JNCC Report
No: 495 Phase 1

Making Earth Observation Work for UK Biodiversity Conservation

Part A - Final Report
Part B - Annexes

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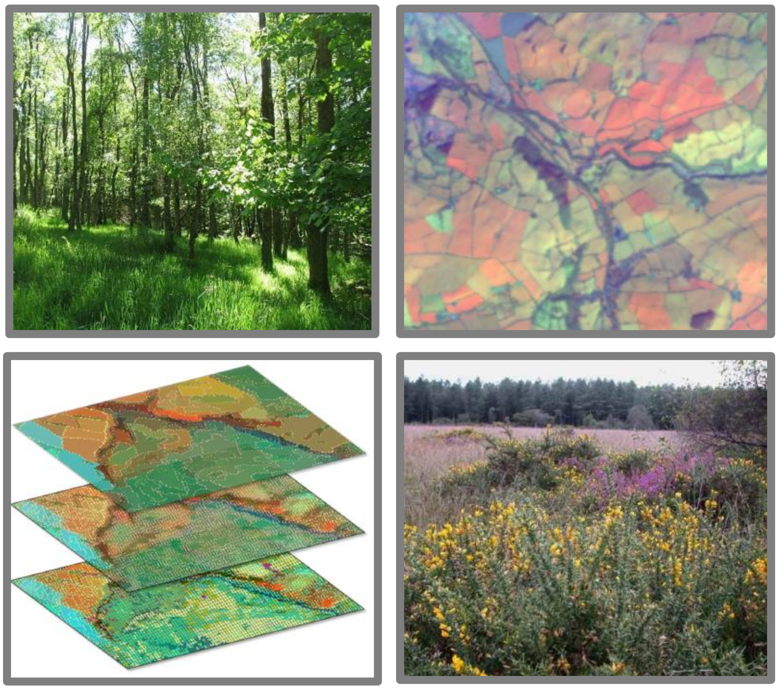
Making Earth Observation Work for UK Biodiversity Conservation – Phase 1

Part A—Final report



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This document constitutes the main final report, the evidence and analysis that this report draws on can be found in the accompanying document, Part B - Annexes and technical evidence.

Executive summary

Recent reviews have shown that there are significant opportunities to contribute to the knowledge on, location and changes of important, less common and more intricate habitats. These include many Annex I and BAP Priority Habitats, particularly outwith the protected sites network. These “higher priority” habitats are particularly difficult and expensive to map and monitor using traditional survey techniques. The country conservation agencies are considering how to meet the demanding requirements for habitat surveillance within tightly constrained resources. Recent research and inventory programmes have shown that earth observation techniques, together with the development of geoinformatics has the potential to provide techniques and approaches to assist current surveillance and monitoring requirements and deliver cost efficiencies. The more effectively fieldwork can be targeted and assisted, the more likely we are to have sufficient knowledge about our environment to assist with habitat protection and in the reporting of biodiversity and ecosystem goods and services.

Environment Systems Ltd., together with partners Team Projects Ltd., Callen-Lenz Associates Ltd. and Aberystwyth University, Institute of Geography and Earth Science was commissioned in October 2010 to undertake Phase 1 of a three Phase project to address habitat monitoring and surveillance needs in the UK, supporting the implementation of the UK Terrestrial Biodiversity Surveillance Strategy.

The aim of Phase 1 was to review recent activity reporting the potential of Earth Observation techniques for operational biodiversity surveillance of terrestrial and freshwater habitats, summarise the use of such techniques by UK country conservation agencies and identify their potential as a cost effective solution to current surveillance and monitoring needs.

The review was based on a systematic assessment of documents and follow-up structured interviews with professional staff. It encompassed a range of initiatives for biodiversity surveillance funded by UK government, government agencies and other members of the Forum for Earth Observation Applications. Account was also taken of relevant EU projects. In total 24 UK initiatives were included in the detailed review, including both field-survey based and EO-based projects. A further 17 EU initiatives and UK initiatives not specifically based on habitat mapping were also considered, albeit in lesser detail.

The project focus was on immediate priorities (e.g. basic habitat inventories) and medium term priorities (e.g. cost effective repeat sampling for condition and service contribution) but some consideration was also given to longer-term research considerations. In this respect, the project also took a limited forward look, exploring the potential for use of satellite and airborne radar, hyperspectral sensors and unmanned aerial vehicles (UAVs) to deliver a flexible and timely source of high resolution EO-derived information.

Each initiative was characterised, then evaluated by a SWOT approach. The available evidence was collated and reviewed against three key headline topics:

- The identification of areas where provision of information is not as comprehensive or efficient as necessary
- EO techniques available and the context in which they had been used
- Suitability of techniques for wider application and roll-out

The review process then compared relative merits that the groups of techniques offered including the value for money and relative comparison of costs of different approaches for surveillance and monitoring of habitats.

During the review and consultations it became clear that current habitat classification systems based on broad habitat assemblages are not necessarily suitable for describing habitats using EO. The project proposed the Crick Framework, grouping habitats based on features identifiable using EO. This was considered a novel and valuable way of identifying appropriate surveillance and monitoring opportunities by the steering group.

The review concluded that many of the EO based techniques are technically effective for filling gaps in provision and mapping the location and extent of a range of habitats including those with dynamic environments. They were also highly cost-effective in comparison to field survey methods and manual EO interpretation, over significant areas.

A range of recommendations are made for future actions to promote best practice and facilitate uptake of the most promising techniques, grouped using key themes originating from the work. Related potential "Pathfinder projects" are outlined and summarised in a roadmap that provides a framework for scoping next steps. These consist of technical projects (which will help with capacity building in government, planning for role out and enabling the technology to work with monitoring data) and communication projects, to ensure there is better and more widespread understanding of earth observation concepts and techniques with most potential to meet habitat surveillance needs.

Key recommendations address:

- Raising awareness with environmental professionals of the value of remote sensing for habitat surveillance and monitoring (by knowledge transfer and confidence building in EO)
- Keeping up to date with current thinking and advancing biophysical science (to allow projects to be as efficient as possible and not be out-dated before reporting)
- Maintaining an active engagement with local authorities, interest groups and volunteers
- Understanding how EO methods describe vegetation structure and condition and are used for monitoring purposes
- Understanding and Integrating data at different accuracies, scales and resolutions and with different uncertainties
- A strategic rollout of an integrated (rule-based) mapping system

It is clear that a "one-size-fits-all" approach will not deliver information on any habitat measure for the full range of higher priority habitats. This is due to inherent differences in habitat characteristics from a remote sensing perspective and differences in the scale of approach that is needed for reporting on measures for different purposes. There is also a wide variation in the use, knowledge and capacity of organisations to adopt the range of EO techniques currently available or under development.

Overall surveillance and monitoring needs are going to require a range of techniques tailored to the particular habitats, the features of interest and size of the area under surveillance. This will often require a combination of techniques including:

- Automatic methods
- Manual API for QA
- Semi-automatic methods (if only small areas are required to be mapped)
- Targeted field campaigns for validation and picking up the presence of habitats defined by small species which occur in low frequency,

There is strong evidence that EO and geoinformatic techniques together have a valuable role to play in an integrated approach, offering a more efficient and cost-effective means of surveillance for many habitats and contributing to effective targeting of field survey for habitats that will continue to require field survey for their identification.

Acknowledgments

With thanks to all at JNCC and Defra, along with all those on the steering group from country agencies and associated organisations who have had input into this project.

We would particularly like to acknowledge the input of Mark Crick into this project, his knowledge and enthusiasm made him a pleasure to work with and his passion for moving this area of work forward was clearly evident. The tier system of habitat classification developed though this work has been named the Crick Framework, as a tribute to him.

Contents

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Glossary

API	Air Photo Interpretation
AWiFS	Advanced Wide Field Sensor
BAP	Biodiversity Action Plan
Boolean	A system of logic/algebraic processes (e.g., AND, OR)
BNSC	British National Space Centre, replaced in 2010 by the US Space Agency
CASI	Compact Airborne Spectrographic Imager
CBD	Convention on Biodiversity
Confusion matrices	A matrix that displays statistics for assessing image classification accuracy by showing the degree of misclassification among classes.
CIR	Colour Infrared
DMSP	Defence Meteorological Satellite Program, US Department of Defence satellite system
eCognition	Software for developing segmentations and rule-based classifications
DEM	Digital Elevation Model
DTM	Digital Terrain Model
Envisat	Environmental Satellite
EO	Earth Observation
GIFTSS	Government Information from The Space Sector, funding programme for government departments and agencies make the best use of information we get from satellites.
GIS	Geographic Information System
GMES	Global Monitoring for Environment and Security
HAP	Habitat action plan
HRG	High Resolution Geometric
Ikonos	Commercial EO satellite
IRS	Indian Remote Sensing Satellite
Kappa	Camera calibration coefficient - rotation about the twice rotated ground Z axis
Kappa coefficient	A statistical measure of the agreement, beyond chance, between two maps (e.g. map of classification and ground truthed map)
Landsat	Land Satellite
Lidar	Light Detection and Ranging
LWEC	Living With Environmental Change, a partnership of UK government departments and agencies, devolved administrations, local government and research councils, looking at economic and social challenges to do with climate change
MERIS	Medium Resolution Imaging Spectrometer
MHW	Mean High Water
ML	Machine Learning
MLP	Multilayer Perceptron - a feedforward artificial neural network model that maps sets of input data onto a set of appropriate output
MMU	Minimum mapping unit - used to describe the smallest sized features recorded in a mapping exercise
NCEO	National Centre for Earth Observation
NDVI	Normalized Difference Vegetation Index
NIR	Near-infrared
Orthorectification	A process of geometric referencing of an image to a map coordinate system that considers variations in the topography of the earth surface and the tilt of the satellite sensor.

