared with a map.
Radiometric processing	Colour balance across survey area, radiance if possible	At a minimum the colour balance across and between images should be corrected so that when combined the boundaries between individual images are not visible. Some systems may include a calibration to physical units. Radiance is a measure of the amount of radiation entering the sensor.

Figure 3 overleaf gives examples of different spatial resolutions derived from the same 12.5 cm input data. It demonstrates that the fine detail may be required for identifying and mapping specific objects such as tree-guards, but for habitat patch and field scale mapping often slightly coarse detail can be adequate and may also usefully generalise some of the complex features of the fine detail data.

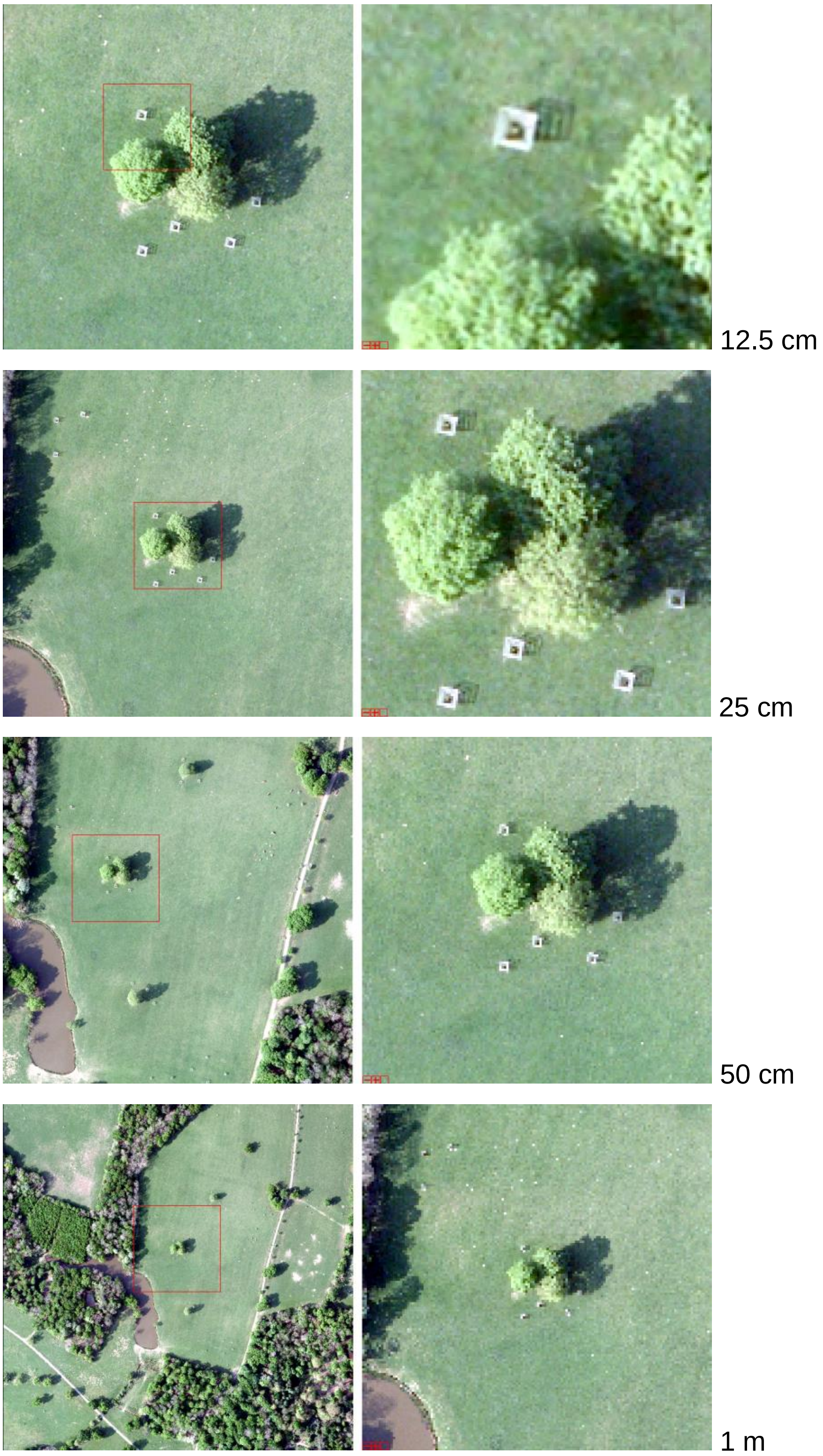

Figure 3 A comparison of different spatial resolutions.