OSMM	Ordnance Survey MasterMap dataset
Pre-processing	Ortho, atmospheric, topographic and other corrections to prepare imagery for classification.
RGB	Red Green Blue, or true colour used for describing aerial imagery
Rule base	A series of structured statistical rules (e.g. NDVI < 0.9) applied to satellite imagery, airborne imagery and/or thematic data layers to produce a user defined map.
SAC	Special Area of Conservation
SAR	Synthetic Aperture Radar, type of active satellite sensor
Segmentation	Grouping of pixels based on similar values – a type of automated vectorisation (digitising).
Shapefile	A set of files used by ESRI Arcmap the contains points, arcs or polygons holding tabular data and spatial information
SNCO	Statutory Nature Conservation Organisations, government agencies
SPOT	Satellite Pour l'Observation de la Terre, French satellite supporting the HRG sensor
SWIR	Short Wave Infrared
Topographic shadowing	Shadowing of a surface by the surrounding topographic relief and as a function of solar angle.
UAS	Unmanned Aerial System - the system required either for safe flight (from a regulatory perspective) or for the delivery of data products
UAV	Unmanned Aerial Vehicle - an aerial platform that can carry a sensor
UKSA	UK Space Agency
WFD	Water Framework Directive

1. Introduction

1.1 Purpose and scope of the project

This report identifies the role that Earth Observation (EO) and geo-informatic approaches can provide in supporting ongoing habitat surveillance and monitoring activities carried out by country agencies in the UK. It highlights the potential for use of these methods to fill gaps and complement the specific exploratory work by these bodies and the country governments. It presents the findings of a short-term scoping study; the first phase of a three phase project to address habitat monitoring and surveillance needs in the UK, and thereby support the cost-effective implementation of the UK Terrestrial Biodiversity Surveillance Strategy (JNCC, 2008). It is concerned with terrestrial and freshwater habitats, with a particular focus on the monitoring and reporting needs for EC Habitats Directive Annex I habitats and UK Biodiversity Action Plan (BAP) Priority Habitats.

There have been advances in the application of remote sensing to habitat surveillance in recent years. Ongoing initiatives led by country governments, agencies and others, continue to further the progress made to date. New processing techniques have been developed and there are further sources of satellite, aerial and ancillary data. However, the scale of the task, means that despite this progress and considerable field effort, there remains an acknowledged gap in information on extent, location and condition of habitats at a UK and country level, particularly outwith the protected sites network. The more effectively fieldwork can be targeted and aided, the more likely we are to have sufficient knowledge about our environment to assist with habitat protection and in the reporting of biodiversity and ecosystem goods and services.

Reviews of the adequacy of biodiversity surveillance (JNCC, 2008) to meet the needs of key legislative drivers have demonstrated the general lack of surveillance adequate for identifying stock and change of higher thematic resolution habitats (i.e. BAP Priority and EC Habitats Directive Annex I), particularly outside the statutory site series[1]. The country conservation agencies are considering how to meet the demanding requirements for habitat surveillance in sites and in the wider countryside within tightly constrained resources and they are considering a number of options. These include focussing surveillance activity where it is of most use, using a risk based approach, better integration of different surveillance programmes so that multiple needs can be met using the same surveillance, and the use of new more efficient surveillance techniques. EO and geo-informatics is a critical area they are all considering as a means of providing a significant contribution to the information needed within available resources.

The review is based on a systematic assessment of existing information sources describing a range of initiatives funded by Defra, JNCC, country agencies, members of the Forum for Earth Observation Applications and relevant EU projects. The project focus is on immediate priorities (e.g. basic habitat inventories) and medium term priorities (e.g. cost effective repeat sampling for condition and service contribution) but some consideration is given to longer-term research considerations. In this respect, the project also takes a limited forward look, exploring the potential for use of satellite and

[1] The statutory site series comprises Ramsar sites, SSSIs/ ASSSIs and Natura 2000 sites

airborne radar, hyperspectral sensors and unmanned aerial vehicles (UAVs) to deliver a flexible, timely source of high resolution EO-derived information. In addition to this, geo-informatics is providing the ability to incorporate more than one source or type of data together in a geographical analysis. This means that the potential to exploit these new data sources and combine them with information from existing data sets is much greater than it was.

Within this report we have considered situations where the need for information for surveillance and monitoring is not being fully met, or where efficiencies in the current surveillance and monitoring processes could be improved. For ease of description we have referred to these situations as 'requirements'. These are described and characterised and those which have potential to be filled in a cost effective manner by utilising earth observation techniques are identified. A range of recommendations are made of future actions to promote best practice and facilitate uptake of the most promising techniques; these recommendations are grouped using key themes originating from the work. Related potential "Pathfinder projects" are outlined. These consist of technical projects (which will help with capacity building in government, planning for role out and enabling the technology to work with monitoring data) and communication projects, to ensure there is better and more widespread understanding of earth observation concepts and techniques with most potential to meet habitat surveillance needs.

1.2 Policy Context

In the UK, nature conservation is delivered by a partnership of Government, statutory bodies and non-governmental organisations. The framework for conserving biodiversity is driven by a wide range of policies, legislation and agreements; including international agreements and European legislation.

The legislative and policy framework is set by Government (Defra, the Scottish Government, the Welsh Assembly Government and the Northern Ireland Executive). UK-wide and international aspects are the responsibility of Defra, who have a role both in shaping and delivering international agreements.

Statutory bodies are responsible for delivering nature conservation on the ground and advising government. Natural England, Scottish Natural Heritage and the Countryside Council for Wales perform these functions in England, Scotland and Wales respectively. Each operates as a non-departmental public body at arm's-length from Government. In Northern Ireland, the Northern Ireland Environment Agency (an executive agency of the Department of the Environment) has broadly similar responsibilities and the Council for Nature Conservation and the Countryside provides advice to the department. UK-wide and international nature conservation functions are undertaken by JNCC.

Many other Government bodies also make an important contribution, including organisations with wider environmental remits like the Environment Agency, the Scottish Environmental Protection Agency and the Forestry Commission. The approach to conserving biodiversity in the UK also depends upon wider partnerships – involving statutory bodies working with voluntary, scientific and business sectors.

At a global scale, the Convention on Biological Diversity (CBD), signed by the UK in 1992, promotes the conservation and sustainable use of the world's biological diversity and provides targets that provide a clear focus for national strategies. It has been highly influential, leading the UK to be the first country to produce a national Biodiversity Action Plan, in 1994, which has subsequently been translated into country biodiversity strategies and contributed to the development of the Sustainable Development Strategy. At CBD COP10 in Nagoya last October the UK joined other Parties in committing to take effective and urgent action to halt the loss of biodiversity in order that by 2020 ecosystems are resilient and continue to provide essential services, thereby securing the planet's variety of life, and contributing to human well-being, and poverty eradication (CBD, 2010). There are various other international agreements or conventions that are concerned with specific species or ecosystems, issues that affect biodiversity or geographical areas (e.g. the Ramsar Convention on Wetlands of International Importance).

Within the European Union, the Habitats Directive (92/43/EEC) and form the cornerstone of Europe's nature conservation policy. Other legislation, such as the Water Framework Directive, also deals with nature conservation as well as having wider environmental objectives.

Specific UK legislation, such as the Wildlife and Countryside Act, 1981, provides protection for habitats and species. Increasingly, emphasis is being placed on bringing biodiversity conservation and environmental protection into all Government activities (e.g. through the Natural Environment and Rural Communities Act, 2006).

For land outside the statutory site series, protection is afforded through non-statutory designations (e.g. local wildlife sites), targeted voluntary agreements (such as agri-environment schemes) that encourage farmers and land managers to manage land for environmental benefit, planning policy and controls. It is important to note that Annex I and BAP priority habitats are located on land within and outwith the protected sites network.

Policies and priorities for nature conservation continue to develop, being shaped by major work programmes to understand and manage the impacts of environmental change, brought about by climate change and other pressures on biodiversity such as invasive species and pollutants. This work, including major activities such as the National Ecosystem Assessment is improving our understanding of the importance of the UK's natural environment in providing ecosystem goods and services and establishing its contribution to economic prosperity and human well being. There is an increasing recognition that to increase the potential for successful adaptation to climate change and to improve the resilience of biodiversity, conservation efforts will increasingly be required to operate at the landscape scale, extending beyond the network of protected sites to achieve habitat interconnectivity.

1.2.1 Habitats of high priority for conservation

This review is concerned with two specific groups of habitats, recognised as being of high priority for conservation action - EC Habitats Directive Annex I habitats and Biodiversity Action Plan Priority Habitats (Appendix 1). These habitats are of national, European and international significance for biodiversity.

Annex I habitats

The EC Habitats Directive, came into legal force in 1994, its aim is to promote the maintenance of biodiversity. It specifically seeks to protect and bring into favourable conservation status natural habitats of recognised importance at the European scale that are considered to be under threat in the EU because they are in danger of disappearance or have a restricted range in Europe. Habitats are also included that present outstanding examples of one of the five bio-geographical zones into which the EU is divided. 75 terrestrial and freshwater Annex I habitats are represented in the UK and are listed in Annex I of the Directive. The Habitats Directive requires the selection, designation and management of a network of Special Areas of Conservation (that protect habitats and species listed in the Habitats Directive), which together with the existing Special Protection Areas (designated for birds) and Ramsar sites (wetlands) form a network of protected sites across the European Union called Natura 2000. There are currently over 600 terrestrial and freshwater SACs already designated, in the UK covering over 2.6 million hectares; the process of designation is ongoing and a further list of about 25 candidate sites have been identified.

Favourable Conservation Status of an Annex I habitat is considered to have been achieved when:

- Its natural range and areas it covers within that range are stable or increasing, and
- the specific structure and functions which are necessary for its long-term maintenance exist and are likely to continue to exist for the foreseeable future, and
- the conservation status of its typical species is favourable as defined in Article 1(i).

In 2007, the JNCC produced a UK report on the status of the Annex I habitats and published an assessment of the most urgent actions needed to improve them (JNCC, 2007). This was in response to Article 17 of the Directive which requires EU Member States to report on the state of their protected areas every six years.