The specification described in this section should be reviewed and discussed during the completion of this report if it is to be the basis for a tendering process.

Table 3 identifies a list of suitable survey companies who could undertake the image acquisitions and supply the final products in a suitable format for mapping at Knepp. The list includes the major UK players, but there are other local / regional outfits which may be able to offer similar services.

Table 3. Suppliers of aerial photography

Supplier	**Comments**
Blom Aerofilms UK (www.blomasa.com/blom-uk.html)	One of the largest providers of aerial imagery and geospatial data based in the UK with a fleet of aircraft and scanners. Can provide oblique and vertical aerial photography and topographic survey data using LiDAR. Products used for 3D models and vector mapping, for local and regional government, transport, infrastructure, engineering and environmental industry sectors. Formerly Simmons Aerofilms.
BlueSky (www.bluesky-world.com)	Set up in 2003 and has experience in the acquisition, processing and application of a range of geographic data, in particular aerial photography, LiDAR and thermal imagery. Also specialises in the creation of GIS data for modelling environmental and climate change. A privately owned company based in Leicestershire, UK.
Environment Agency / Geomatics Group (www.geomatics-group.co.uk)	A specialist business unit within the EA, supplies high quality, geospatial data that meets the rigorous quality requirements of the regulatory community. In addition to holding a large archive of spatial data, they can capture a wide range of data types from airborne, terrestrial and marine platforms including: LIDAR, multi-spectral and hyper-spectral imaging, digital aerial photography and thermal imaging.
Fugro-BKS (http://www.bks.co.uk/)	Traditionally an aerial survey company, Fugro-BKS is recognised as one of the UK´s leading suppliers of geo-information. Fugro-BKS provide a complete range of aerial imaging, digital mapping and data capture services to the public and private sectors enabling clients to access and process information more effectively.

Supplier	Comments
GeoInformation Group (http://www.geoinformationgroup.co.uk/)	A leading provider of geospatial information products and services. Home to Cities Revealed, UKMap and Training4GIS. Mainly focused on urban application
GetMapping (http://www2.getmapping.com/Home)	Uses the latest digital camera technology to maintain the high quality vertical imagery at high spatial resolution for the whole of Great Britain. From 2010 this includes 12.5 cm for most of England and Southern Wales, and 25 cm for the rest of Britain. Also acquire height data and generate information products.
Airborne Research and Survey Facility (http://arsf.nerc.ac.uk)	Part of the Natural Environment Research Council (NERC), ARSF offers research and commercial image acquisition capabilities with digital cameras, LIDAR and multi-spectral scanners.

3.4 Product prototype products

Once the aerial photography or satellite imagery has been obtained it can either be used as a simple visual back drop for manual interpretation or converted into information products in a semi-automatic fashion. The types of products that can be delivered will depend on the specification of the input data, the availability of ancillary information, the analysis systems in operation and the amount of resources that can be directed at the production.

This final section of the report will propose and demonstrate a set of test products related to the monitoring requirements for the site (e.g habitat patches / patterns, hedgerows, scrub encroachment). These test products are only examples and can be expanded upon and tailored based on a review within the monitoring community at Knepp.

1. **Scene component mapping.** This is the approach which has been applied at Wicken Fen and Darlow's Farm as part of the Great Fen restoration work being undertaken by Anglia Ruskin University. Within that work it has been tested on the FCIR AP from 2007 and has been selected for the analysis of the data to be acquired in 2012.

This approach was developed for the extraction information from aerial photography and very high spatial resolution (VHR) satellite data in support of habitat mapping and habitat characterisation by local experts. It was an extension of other work using VHR data in combination with object-based data structures and has been used for a number of test cases. Due to the limited spectral information content and the extremely high level of spatial detail within VHR datasets this approach employs a simple scene component analysis as its first step to extract the maximum amount of spectral information from the data. A later step involves the use of an object-based contextual spatial framework to analyse the spectral information within a realistic landscape structure.

The approach is made up of the following basic tasks:

- Check quality: A visual quality check to understand the information content and limitations a particular image may present.
- Pre-processing / spatial resample: Remove defects and normalise the values in the image. In this case the 12.5 cm WSCC 2007 data was re-sampled to 50.0 cm spatial resolution and a test area extracted for further analysis.
- Unsupervised clustering: An unsupervised clustering approach maximises the information that can be extracted without imposing an unrealistic nomenclature on the results. This approach automatically divides feature space, effectively the information space, without the aid of ground reference data or external constraints. It divides the image into a number of different surface types. A standard ISODATA algorithm was used to identify 40 spectral clusters within the image data.
- Interpretation of clusters: The clusters generated can then be labelled into scene components using domain expertise once the information content has been determined. For this test the remote sensing operator's knowledge of visual airphoto interpretation was used to label the clusters and merge them into the 9 scene components shown in Table 4.

Table 4. Scene components extracted from Knepp test area.

No.	Component	Colour
1	Water	
2	Bare ground	
3	Soil	
4	Grass	
5	Pasture	
6	Wet grass	
7	Woody	
8	Deadwood	
9	Shadow	

The area extracted for testing and the resulting scene component image are shown in Figure 1. The area covers a representative selection of habitats and land cover types within the Knepp Estate. These include various woodland and grassland types and some areas of floodplain along water courses. There is also a considerable amount of water (with surface / submerged vegetation) and areas of bare soil and sealed surfaces. It should be noted that buildings are not included in the scene components specifically as they appear as bare ground within this approach.

The scene components highlight the mixtures of surface types within individual landscape units. In the fields, the proportions and distribution of grass, pasture and soil give an indication of the levels of productivity and heterogeneity and the presence or absence of the wet grassland component may indicate wetter and dryer conditions. The woodlands are a mixture of trees in leaf and bare branched. This could be due to image acquisition in the early part of the growing season or the presence of dead trees.

Finally there will always be some confusion within the results due to the similar nature of some of the scene components. Bright soils may be recorded as bare ground and dark bare ground may be recorded as soils. Grass and pasture may be present in the woodlands as they represent the brightly illuminated parts of the canopy. The vegetation features within water are giving some interesting results which would require further discussion with local experts. The WSCC 2007 data also contains quite a high proportion of shadow due to the time of year and the time of day of the acquisition.

In an operational situation the scene component map completed by the remote sensing operator would be passed to local experts to refine the cluster labelling and merging to scene components.

The scene component map can be used as a complement to the original image and can be used in the same way by comparison with existing maps or ground reference / survey data.