Biodiversity Action Plan Priority Habitats

The UK's commitment to the conservation of biodiversity is delivered through the UK Biodiversity Action Plan (Defra, 2007), an internationally recognised programme comprising a series of plans to target action for particularly vulnerable habitats and species. The UKBAP describes the biological resources of the UK and provides detailed plans for conservation of these resources, at national and devolved levels. The original list of UK BAP priority habitats was published in 1995-1999, but has since been reviewed and updated (Maddock, 2008, updated 2010). The review generated a large increase in the number of habitats and species requiring action. There are currently 51 terrestrial and freshwater priority habitats (Appendix 1) selected on the basis of international importance, evidence of risk (such as rarity or rate of decline) and their importance for key species.

Habitat Action Plans (HAPs) have been produced for most priority habitats. These define the habitat in terms of constituent habitat sub-types (e.g. NVC, Annex I), identify associated habitats and species, describe its distribution and extent, identify factors affecting the habitat and management needs, and provide objectives for management and protection and any barriers to achieving these.

In England, recent work (Webb et al. 2010) has identified the habitat requirements of all UKBAP species relevant to priority habitats in England. This will facilitate a move towards greater emphasis on achieving biodiversity targets through habitat-based delivery. The findings suggest that for species conservation to be effectively integrated into a habitat-based approach much greater emphasis needs to be placed on creating the component niches and resources required by BAP species, rather than managing habitats generically. Structural variation within and between habitats is often an important factor, both because different species require different structural states and because many species rely on many different states to complete their life cycles. In wetlands, hydrology, water quality and the transitional zone between aquatic and terrestrial habitats are all critical components of priority species requirements.

1.2.2 What habitat information is currently necessary for surveillance and monitoring of Annex I and BAP priority habitats?

Information requirements for surveillance and monitoring of habitats arise from various stages in the policy cycle (Figure 1). For example, information on the extent and location of habitats are needed as a start-point to understand the overall situation to ensure habitats are adequately protected and management action targeted appropriately. Reporting obligations are in place and these lead to a requirement for information on status and trends to assess how the implementation of policies is affecting habitats and species.

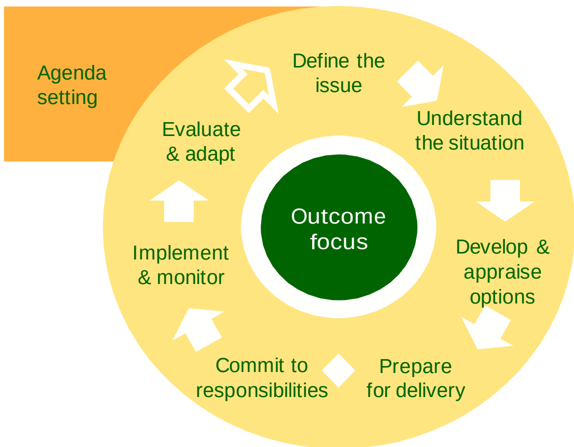

Figure 1. Policy making in Defra. Source: Corporate plan 2009/10 - 2011/12

In relation to the policy context described in section 1.2, Defra, JNCC and partners require information about Annex I and BAP priority habitats in order to:

- Provide reliable, sufficiently detailed information on both the state of and changes to biodiversity at country and UK scales to meet domestic, European and international monitoring and reporting requirements (in particular the EC Habitats Directive and the UKBAP);
- Target spend and resources more accurately to influence outcomes for biodiversity, and to measure those outcomes more consistently (for example to assess the effectiveness of agri-environment spend);
- Identify the state of and changes to ecosystem functions and services.
- Identify and attribute the impacts of different pressures on habitats and ecosystem services.
- Report on the condition of protected sites and inform on their management.
- To effect better outcomes for biodiversity through strategic and local planning processes.

What kind of habitat measurements are required?

Surveillance and monitoring information needs can be described in terms of a range of particular measures that are used to express the status and trends of these habitats. For the purposes of this project four distinct measures have been adopted; namely "extent", "condition", "change" and "services" and these are defined / described in Table 1.

It is essential when monitoring habitats over time that the measures used are repeatable.

"Measures of dynamic processes" have also been included; these relate specifically to highly dynamic environments. The temporal cycling of these environments is much shorter than that of most habitats, and the associated change is of prime importance to their biodiversity. In common with other habitats, the measures for dynamic environments are also concerned with condition, extent, change and service provision, however the distinction is that the information needs for these environments are needed on a much more frequent temporal scale. Extreme events and regular weather changes can cause dramatic alterations in the habitats within a matter of hours, for example, a large storm can remodel a sand dune in under 24 hours, re-setting the seral stages of development of significant parts of the area.

Table 1. Description of measures used in habitat surveillance and monitoring

Measure	Description	Comment
Extent	This is the spatial expression of a particular habitat. It includes its bio-geographical range and how it interacts with the surrounding land.	Natural habitats rarely have "hard" boundaries and often merge into adjoining habitats through an area known as an ecotone. Some habitats must be surrounded by other complimentary habitats in order to survive, therefore extent is taken to encompass this range of features. Habitat inventories describe the distribution of habitats – providing information on both extent and location. They can contain a wealth of information including habitat features, condition, relationship to other classes and the certainty of mapping. Thus a habitat inventory is not necessarily a static map and could produce one of any number of maps.
Condition	Condition is an assessment of how close a habitat is to its ideal fully functioning state. A habitat in poor condition does not have all the necessary components to function in ecological terms, or these components are in less than ideal numbers or proportions.	Condition of habitats has been described in detail by Common Standard Monitoring. For each habitat species indicative of good condition and poorer condition are recorded, along with other features such as wetness and bare ground. In many cases negative indicator species and features can be easier to detect, therefore a lack of these can be taken as a proxy for the habitat being in good condition.
Change	Habitats tend to evolve through a series of natural processes towards the final seral stage of development – in the UK this is mainly woodland. Management practices arrest habitats at a particular point in this process, for example grazing prevents grassland eventually evolving to scrub and then woodland. As management practices change with the pressure on the land, it is important to monitor the state of the habitats and changes both positive and negative.	Change is monitored against a baseline of the habitat at a particular point in time. Change is traditionally measured through repeat assessments of extent and condition, within ecological habitat surveys. Only substantive change is of interest. Normal cycles of management activity, such as heather burning, or grassland cutting are considered as part of the natural process.
Services	As well as the ecological carrying capacity inherent in any ecosystem, it also provides a range of other 'services' for the benefit of the wider countryside, and the human population. For example a woodland supports a range of plants, animals and insects and will also intercept rainfall slowing the passage of water through the system to mitigate against flooding.	Identification of services is still underway for many habitats/ biotopes (e.g. through the work of the National Ecosystem Assessment) and is often highly context-dependent. Data needs are also not yet fully understood for all services.
Measures of dynamic processes	Some habitats in the UK are special because of their highly dynamic nature and fast changing features. These habitats change very rapidly and are heavily modified by weather and tidal conditions, altering significantly after certain storm events that can happen very frequently.	Coastal processes, soil erosion, woodland management, moorland burning

Section 2 of Part B of this report, Annexes and Technical Evidence, provides a summary of information needs for surveillance and monitoring of higher priority habitats that arise from key policy areas and legislative drivers.

In summary, there is a need for:

- accurate mapped inventories of consistent quality throughout, or with known consistency, that can be updated, showing the <u>location</u> and <u>extent</u> of higher priority habitats in the UK;

- information that supports the content of inventories, including size and location of ecotones, representation of mosaics and gradients in the inventories, measures of certainty of classification;
- mapped information relating to surrounding habitats and landcover - sufficient to provide context for a diverse range of assessments relating to the priority habitats;
  (e.g. to assist with strategic planning, target setting, targeting agri-environment scheme uptake, assisting with planning control decisions, assessing habitat connectivity, establishing value of habitats for wildlife etc);
- information on the current and potential natural range of higher priority habitats, now and in the future;
- robust mechanisms for updating mapped inventories to identify change in the location and extent of these habitats;
- measures of dynamic processes (coastal processes, soil erosion, woodland management, moorland burning) – produced on a frequent enough cycle and suitable for site management and monitoring or landscape scale assessments.
- consistent and repeatable measures that contribute to establishing the condition (quality) and change in condition of habitats - to site level. This includes:
  - measures based on presence of species or vegetation composition,
    (e.g. grass/herb ratio, presence of characteristic species (positive indicators) or undesirable species (negative indicators));
  - measures of quality, based on structural characteristics of vegetation
    (e.g. average minimum or maximum height, presence of range of vegetation zones);
  - physical / process related measures
    (e.g. presence of physical conditions upon which the habitat depends – minimum amount of bare soil, or negative features such as the presence of a seawall),
- consistent and repeatable measures that identify the state of and changes to ecosystem functions and services (e.g. the suitability of habitats for plant or animal species or changes that signal potential changes in condition due to pressures on habitats) - required at a variety of scales. Includes:
  - biophysical measures of structural variability, vegetation heterogeneity, productivity, wetness, plant stress, and plant growth form (e.g. if the plant is leafy and forms patches, or if it is woody etc).

1.2.3 Key Surveillance and Monitoring activities in the UK that inform on the state of higher priority habitats

Current key surveillance and monitoring activities that inform on the status and condition of higher priority habitats are described by JNCC (JNCC unpublished, 2010) and in summary comprise:

Digitally mapped habitat inventories. A number of habitats, particularly woodlands and coastal habitats, have benefitted from work to assemble inventories of the resource at country or UK level. These inventories have drawn data from a range of sources, some of which are repeatable and some of which are not, or contain a paucity of information. Classifications used in these inventories vary according to purpose, but for higher priority habitats, Phase 1, BAP Broad or Priority Habitats and (less frequently) Annex I classifications are used. Natural England has a well-established programme, compiling digital inventories for BAP Priority Habitats. For some habitats, sampling against these inventories to assess condition of the resource outside statutory sites has been undertaken for BAP reporting. In addition to the National Forest Inventory (formerly NIWT) the Forestry Commission also carries out other relevant activity such as the Native Woodland Survey of Scotland. Forestry Commission are also involved in work to providing information more relevant to BAP and Habitats Directive reporting purposes from these inventories. The Environment Agency has created a full extent map of saltmarsh in England and Wales for the period 2006-09 using high resolution aerial photography. The primary aim of this work has been to inform monitoring, surveillance and reporting requirements under the Water Framework and Habitats Directives and BAP reporting. However this output also provides the first high accuracy baseline of saltmarsh extent in England and Wales with which future maps can be derived from. SEPA is leading work to develop a wetland inventory for Scotland. This work uses a newly developed wetland typology, referable to both BAP Priority Habitat and Annex I habitat types. Other coastal habitats have been mapped comprehensively by the Environment Agency in Southern and South West region's Regional Coastal Monitoring Programmes, using the Integrated Habitat System (IHS) of mapping.