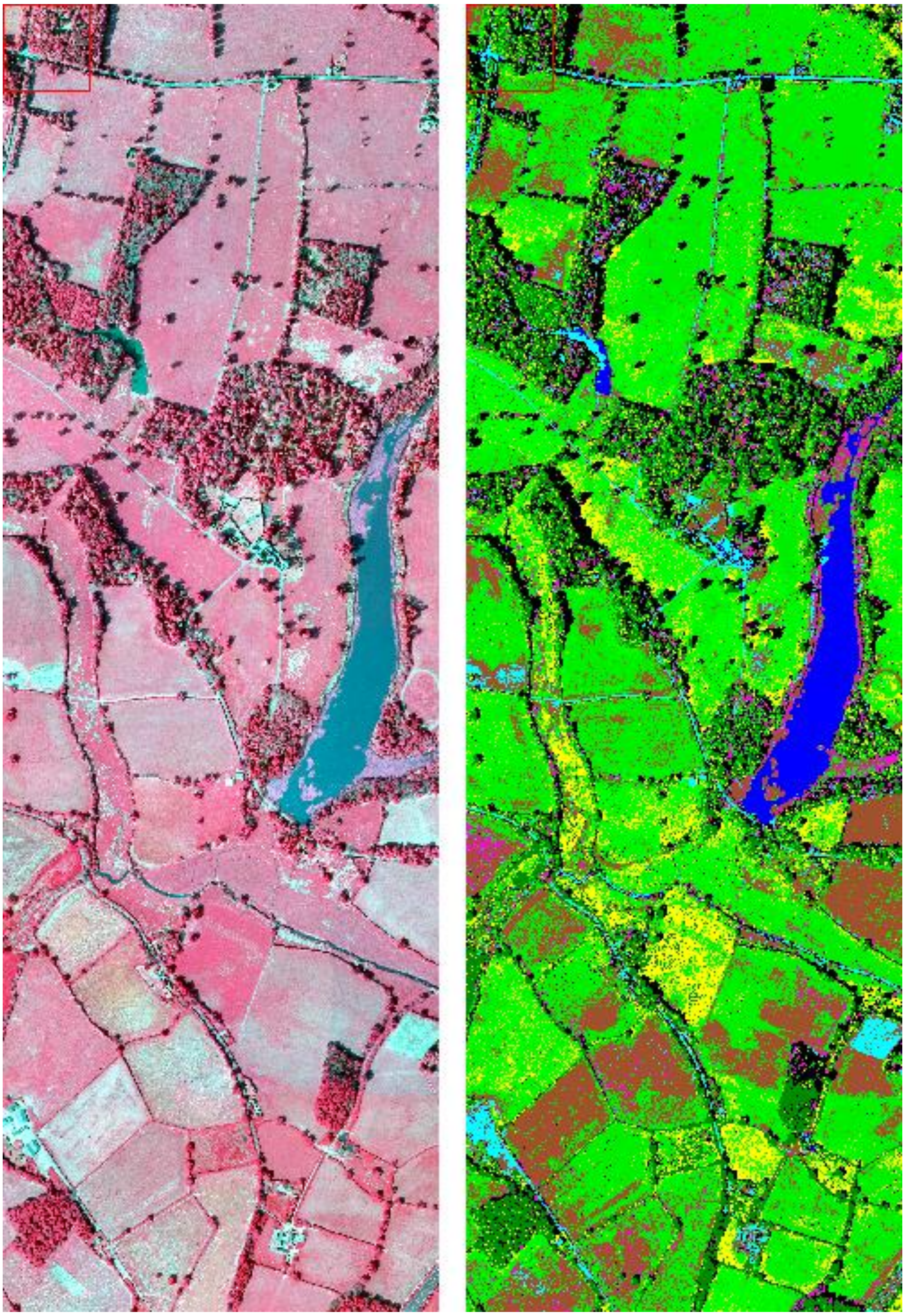

Figure 4. Test area in FCIR representation and the equivalent scene component image (see Table 4 for key to colours).

2. **Aggregated scene component proportions on object:** Often a site or landscape is managed in terms of specific spatial units or objects such as field or woodland compartments etc. In such cases it is therefore useful to aggregate the scene components within a particular object and report a summary for that object. In this way some of the confusions become minimised and the proportions and heterogeneity of the scene components become important indicators of the situation and condition within the object.

Continuing on from the scene component mapping above this work includes the following steps:

- Analysing the scene component proportions on objects: In the scene component map (Figure 1) the different land cover types and habitats present will be seen to have different proportions and patterns of scene components. The challenge is to capture these proportions and patterns and then extract information on the habitat patch characteristics. Usually, some form of land parcel reference data from existing sources or image segmentation can be used to generate an object data set. A set of tools are then available to summarise the scene components on each land parcel as proportions, levels of variability and patterns / texture. The tools can include functionality for avoiding the use of data from around the edge of objects which may include boundary features, their shadows and other habitats. In this case a selection of fields and woods were identified which in which to collect scene component proprtions (Figure 5).
- Interpreting cluster proportions: Once each land parcel has had the scene component information attached it can be exported on a parcel-by-parcel basis for analysis of habitat properties. When the scene component content of the data is understood, the relationship of scene components to habitats and condition can be developed and the land parcels themselves can be labelled appropriately. This stage of the process can be very iterative and should involve the local experts.

From the scene component proportion plots in Figure 5 some basic conclusions can be drawn. As would be expected most scene components tend to be present in all land cover objects, but irrelevant components present in only small proportions. This is due to the spectral ‘noise’ in the data where two different features are spectrally similar and are confused, e.g. grass and illuminated tree canopy.

When considering the two woodland examples it can be seen that shadow becomes significant and the proportions of woody and shadow are very different. Shadow will always be associated with features that have a vertical expression and in this case the mix of shadow and woody is an indication of the openness of the canopy. Wood_01 will have a more open canopy than Wood_02, therefore a ratio of shadow and woody could be used as an indicator for canopy cover density.

The field examples were chosen at random, but give interesting indications of the differing conditions to be found in the agricultural landscape. Field_01 and Field_02 would appear to be very similar and are likely to be under very similar management practices. Field_03 has a high proportion of bare soil while Field_04 has a high proportion of wet grassland suggesting very different conditions. Field_05 has over 80% of the area represented by the grass scene component suggesting it is very homogeneous.

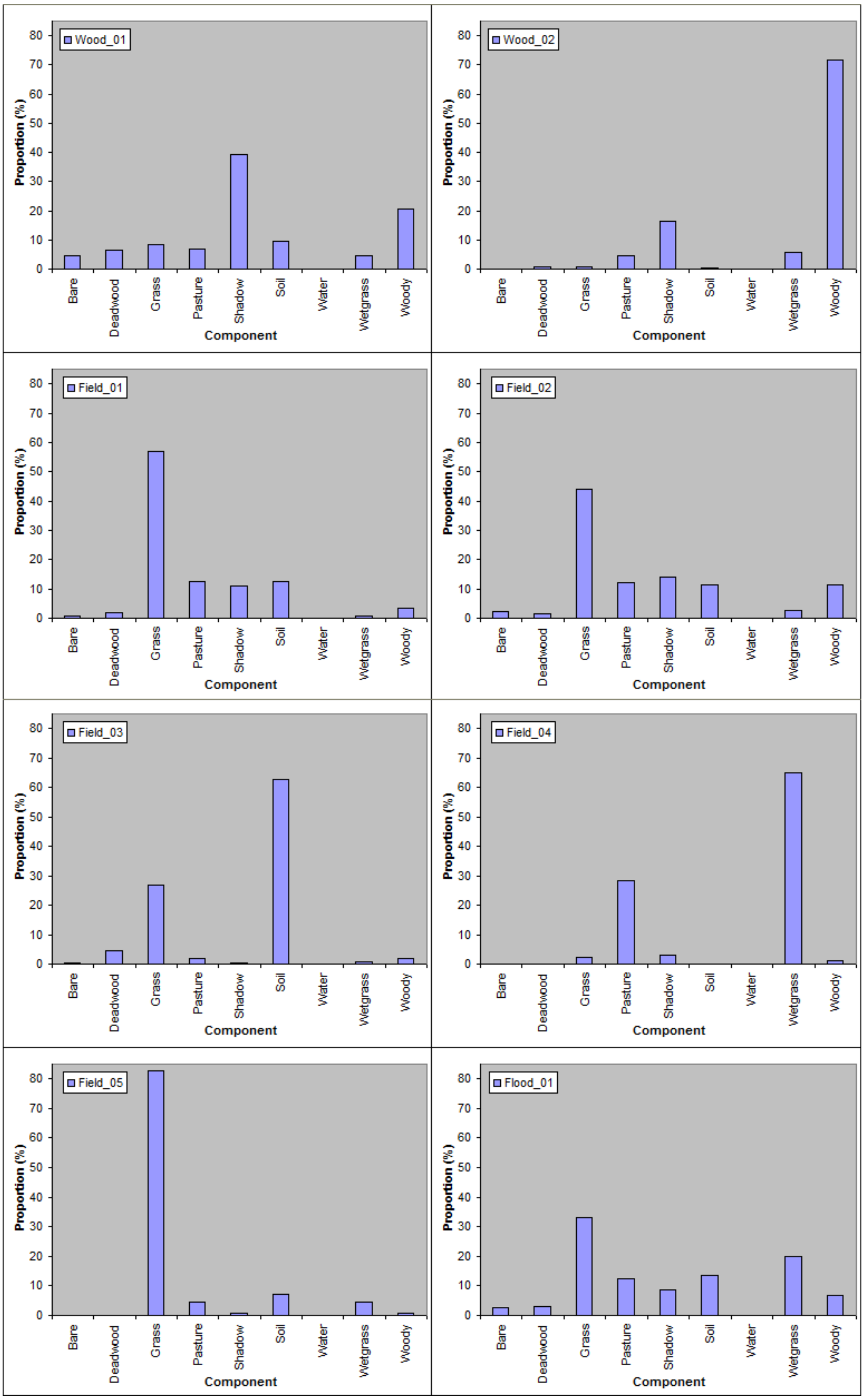

Figure 5. Examples of scene component proportions for a number of different landscape features.