Common Standards Monitoring of protected sites (SSSI/ASSI, SACs) – is undertaken by measuring a common set of parameters agreed at UK level for each habitat type. These key 'attributes' which are used to assess condition, are set out in guidance implemented through programmes developed at country level. Monitoring measures progress towards targets for condition, set at a site level and across the whole stock of SSSIs/ASSIs. Currently the use of overall targets is under review, and future deployment and development will be determined by the work to revise country environment/ biodiversity strategies. This monitoring includes Annex I habitat features within SACs, which in the UK are effectively treated as an additional designation onto of parts of the SSSI network.

Agri-environment scheme monitoring is carried out on a range of habitats and species to assess the effectiveness of schemes designed to maintain or restore, habitats or species populations, strongly associated with farmed land; and hence compliance with the aims of original legislation. Methodologies and periodicity vary according to the component. In England, work is proceeding to integrate this monitoring with other site-based monitoring activities, including Common Standards Monitoring.

River Habitat Survey is a technique developed to record physical habitat and geomorphology along a designated 500m stretch of river. It is used throughout the UK as a tool for environmental assessment and catchment planning, providing information for the Habitats Directive, WFD and State of the Environment reporting. It is designed to offer a reproducible semi-objective method of assessing river habitat quality and naturalness.

Countryside Survey is a regular programme of field survey (from a sample of 1km squares across GB in co-ordination with the separately undertaken Northern Ireland Countryside Survey) and national mapping of UKBAP broad habitats, derived from satellite imagery (UK Land Cover Map). The survey covers both freshwater and terrestrial habitats and provides assessment of the general state of the UK countryside and many widespread BAP Broad Habitats. The sampling frame and stratification are insufficient for providing information on stock and change of certain smaller BAP Priority and Annex I habitats, however they can be used for larger habitat areas and could provide an extremely useful extra source of information for geoinformatics modelling.

1.2.4 What is known about current gaps in provision for higher priority habitats (all measures, all habitats, all geographic contexts)?

Table 2. Summary of known current gaps in provision

Measure	Nature and characteristics of gaps in provision
Gap 1 Extent / Location	• up-to-date digital mapped habitat inventories are incomplete as a UK wide resource - existing coverage is highly variable in terms of completeness: o geographically (best in Wales and England, at varying stages in Scotland, and limited in NI); o thematically, (very little available for freshwater habitats or hedgerows); o between statutory and non-statutory sites, (identifying gaps in coverage outwith protected sites is problematic and costly); • lack of consistent quality and repeatable survey information; • limited available accurate mapped site-level evidence of the baseline extent of features extent of notified habitats for site surveillance; • lack of sufficiently detailed information to feed into habitat system conversion tools to enable better understanding of the relationships between available inventories; • limited proof of success of habitat system conversion tools; • inadequate representation of mosaics and gradients in mapped inventories, particularly those that have been derived on a thematic basis; • insufficient description of interactions with surrounding land parcels, including size and location of ecotones; • lack of a three-dimensional view of habitats in mapped products.
Gap 2 Condition	• insufficient knowledge of condition outwith statutory sites; • there are few proxy condition measures developed for use that do not require fieldwork and which could be used remotely to; o support assessment of habitat condition (e.g. to direct fieldwork on a risk based system for protected sites); o establish presence and suitability of habitats for plant and animal species – e.g. measures of structural diversity, vegetation heterogeneity, productivity, wetness) or to identify suitable sites for re-creation of the habitat; o determine the presence and status of interactions between habitats – e.g. In wetlands, hydrology, water quality and the transitional zone between aquatic and terrestrial habitats.
Gap 3 Change	• insufficient information on change in extent available – baseline maps often still being produced; • few established geoinformatic approaches that can produce habitat change information for available data; • limited availability of established methods to measure change to supporting processes; • potential future natural range of habitats (under scenarios of climate change) is not well understood.
Gap 4 Services	• the science of considering ecosystems as holistic systems, with all the nuances and interactions is a very young discipline and much research is currently underway before this becomes an established practice; • specification of information requirements for local, regional and national modelling is currently under development, and as such still has a system of consultation and development before these systems are robust; • work emerging suggests that the more detail and precision put into the initial work the better the final result, there is however still a lack of ubiquitous regional/national data to run scenarios to an optimum level.
Gap 5 Dynamic environment issues	• frequency of change in dynamic environments outputs means that information is required after any major event, this level of temporal detail is not yet available for the whole coastline; • incomplete information on the specific habitats and species occupying coastal cliffs and how these are affected by major change events; • traditionally only a two-dimensional view of the landscape is considered, which leads to gaps in the ability to display vertical structures.

Table 2 shows that there are opportunities for EO to enhance existing data collection, as well as to add information to update where current provision is inadequate. In addition, EO and geoinformatic techniques offer opportunities to provide habitat information in areas where there is no current surveillance.

Priority information needs

There are priority information needs, with information on some measures being required more urgently than others. The most immediate need is to complete the habitat inventories, as these underpin a wide range of ongoing and planned activities. In addition, there is a need for information on condition, function and change of Annex I and BAP Priority Habitats, and their context within the landscape.

1.3 Earth observation and geoinformatic approaches

1.3.1 Earth Observation

EO, including satellite and airborne systems, allows for mapping and monitoring of the surface of the Earth, it is the ‘earth facing’ discipline of remote sensing. EO technologies are most commonly used through the acquisition and use of aerial photography, with satellite-based EO starting up in 1972 with the launch of the first Landsat satellite. Since then, there have been progressive improvements in spatial, temporal and spectral resolution, across a range of mapping scales for a variety of mapping requirements.

EO provides the opportunity for consistent, objective mapping, using data from a number of sources and sensors, over a range of mapping scales. EO-based applications may be deployed for contiguous wide-area coverage, to:

- determine land cover/habitats;
- monitor change in land cover/habitats;
- monitor biomass production and carbon storage issues;
- monitor land management features;
- monitor atmospheric conditions.

EO data is not a universal panacea; not everything can be mapped, all of the time. However, combining imagery at different working scales and timings, can provide information from field scale to a wider area perspective. Using differently timed data it is also possible to track temporal change and determine system function such as cause and effect of change, not directly possible with field work. Optical EO systems are categorised into four resolution classes:

- Very High Resolution (VHR) ≤ 5 m
- High Resolution (HR) ≤ 30 m
- Medium Resolution (MR) ≤ 300 m
- Low Resolution (LR) ≤ 5 km

All aerial photography should be considered 'Very High Resolution'. Higher spatial resolution typically means a smaller geographic footprint. Wider area coverage can be achieved by mosaicing several scenes together.

1.3.2 Geoinformatic approaches

Geoinformatics has been described as "the science and technology of dealing with the structure and character of spatial information, its capture, its classification and qualification, its storage, processing, portrayal and dissemination, including the infrastructure necessary to secure optimal use of this information". An integrated approach based on geoinformatics is considered increasingly important in the drive to address diverse socio-economic challenges brought about by environmental pressures. Responses to such challenges require integrated and innovative solutions for analysing, modelling, managing, and archiving extensive datasets.

Geoinformatics has a significant role to play within habitat mapping and monitoring exercises. The science gives a structured approach project to deal with likely technical issues that may arise when integrating different habitat surveys conducted under different protocols, or using information from more than one type of survey or report to build up a model of an ecosystem.

1.3.3 EO and geoinformatic approaches currently used in habitat mapping

Approaches using both EO and geoinformatics are already in use for BAP inventory mapping and in the production of the Phase 1 inventory in Wales. An example of how this approach can be used is found within the modelling of Caledonian forest in Scotland (Hester et al. 2000). A model has been built to incorporate multiple datasets to infer where the BAP priority habitat is likely to occur. Another example is within the Phase 1 habitat inventory for Wales where over 30 layers of data can be used together and techniques of fuzzy membership help to describe boundaries and ecotones and Dempster-Shaffer belief functions are used to provide the means to produce the crisp Phase 1 classes (Lucas et al. 2011).

Both EO and geoinformatics approaches are in use in a number of active projects and as such they can be evaluated in terms of filling in gaps in knowledge and providing an analytical approach to mapping and monitoring. This study examined existing pieces of work utilising these approaches in order to assess opportunities for further incorporating the technologies to answer questions of importance.

2. Project Approach

2.1.1 Overall Project Approach

This review is based primarily on systematic assessment of information sources describing a range of recent or current initiatives funded by Defra, JNCC, country agencies, members of the Forum for Earth Observation Applications and relevant EU projects. The evidence from these sources has been used to provide:

- a baseline assessment of current methods of habitat surveillance by means of a synthesis, describing their characteristics and methods, identifying known gaps in provision, establishing their fitness for purpose, and barriers to their operational use;
- a short structured assessment of relevant approaches for habitat surveillance in other EU Member States; and,
- a short structured assessment of relevant approaches in other sectors in the UK.

The information available from documented sources has been supplemented by consultation with technical and policy specialists from the organisations involved with the review. This was conducted by email and telephone interviews.

The information is brought together and evaluated to:

- characterise known gaps in provision (section 1);
- identify which techniques can address these gaps; describe how techniques address information needs (section 3);
- prioritise solutions based on their fitness for purpose and identify whether EO techniques are likely to provide value for money (section 3);
- identify short, medium, long-term solutions; (section 4);
- identify any barriers to implementing solutions (section 3);
- identify research needs (section 4).

Recommendations comprise steps which are required to facilitate the wider use of earth observation for biodiversity surveillance and monitoring. Finally, a range of potential “Pathfinder projects” are outlined.

A workshop was held to check and validate the findings before they were finalised and discuss actions needed to realise the potential of these techniques (section 5).