Finally, the field Flood_01 located around a stream course has a relatively even mixture of the vegetated, bare ground and shadow components showing a highly heterogeneous situation. This is common among objects containing semi-natural habitats and mosaics suggesting that this area is not affected by intensive management and is likely to be more natural and have a higher biodiversity.

In the longer term, when more than one date of imagery, and thus scene components, are available the proportions and patterns of scene components can be monitored over time. In an example prepared for the Wicken Fen work (**Figure 6**) the conditions within a field or wood etc. can be compared over time to determine whether the management applied is producing the required result.

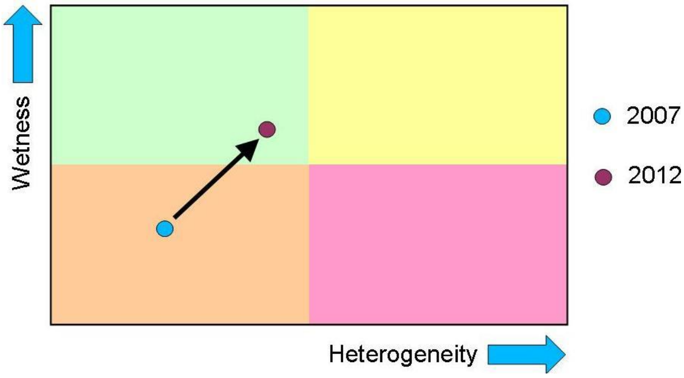

Figure 6. Example of monitoring a landscape object to identify vectors of change

The actual use of scene component proportions can be determined by the local experts based on their particular monitoring requirements.

3. **Woody vegetation mask:** The final product is a further extension of the scene component map which aims to deliver a more generalised mask of woody vegetation. The scene components of woody and deadwood have been combined and extracted. As the scene components were based on 50 cm image data they were still relatively complex spatially, therefore spatial processing was used to remove noise and generalise the location of the areas identified as woody.

Figure 7 shows two examples of the woody vegetation mask for a woodland patch and a network of hedgerows respectively. The spatial processing is yet to be fine tuned and so there a some unusual features caused by the shadow scene component, but the examples demonstrate that from this type of product it would be possible to monitor woodland characteristics and estimate the amounts of hedgerow present in an area. The shadow in the image is both a problem and an opportunity. Depending on the distribution of tree and hedge species and the illumination direction the shadow scene component can produce considerable gaps in the woody mask which may result in the fragmentation of the hedgerow features. A simple combination of the shadow into woody mask would produce an over estimation of the total area. The shadows do however provide information of the openness of canopies, the proportions of trees within hedgerows and the general height of vegetation.

As with the other products, after an initial demonstration of the approach it can be adapted and tailored to meet the requirements of the local managers and experts.

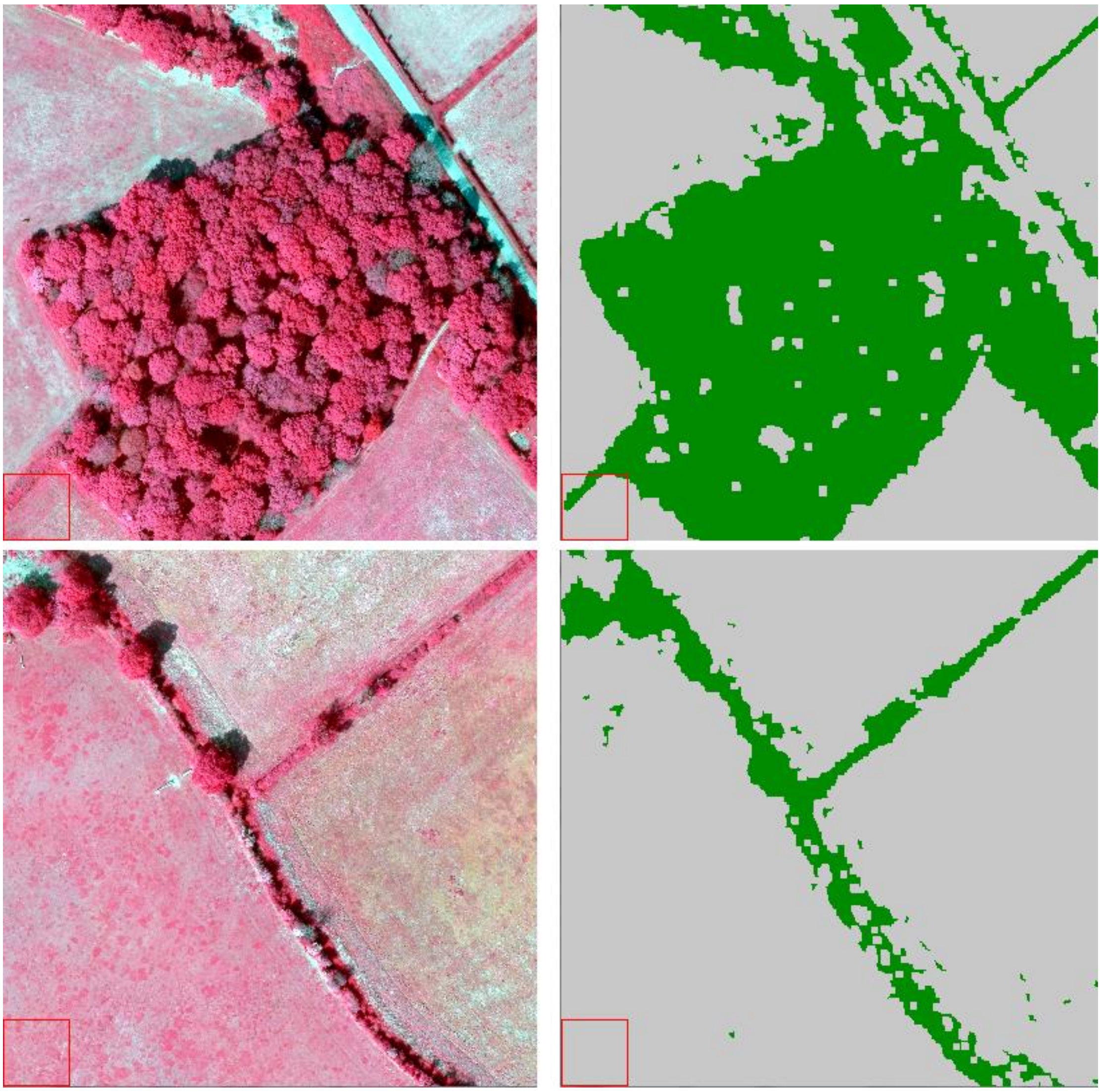

Figure 7. Two examples from a prototype woody vegetation mask.

4 Conclusions and recommendations.

The conclusions and recommendations from this work are based on a number of reviews, prototype specifications and demonstrations and are therefore open fully to discussion with the managers and local experts at Knepp Estates. The initial set of outcomes are as flows:

- The links to WSCC have been maintained, and strengthened in a technical sense, by communication with the team at WSCC and their aerial survey contractor. Access has been agreed to the 2012 WSCC data once acquired and, although it is sub-optimal compared to the previous WSCC datasets, it should provide some useful information for Knepp.
- The archive searches were not as fruitful as expected, mainly due to the lack imagery being acquired within the main growing season. However, a set of possible data purchases have been identified for further consideration which could support the key dates in the development of the work at Knepp.
- A specification for a bespoke aerial photography survey has been proposed, along with a set of suitable survey companies. The specification has been explained, but can be further refined based on the overall requirements at the site.
- Three prototype products have been described which aim to maximise the benefits that can be obtained from aerial photography while keeping it grounded in the context of the local expertise and likely requirements for monitoring. Once these examples have been considered further tailoring or product development can be undertaken.

Overall, this document aims to provide sufficient back ground information and examples for the team working at Knepp to understand the limits and capabilities of remote sensing / Earth Observation and optimise its use in monitoring at the estate. Hopefully this report can be used as a reference source for future activities and could be the basis or a remote sensing strategy in support of the long term monitoring of Knepp.