2.1.2 Headline Questions

Based on the objectives, a set of headline questions were formulated (Table 3) to ensure the review addressed the project aims. This report is structured to bring the available evidence together to address these questions.

Table 3. Headline Questions for the project to address

Establishing information needs and current costs of provision

- What habitat information is currently necessary for surveillance and monitoring?
- What is known about current gaps in provision (all measures, all habitats, all geographic contexts)?
- What are the costs of current habitat surveillance techniques (non-EO based)?

EO based techniques available

- How many EO based techniques offer potential and what characterises these techniques?
- How many of these techniques have been implemented or trialled across the UK for habitat surveillance?

Evidence of their likely suitability from a technical perspective

- What evidence is there that these techniques are suitable or have potential for producing reliable habitat measurements for PH and Annex I habitats?
- From a technical perspective, do they have potential to provide a full or partial solution (all measures, all habitats, all geographic contexts)?

Identifying cost-effective solutions

- What do we know about the cost of these techniques?
- How can current habitat surveillance methods be fairly compared to each other to judge cost and effectiveness?
- What is the likely cost-effectiveness of each technique, taking into account costs of current surveillance methods and known gaps in knowledge about the habitats?
- Are the techniques likely to provide a cost-effective solution for all habitats, all measures, and in all organisational contexts?

Moving to an operational scenario

- How many of the approaches identified are cost-effective or potentially cost-effective now, or in the near future for filling knowledge gaps and/or for increasing the efficiency of habitat surveillance?
- If they are potential cost-effective, what technical, organisational or other barriers need to be overcome to make them operational? What research is required? How long would this take?
- How would they fit within the current framework of habitat surveillance?

2.1.3 Projects and Initiatives included in the Review

Table 4 provides a summary of the projects and initiatives included in the review and the type of information they provided.

Table 4. Description of projects included in the review
(Project IDs highlighted blue are ongoing projects – assessed for UK activity only)

Project ID	Project / report short title	Description	Habitat surveillance UK	Habitat surveillance EU	UK other sector	Policy/ Strategic context
1	Habitat Inventory - vegetated shingle (Scotland)	Draft interim report detailing the current progress and method for developing a shingle inventory for Scotland using pre-existing surveys, aerial photography, and basemapping as support material for field visits, which will feed back into the API procedure.				
2	Habitat Inventory - vegetated shingle (England)	Series of work over about a decade, pulling together all the previous survey material and updating the information with aerial photography and rules for subsequent digitising and fieldwork.				
3	Habitat Inventory- maritime cliff and slope	Assessment of subsequent surveys against the survey, digitisation and attribution standards set out in earlier work. This work specifically looks at identifying soft cliff habitats.				
4	Validation of Meadow Habitat Inventories in NW England (2010)	Field validation of 193 sites to establish their habitat type. Sites mostly identified from the BAP Priority grassland habitat inventories and targeted areas where certainty of the habitat was low.				
5	Modelling Annex I Bog woodland	There is an internal piece of work, currently ongoing, by SNH to establish how well areas of H91D0, bog woodland can be identified from air photography.				
6	Saltmarsh Mapping (England)	Creation of a saltmarsh inventory from 3 sets of saltmarsh mapping work using air photography. Used both manual interpretation and automated segmentation combined with manual interpretation. Applies a correction to the 1989 Burd saltmarsh survey data, based on expert judgement to allow for detection of meaningful change. Final project report to be published end of June 2011				
7	Saltmarsh mapping (Scotland)	First year of a 3 year programme to visit every saltmarsh site in Scotland and complete an NVC survey and CSM review. (pre-reporting personal communication only)				
8	Native Woodland Model	Developed for SNH to identify some PAWS woodland and other potential sites for new woodland plantings which will meet the criteria of Priority Habitat types. The model is based on soil maps together with landcover. (pre-reporting personal communication only)				
9	NIWT/ National Forest Inventory	The NFI is ongoing, updating the pre-existing National Inventory of Woods and Trees (NIWT) using satellite imagery and aerial photography, looking at all woodland blocks over 0.25ha. (pre-reporting personal communication only)				
10	Native woodland survey of Scotland	Is currently updating earlier work by a ground-based survey to identify the location, type, extent, composition and condition of all native, nearly native woodlands and PAWS woodlands in Scotland, down to a minimum mapping size of 0.1ha. (pre-reporting personal communication only)				
11	Phase 1 mapping of Wales – habitat inventory	A Wales-wide inventory of Phase 1 Habitat types. Designed to operate as a baseline to monitor change and will ultimately be compared to the 1990's field based Phase 1 Habitat mapping. Fuzzy membership has been used to indicate spatial variation and ecotones. Some features with hard boundaries have been mapped as Boolean classes.				
12	Tweed catchment study	The catchment was mapped predominantly from aerial photography using automated segmentation and semi-automatic classification techniques to produce a phase 1 habitat map, which was later used for habitat network analysis.				
13	Developing Inventories of Upland BAP and Annex I habitats in Scotland	Interim report looking at using a knowledge and rule-base to pull together existing habitat data and modelling the likelihood of the presence of BAP and Annex I habitats in the Uplands of Scotland.				

Project ID	Project / report short title	Description	Habitat surveillance UK	Habitat surveillance EU	UK other sector	Policy/ Strategic context
14	Scotland Inventory of Upland BAP and Annex I habitats	Interim report on how to fill gaps in knowledge of Upland habitats in Scotland. 3 approaches are being tested - heads up digitising, automated digitising and an object-orientated rule-based approach.				
15	ASSI Phase 1 mapping pilot (Northern Ireland)	Pilot sites mapped using Phase 1 classification from any pre-existing habitat survey material, and updated by visual interpretation with recent orthophotos. Boundaries hand-drawn then digitised, project ongoing, only very draft report.				
16	CS LCM 2007	Countryside Survey Land Cover Maps are digital datasets constructed mainly from satellite images which provide stock and change of land cover and Broad Habitats in the UK. LCM 2007 combines automated segmentation (based on Ordnance Survey (OS) MasterMap data) and a pixel based 'maximum likelihood' classification to produce a 'field by field' resolution dataset (min. mapping unit 0.5ha).				
17	Dartmoor National Park Authority Remote Sensing Project 2011	Assessment of the extent and condition of key habitat types and features of archaeological and landscape interest using a range of automated, semi-automated and manual interpretation approaches. Used specifically flown CASI and LiDAR data.				
18	Mapping Dune System Habitats (Kenfig NNR, Wales)	Mapping of Dune system habitats at the Kenfig NNR in South Wales in the late 1990s, using high resolution airborne data. Supervised classification using ground control points, to determine vegetation types solely by spectral signal.				
19	NE remote sensing for marine SACs	Methods for mapping a series of intertidal habitats were tested across candidate SACs around England. Used CASI, LiDAR and aerial photography. In most cases, data from two separate years used to compare the method and potentially detect change.				
20	Remote Sensing of Bog Surfaces	Three lowland raised bogs were mapped using a variety of remotely sensed imagery, bog features were identified using a maximum likelihood supervised classification.				
21	Extent and Severity of Erosion on the Upland Organic Soils of Scotland	Satellite EO was examined as a cost-effective method of assessing the extent and severity of erosion in the upland organic soils of Scotland. Peat extent mapped using object orientated rule-based approach; risk of erosion was established.				
22	Application of RS to identify and measure changes in the area of moorland burned as part of a management system	Work occurred in 2 phases, development and implementation. Natural England use a semi-automated system that allows VHR satellite imagery to pick out areas of vegetation in the uplands that have been burned as part of management practices. Originally for SSSI monitoring but also useful tool for compliance and regulation of improper burning, and then targeting restoration.				
23	Random Forest characterization of upland vegetation and management burning	RGB and CIR aerial photography was classified using the Random Forest ensemble machine learning algorithm into three classifications: main classification into one of seven upland land covers, subsequent classification of the 'heather' class into one of four growth phases, and then reclassification of misclassified 'newly burnt heather' class.				
24	Integrated Assessment of Countryside Survey data to investigate Ecosystem Services in Great Britain - ongoing	This project aims to provide a long-term, large scale integrated dataset which will be essential for a scientific understanding of effective management for Ecosystem Services . The method adopted is trying to demonstrate potential approaches to quantify current status and trends and understand and quantify past change of a selection of ecosystem services and uses this to understand possible futures.				

Project / report short title	Description	Habitat surveillance		UK other sector	Policy/ Strategic context
		UK	EU		
BIOSOS (BIOdiversity multi-Source monitoring System)	Developing tools and models for consistent multi-annual monitoring of NATURA 2000 sites and their surroundings using EO.				
PHAVEOS (Phenology And Vegetation Earth Observation Service)	Using MERIS data, vegetation change can be monitored using a variety of measures with spatial-temporal resolutions of 300m every 2-3 days. Products from PHAVEOS, enable researchers to monitor phenological variables more accurately and precisely.				
CORINE (Coordination of Information on the Environment)	Production of a harmonized single map of land cover for Europe. There are editions for 1990, 2000 and 2006 and it has been based on interpretation of satellite images, mostly Landsat.				
ECNA-Net / EBONE (European Biodiversity Observation Network) workshop	An EU FP7 project that provides the European contribution on terrestrial monitoring to the Group on Earth Observations Biodiversity Observation Network (GEO BON).				
LANMAP (LANdscape MAP)	Aimed to provide a new hierarchical European Landscape Classification that can be used as a framework for indicator reporting and environmental sampling.				
SIOSE (Sistema de Información de Ocupación del. Suelo en España) project in Spain	Production of a land cover/land use database using EO that is periodically updated for national and regional administrations.				
DeCover in Germany	National extension to the GMES activities providing LU/LC information services to decision makers at different scales using multi-temporal satellite data used to detect changes based on existing reference geometries.				
COS 2007 (Carta de Ocupação do Solo) - Portugal	Production of a Land Use and Land Cover Map of Continental Portugal for 2007 based on visual interpretation of aerial photography with the use of some seasonal satellite imagery.				
HABISTAT (HABItat STATus)	Work by Belgian and Dutch research teams, focusing on how remote sensing techniques could be used for Natura 2000 habitats monitoring, with a pilot study on heathlands.				
EPA EO based habitat mapping - Ireland	Pilot project trialling the transfer of the EO rule-based method used in Wales, to provide detailed habitat mapping in Ireland.				
MEDWET (MEDiterranean WETlands)	Inventory, assessment and monitoring of Mediterranean wetlands				
NILS (National Inventory of Landscapes in Sweden)	Habitat mapping of Sweden using sample units and rule base with dichotomous key for API.				
Monitoring change in the Biosphere reserve of Terras do Mino case study NW Iberian peninsula	Classification of Landsat data into an ecological system based on EUNIS, CORINE with a sub-regional classificatory system built on ecological units, to monitor change in the landscape over 12 years (1990-2002) to establish the impact of the European agricultural policy.				
Infoterra report (2007)	Report looking at supporting the uptake of EO data within the wider Defra community				
Defra 'stake site/hub and spoke' project	Investigates the concept of a central data repository with 'spokes' delivering online products to users. Considers a range of data applications including woodland change, land cover determination and change, flood management and animal disease outbreaks.				
OS LC and LU ontological work	Creating a framework for combining spatial data with more descriptive land use information.				
The UK Terrestrial Biodiversity Surveillance Strategy (2009)	The UK Terrestrial Biodiversity Surveillance Strategy has been developed, initially by JNCC, to improve the fit between UK current biodiversity surveillance and monitoring activity, known gaps and likely future need.				

2.1.4 Collation of Information

Current habitat surveillance techniques in the UK (EO and non-EO)

A template was developed to assist with characterising the various approaches described in 23 reports/ documents relating to UK habitat surveillance activity. Such a method was used to ensure relevant information about techniques was collected consistently for each of the habitat measures (extent, condition, change, ecosystem services, dynamic environment issues). This following factors were considered in relation to each measure:

- Characteristics of method and evidence of applicability;
- Data/ information sources used;
- Indicative accuracy;
- Scale of work;
- Techniques and stage of development;
- Known gaps in provision;
- Potential Issues; and,
- Future uses/ development of technique.

A SWOT analysis was then produced for each activity to summarise key observations about the technique. The SWOT analysis assesses each technique in terms of its potential applicability for habitat surveillance, beyond the scope of the project it relates to, in order to identify its broader relevance. No account is taken of the information needs of individual organisations or their capacity for adopting the technique as these differ between organisations. Completed templates for each activity are provided in PART B - Annexes and technical evidence.

Use of EO and geoinformatic techniques for habitat surveillance in the EU

A short indicative review of other techniques that have been trialled in Europe, that could assist with habitat surveillance in the UK has been conducted. The sources of data used are described in Section 3 of Part B of the report, and include the findings from a recent European ENCA-Net/ EBONE workshop on using remote sensing in operational surveillance for biodiversity, and recent supra-national reviews.

Use of EO and geoinformatic techniques in other sectors

Key developments arising from other sectors have been included where they are relevant to the discussion. The sources used include the report "Development of Land Earth Observation Requirements as Input to the Defra Earth Observation Strategy" (Lamb et al., 2007), the subsequent 'Hub and Spoke' project (Lamb et al., 2010) and recent work on phenology mapping. In addition, an overview of Unmanned Aerial System (UAS) technology has been obtained from an industry specialist and its relevance to habitat surveillance assessed.

2.1.5 Adopting an EO based perspective of habitats

EO data and techniques differentiate vegetation types and habitats by identifying specific features that are shown up by different spectral bands or combinations of bands. These include features such as:

- the ratio of living to dead plant material;
- the productivity of the vegetation;
- the 'wetness' of the vegetation;
- the amount of ‘woody’ material;
- the number of plants with horizontal fleshy leaves as opposed to thin upright leaves etc.

These characteristics have been used to provide an indication of the likely applicability of different EO/ geoinformatic techniques for identifying BAP Priority Habitats and EC Habitats Directive Annex I habitats, by adopting EO based perspective of habitats. The results are presented in section 3.3.

2.1.6 Briefing Papers

Briefing papers have been produced as part of the project, in order to communicate some of the more complicated remote sensing issues to those less familiar with EO/geoinformatic techniques. These are provided in PART B - Annexes and technical evidence.

2.1.7 Consultation

Two rounds of consultation were undertaken. At the outset of the project an email based questionnaire was sent to Steering Group members to establish habitat and surveillance information needs and gaps, as well as to identify sources of information for the review. Following the review of reported UK projects, telephone interviews were undertaken when further elucidation of specific points was required for the analysis.

2.1.8 Value for Money assessment

The project specification envisaged comparative assessment of the cost of a range of surveillance techniques, including EO-based techniques in use and under development. However, there is no published work on the cost comparison of different techniques. Where costs could be sourced they were not in a comparable form, with significant variation in detail and content. Participating organisations felt that the work involved in providing suitable information on detailed costs was not achievable within the timescale of the project. The Steering Group felt that analysis of the cost-effectiveness of techniques could only be done at a broad scale and it was agreed that this should be preceded by a description of the techniques in terms of 'value for money'. This involved identifying the contribution and added value that improved data and techniques can bring to key policy areas, and to other areas of science, and relating these to the known policy costs. The results are reported in section 3.4, with the cost ranges presented in section 3.4.3.

3. Synthesis and Review of Evidence

The evidence collated from all sources has been considered in relation to the headline questions, which form chapter sub-headings in this section. This is preceded by a synthesis that characterises the various approaches described in the 23 reports relating to UK habitat surveillance activity.

Characteristics of techniques included in the review (UK habitat surveillance activity)

Most reported activity (Table 5) seeks cost-effective solutions to meet immediate priority information needs, being concerned with:

- refining/ updating the information content of existing habitat inventories;
- developing new habitat inventories from scratch, using established habitat classifications to identify a range of habitats within coherent landscapes;

There is also a range of research and development of operational products that:

- produce maps and information to support condition assessment and condition monitoring.

Table 5. Summary description of the UK-based studies included in the Review

Category of surveillance or monitoring activity	Focus of projects (habitats, areas, processes or practices)	Habitat classification used (where applicable)	Location of project sites (Lead organisation(s)) and Project ID	
Group 1: Inventories / mapping habitats (thematic basis)	Coastal vegetated shingle	UKBAP Priority Habitat	Scotland (SNH)	1
	Coastal vegetated shingle	UKBAP Priority Habitat	England (NE /EA)	2
	Maritime cliff and slope	UKBAP Priority Habitat	England (NE)	3
	Validating habitat inventories by field survey	UKBAP Priority Habitat	England (NE)	4
	Bog woodland	Habitats Directive Annex I	Scotland (SNH)	5
	Saltmarsh	Integrated habitat classification	England & Wales (EA)	6
	Saltmarsh	NVC and CSM	Scotland (SNH)	7
	Native Woodland Model / Survey		Scotland (SNH)	8 / 9
	National Forest Inventory /NIWT		Great Britain (FC)	10
Group 2: Inventories / mapping landscapes (spatial basis)	Whole of Wales	Phase 1	Wales (CCW)	11
	River catchment	Phase 1	Scottish Borders LA	12
	Uplands – using existing datasets	UKBAP Priority Habitat + Annex I	Scotland (SNH)	13
	Uplands – developing methods to fill gaps	UKBAP Priority Habitat + Annex I	Scotland (SNH)	14
	Mapping Pilot sites	Phase 1	NIEHS	15
	UK Land Cover Map	UKBAP Broad habitats	UK (CEH /Multi-partner)	16
	Uplands	Various, PH, Annex I, CSM	Dartmoor NPA /EA	17
Group 3: Dynamic Environment Processes	Mapping dune system habitats (NNR)	Annex I	Wales (CCW)	18
	Inter-tidal habitats (SACs)	Annex I	England	19
Group 4: Condition monitoring	Remote sensing of bog surfaces		JNCC	20
	Peat extent + severity soil erosion (uplands)		Scotland – GIFFTS	21
	Moorland burning (uplands)		England - GIFFTS (NE)	22
	Moorland burning (uplands)		Academic study (Belgium)	23
Group 5: Ecosystem Services	Integrated assessment of CS data	UK BAP Broad Habitats	UK CS sample sites	24

Project explores technique in relation to: Baseline habitat mapping; Habitat mapping + detecting change; Habitat mapping + assessing condition; Condition monitoring.

These projects have been commissioned primarily by SNCOs in Great Britain. Most focus on mapping to a specific habitat classification (e.g. Phase 1), though recently commissioned work in Scotland is addressing modelling the presence of both Annex I and BAP Priority habitats. Only one project in the review specifically focuses on techniques for assessing Ecosystem Services. Most studies (13) are ongoing (Table 4, section 2) particularly those informing the production of habitat inventories/ landscape scale habitat mapping.

These studies evaluated the potential of a range of techniques using various types of imagery, both aerial and satellite (Table 6). In some projects a range of techniques are trialled on particular image types or combinations of imagery. Many projects make use of ancillary datasets, such as OS boundary datasets and digital terrain models.

Table 6. EO techniques applied to imagery in the UK-based projects

	Technique					
	Manual	Semi-automated or automated				
Imagery	Visual interpretation	Semi-automated digitisation	Image segmentation	Supervised classification e.g. maximum likelihood	Algorithm derived measures	Rule-based classification
Aerial photography (RGB)	X	X	X			
Aerial photography (Colour Infra Red)	X		X		X	X
CASI	X		X	X	X	X
LiDAR	X					X
Satellite imagery (multi-spectral)		X	X	X	X	X

It is notable that recent research and applications development for habitat surveillance and monitoring does not involve the use of satellite, airborne radar imagery or hyper-spectral data, both of which are in use or under development for commercial use in other sectors (section 3.1.3).

There is a broad spectrum of approaches in use, involving field survey, manual interpretation of imagery, semi-automated analysis and techniques that are based on an automated rule-based approach and combinations of these:

- Targeted field survey (comparators against which to assess EO)
- Manual interpretation of CIR and RGB aerial imagery
- Manual Interpretation of CASI and manual and semi-automated analysis of LiDAR
- Semi-automated digitisation of imagery – air photography CIR or satellite imagery and then manual manipulation and manual classification
- Supervised classification based on CASI or satellite imagery
- Maximum likelihood classification of CASI data to assist a manual interpretation
- Use of algorithms (such as NDVI)
- Automated rule based approach using segmentation, classification and various imagery.

3.1 How many EO based techniques offer potential and what characterises these?

All the techniques evaluated have a potential role to play in surveillance and monitoring of habitats at different levels, however some techniques will be more ubiquitous and useful than others. The section below groups the projects according to their approach (column 1, Table 5) and identifies elements of the techniques that are likely to be of potential use for delivering known habitat surveillance and monitoring needs. These techniques may allow greater efficiency, helping existing resources go further and/ or by filling gaps in knowledge for any of the measures of interest. No account is taken at this stage of the readiness of organisations to adopt particular techniques or the current information needs of each organisation.

3.1.1 Techniques in use or under development for habitat surveillance and monitoring in the UK

EO based techniques to support the habitat inventories

The vast majority of projects are concerned with the production of digitally mapped habitat inventories, habitat or land cover maps (Table 5). There are two distinct approaches, thematic-based approaches which consider specific inventories, one habitat at a time, and landscape-scale mapping which considers all the habitats within an area, mostly in upland or western parts of the UK. Thematic approaches have mainly used manual interpretation of aerial photography, in contrast landscape-scale mapping approaches favour semi-automated or automated techniques.

<u>Group1: Characteristicsandpotentialoftechniquesusedforthematicbasedmapping</u>

Three projects focus specifically on techniques for thematic priority habitat inventories (project IDs 1, 2, 3), using skilled manual interpretation of true colour or CIR aerial photography. In each case, the aerial photography was used as a benchmark dataset to more accurately locate boundaries from previous mapping work, apply minimum mapping units, check for the presence of the habitat and record previously unmapped areas. Such an approach makes effective use of pre-existing data. For the specific habitats in question a working draft digital national inventory has been produced. Significant fieldwork is required to resolve discrepancies. A project describing the fieldwork required to validate the presence of potential BAP Priority grassland habitat inventories in north-west England (project 4) illustrates the scale, time-consuming nature and access issues of the fieldwork that can be required, where species level identification is required.

Ongoing, saltmarsh mapping in England and Wales (project 6) uses aerial photography and digital tide height data for three distinct EO approaches, including manual and semi-automated approaches. For the manual method, vegetation is mapped using the Integrated Habitat System (IHS) which translates to both priority habitats and Annex I habitats (SERC, 2002). For the semi-automated approaches, automated object-orientated image segmentation was followed by manual interpretation or semi-automated classification of NIR imagery supported by ground truthing to determine the extent of saltmarsh and identify discrete areas of some saltmarsh vegetation types. Good levels of consistency were achieved across the techniques. The project looked at the potential to produce national level change data using 1989 mapped survey data but this was not considered possible due to the vastly different methodologies, however work is underway to amend the 1989 dataset to make it more comparable.

The potential of these techniques with regards to known surveillance needs:

- principles of mapping protocols are transferable;
- they provide a basis for producing spatially accurate baselines from which change can be assessed;
- consistently produced draft national inventories allow for seamless integration of further survey work allowing the inventory to be improved upon;
- some provision for supporting information - the recording of discrepancies and statements of certainty of membership of the habitat;
- manual remapping can take place using the previously derived map.

In addition the work on saltmarsh mapping in England and Wales (project 6) has potential to:

- provide a particularly good baseline map that can be used as a template for both future and retrospective change mapping.
- should provide research findings relevant to retrospective change mapping using previous surveys
- demonstrate the utility of IHS survey data, which can be readily translated to other habitat classification systems, thus meeting multiple policy reporting requirements.

The production of an up to date inventory of saltmarsh in Scotland (project 7) comprises a programme of field survey of all Scottish saltmarsh sites over a three year period to update and review the 1980's saltmarsh inventory. The field survey uses aerial photography as a reference dataset and involves mapping NVC classes and carrying out a condition assessment using CSM. The NVC survey goes into enough detail to be able to determine Annex I categories and the combination of habitat mapping and CSM for every site allows a greater suite of information and view of the situation including dynamic processes to be attained. This work has not been reported on yet.

The Native Woodland Model (NWM) (project 8) has been developed for SNH to identify some PAWS and other potential sites for new woodland plantings in the uplands which will meet the criteria of Priority Habitat types. The model is based on a geoinformatics modelling approach combining soil maps together with landcover (LCS88) and was designed for use at a strategic planning level for woodland expansion. A review of the NWM outputs for the Highlands, and comparison with actual NVC surveys (SNH unpublished 2004), suggest that the NWM accurately predicts site suitability for oakwood, ashwood and pinewood.

The Forestry Commission undertook the National Inventory of Woods and Trees (NIWT) between 1994 -2003. This was a nationwide survey across England, Scotland and Wales showing the position and type of all woodlands over 2ha in size. The National Forest Inventory (NFI) project, is updating this previous work using aerial imagery and OS MasterMap. It includes all coniferous and broadleaved woodlands, as well as woodland blocks over 0.5ha and features as orchards and ancient wood pasture and is running between 2009-2014 (project 9). The mapping is due to be updated annually using satellite imagery in an automated land cover EO change detection system which is being developed.

The Native Woodlands Survey of Scotland (project 10), started in 2007 and led by Forestry Commission Scotland, is currently underway to update the semi natural woodland inventory work by 2013. This is a ground-based survey using the digital woodland map produced by the NFI to identify the location, type, extent, composition and condition of all native, nearly native woodlands and PAWS woodlands in Scotland, down to a minimum mapping size of 0.1ha. This will be used as a digital baseline mapped resource, and also updated as necessary to enable future monitoring. BAP priority woodland types and NVC communities will be recorded for woodland where the canopy comprises at least 50% native species.

These techniques used for national woodland mapping also bring potential for:

- the identification of woodland habitats and areas of search for BAP priority and Annex I tree species

Group2:Characteristicsandpotentialoftechniquesusedforlandscapescalemapping

The seven projects that take a landscape-scale approach to mapping habitats (projects 11 to 17) present a more diverse range of techniques, encompass a wider range of habitat classifications (including UKBAP broad habitats) and have developed, or are currently testing manual, semi-automated and automated techniques.

In common with the thematic habitat mapping approaches, the techniques developed in landscape scale projects have the potential to:

- provide rule-bases, mapping protocols, definitive baselines, inventories that allow for seamless integration of further survey work and some provision for supporting information;

In addition they:

- provide mapped information relating to surrounding habitats (and in some cases land cover) sufficient to provide context for a diverse range of assessments;

National mapping of UKBAP broad habitats derived from satellite imagery is available from the Countryside Survey UK Land Cover Map (project 16). The most recent map, LCM 2007 combines automated segmentation and a pixel based 'maximum likelihood' classification based primarily on IRS satellite data with incorporation of OS MasterMap data to produce a 'field by field' resolution dataset (minimum mapping unit 0.5ha). In Northern Ireland, pilot work is underway to produce landscape scale Phase 1 habitat maps from skilled manual interpretation of aerial photography (project 15), but there is little information to establish any further potential the technique might offer, over that described above.

Mapping of the Tweed catchment (project 12) also used aerial photography (predominantly) to produce a Phase 1 classification, automated segmentation and semi-automatic classification techniques were used together with some skilled manual interpretation. The map is field checked by volunteers and managed by the local wildlife centre.

This technique also brings potential for:

- more rapid production of draft inventories;
- cost-effective maintenance and updating of the inventory.

Ongoing work in Scotland (project 13) is using a knowledge and rule-base to pull together existing habitat data from across Scotland to model the likelihood of the presence of BAP priority and Annex I habitats. The inventory is based on the correspondence between different data and expert knowledge, following a hierarchical approach including an assessment of the statistical validity of the classification. It uses the 1988 Land Cover Map of Scotland, supplemented by a number of vector datasets including Land Cover Map UK from 2000, various existing habitat inventories (blanket bog, lowland raised bog inventory, limestone Pavement) NVC surveys where available, soil maps, topographic and terrain models. The method accommodates datasets produced at differing scales.

This technique also brings potential for:

- inventory production, and identification of gaps in inventories, based solely on available datasets, using a modelling approach suitable for landscape-scale habitat classification;

A Wales-wide inventory of Phase 1 habitat types has been derived using an object-orientated rule based approach (project 11). The landscape of Wales was divided into discrete objects of sizes that varied from individual pixels to entire fields. Habitats were identified at a range of spatial scales using high resolution satellite data and Land Parcel Information System boundaries. For small or narrow features such as hedgerows, CIR aerial photography was used to find objects. A rule-base was developed and applied to distinct bio-geographical zones; it used data from several optical satellite sensors, incorporating spring and summer images which give differences in growth form of the habitats. In addition, derived datasets (e.g., vegetation indices, fractional images) and ancillary information (e.g. topography) to progressively discriminate and map the distribution of 105 sub-habitats across Wales. A second rule-base was then developed to translate the more detailed sub-habitat classification to Phase 1 habitat classes. BAP and Annex I habitats are only considered where they match Phase 1 Habitat types. Fuzzy membership has been used to indicate spatial variation and ecotones. Some features with hard boundaries have been mapped as Boolean classes. The project is designed to operate as a baseline to further monitor change and will ultimately be compared to the 1990's field based Phase 1 Habitat mapping. The potential for improvement and update is characteristic of the approach and the map is "fluid", rule-bases for particular habitats can be reworked based on findings of field survey or accuracy assessment.

In Scotland, ongoing research (project 14) is assessing the relative merits of manual digitising, semi-automatic, and automatic classification methods. This is a small upland trial in two disparate areas.

The techniques developed in these three projects (11, 12 and 13) have the potential to contribute to the following surveillance needs:

- provide an adaptable habitat classification model that can accommodate regional variation in habitat characteristics and can potentially provide other outputs such as condition measures;

- provide further information to support the content of inventories: certainty of membership of classes, ecotones, representation of mosaics and gradients;
- planned work in Wales, will inform on the potential for retrospective mapping (the product is also considered suitable for change detection based on production of a new map rather than update of the baseline but no method has been developed or tested);
- The information is stored within the system, rather than a map product. As a result, the information derived can be presented in a number of ways, depending on the feature of interest, and can be scaled up or down as necessary.
- Once the data stacks are built in a geoinformatic environment, other questions can be asked of the data, and modelled with extreme efficiency.[2]

In addition the Scottish work has potential to provide directly comparable information on the relative merits of traditional manual, semi-automated and automated techniques for priority habitat and Annex I mapping in areas where there are gaps.

LiDAR and CASI were acquired within Dartmoor National Park (project 17) in a project that was characterised by the use of very high resolution and high spectral resolution data for a wide range of targeted analyses. Following trials of automated segmentation and classification, skilled manual image interpretation and on screen digitisation using a range of reference images were used for the identification of features. This included mapping the extent of key habitat types (woodland, moorland), characterising scrub, and mapping features of archaeological and landscape interest such as hedges. The project also assessed the potential for establishing the presence and condition of gully features in bog areas using LiDAR. In addition, the amount of Molina was assessed using a brightness threshold within the NDVI, as an indicator of drying of the bog. LiDAR and a DTM were used in a hydrological analysis which involved creating a flow model, which was used in conjunction with the map of gully erosion to highlight areas of highest erosion risk. The productivity of semi-improved fields was examined using NDVI with limited success. The changes in soil erosion features, both on the deep peat and other peat, and the quality of bog vegetation found in this survey, will allow the data collected in this study to be readily modelled and analysed to give key information about the rate of change of these systems.

The high resolution data and techniques developed in Dartmoor have potential to:

- provide the level of separation of habitats required to identify features of interest in terms of Annex I and Priority habitats, with potential (not assessed) for change detection;
- providing measures to support the assessment of condition and potentially condition monitoring;
- provide measures to describe dynamic environments and monitor processes within them;
- modelling other ecosystem processes.

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[2] Data from Welsh habitat inventory was re-worked and supplied to the Cambrian mountains initiative in only a few days (CCW, 2009)

Group3: Measuresofdynamicprocesses/describingdynamicenvironments

There has been very little work directed specifically at measuring dynamic environment processes in coastal environments. Work at the Kenfig NNR in South Wales (project 18), focussed on mapping of dune system habitats (rather than processes) based solely on spectral differences in a supervised classification of high resolution data with the intention of identifying a range of Annex I habitats. The survey was judged fit for purpose in its representation of the embryo dune slack by comparison with field experience from the sites but with imagery alone did not manage to separate out the semi-natural grasslands successfully.

Methods for mapping a range of intertidal habitats were tested across candidate SACs around England in 2003 (project 19) using two classification systems. These site based analyses, mostly used high resolution CASI, LiDAR and aerial photography with ground control points, where available. A range of classification techniques were used including a neural network classifier, in some cases with manual QA in an expert system classification to remove errors, and unsupervised classification. This work compared the ML classifier with the MLP neural network classifier and in every case it was found that the more sophisticated MLP classifier was more suitable. Each habitat was only assessed at one location. Good results were achieved (80% user accuracy) for sand dunes but results for the other habitats were less consistent due to a range of factors, including lack of ground control points and the use of imagery taken at times of year not ideal for the features of interest. A series of LiDAR data used to create high resolution DEMs, was used to pick up significant change in morphology of shingle over the period (change in the volume, range and profiles) and some evaluation of change in habitat morphology was considered as part of the change assessment which would give indication of dynamic trends within the system. In other habitats differences in the timing of image capture complicated change analysis and it was not possible to detect real change.

The high resolution data and techniques developed in candidate SACs have potential to:

- map and monitor dynamic environment processes for individual sites.

Group4: Measurestosupportassessmentofhabitatcondition/conditionmonitoring

Four projects have a specific focus on condition monitoring, two are concerned with upland bogs and two with moorland burning. GIFTSS (Government Information for the Space Sector) funding enabled two of these projects to be undertaken – (see Table 4, section 2.1.3).

In project 20, three lowland raised bogs were mapped using a variety of remotely sensed imagery, bog features were identified in a maximum likelihood supervised classification. It was found that the Ikonos satellite sensor data were found to be highly suited to the task of lowland raised bog habitat classification, able to identify the major raised bog land cover classes well. The other project (21) looking at bogs was a GIFTSS initiative to evaluate satellite earth observation as a cost-effective method of assessing the extent and severity of erosion in the upland organic soils of Scotland. The spatial extent of exposed peat, intact peat, vegetated bog surfaces and pools is a highly important component in regards to the potential modelling of the carbon budget of peatland and global climate change. By mapping the peat extent using object orientated rule-based approach, the potential risk of erosion could be established.

The other GIFTSS initiative (project 22) used a semi-automated system allowing VHR imagery to pick out areas of vegetation in the uplands that have been burned as part of management practices. This was originally for SSSI monitoring, but is a useful tool for compliance and regulation of improper burning, and also targeting restoration. In project 23, heathland was classified using RGB and CIR aerial photography and the Random Forest ensemble machine learning algorithm. Training points from fieldwork and API were used to inform three classifications: main classification into one of 7 upland land covers, subsequent classification of the 'heather' class into one of four growth phases, and then reclassification of misclassified 'newly burnt heather' class. Classification was based on reflectance values and ratios, and misclassified areas were selected according to parameters of landscape context (e.g. % edge pixels). This facilitated subsequent multivariate analyses of the occurrence of heather management by burning.

3.1.2 Techniques currently in use or under development for habitat monitoring elsewhere in the European Union

Research from across Europe has focused on providing pan-European classifications of land cover rather than habitat classifications, with these aimed at standardisation, such that within and between country statistics can be generated and compared. The number of land cover types discriminated is typically small compared to the number of habitats that exist. Classifications have generally been pixel-based but there is increasing recognition of the benefits of object-orientated methods, which are considered to provide information that is complementary or can be an improvement on techniques such as those associated with hyperspectral data analysis. A number of projects from site to continental scale are ongoing, with these focusing on, for example:

- The use of high spatial resolution spaceborne remote sensing datasets for monitoring Natura 2000 sites. Particular emphasis is on identifying and detecting indicators of change from field and remote sensing data and both within and also on land surrounding the sites (Borre et al., 2011). These indicators are intended to reflect improvements or depletions in site quality and identify actual or future threats to the habitats. The development of standardized monitoring systems is expected to lead to more effective observation and management of Natura 2000 sites. The EU project, MS Monina, is particularly focusing on field-based indicators. This multi-scale concept reflects the specific requirements for sensitive sites and works closely with GMES and INSPIRE.
- Evaluating the future benefits of the Sentinel series of satellites to be launched by ESA, particularly as data from these are anticipated to be the workhorse for future monitoring of the European landscape.
- Investigating new approaches to the classification of habitats (e.g., BIO-SOS), particularly if these can be more finely attuned with what can actually be observed and quantified using remotely sensed data. Key amongst these are the General Habitat Categories (GHCs) proposed through EBONE, with these described more on the basis of their biophysical attributes and structural forms.
- To provide up-to-date cross-border harmonised geo-information. The GEOLAND project , for example, is seeking to develop the following:

- Core Mapping Services, with these leading to basic geo-information products relating to land cover, land use and annual and seasonal changes as well as the variety of additional biophysical parameters which describe vegetation state. These services cover spatial scales from global to local, with an update frequency of 1 day to several years (Geoland, 2010).
- Core Information Services, with these being a set of thematic elements that build upon the core mapping services and aim to address specific European environmental policies and international treaties on climate Change (Geoland, 2010). For instance, Forest Monitoring provides accurate and spatially detailed information on the state and development of forests, whilst suiting different definitions of forest. This is represented as a high resolution Forest Layer with consistent 1 ha minimum mapping units. The benefits of this include fit-for-purpose products meeting the high verification and thematic accuracy requirements for policy reporting and downstream service integration (Geoland, 2010b).
- Research is nevertheless often disjointed and the larger projects are still utilising a number of diverse approaches. Larger research projects that are seeking to integrate European knowledge and expertise are still coming up against the very divergent means and requirements of data collection and description and different opinions as what techniques should be used.

3.1.3 Techniques currently in use or near operational in other sectors

Earth observation techniques are being used in other sectors to good effect. A selection of issues being tackled by EO is presented below:

- Delineating flood risk areas. Multi-temporal radar and thematic data are being used to generate flood hazard by estimating flood frequency and flood depth (van de Sande et al., 2003).
- Hydro-electric decision systems. By integrating EO to map snow extent, elevation data and snow melt algorithms, generating companies better understand flow conditions (Guo et al., 2000).
- Mapping of renewable energy resources. EO imagery in conjunction within thematic information has enabled biomass estimates together with other indicators of renewable resources (Ramachandra, 2010).
- Desertification and food security. Temporal EO imagery of arid areas together with socio-economic data are assisting in the planning of projects to ameliorate the impacts of desertification (Roy et al., 2006).

Geoinformatics techniques are also being used to good effect in other sectors, the following examples explain some of the scope of these techniques:

- Urban planning (Fils et al., 2009).
- Integrating socio-economic, demographic and physical information etc has been undertaken for crime analysis, health studies and modelling of transport networks (Phillips and Lee, 2011).

- Agricultural monitoring and planning integrating socio-economic, physical and biological information; with a particular focus on climate change has been undertaken to model future scenarios and report on food security (Rilwani and Ikhuroia, 2006).
- Geological applications include integrating hard rock geology, surface deposits, faulting and geomorphology to model spatial and temporal distributions of earthquakes (Sinha et al., 2010).
- Environmental management uses include, integration of information such as Earth Observation, ocean and weather data to assist in mitigation, preparedness, response, and recovery of disasters such as oil spill recovery operations (Seppanen and Virrantaus, 2010).
- Ordnance Survey are looking to include more land use information with the spatial information across a variety of land cover types, using geoinformatics techniques (Hernandez and Hart, 2010).

The PHAVEOS project is designed to look at wide scale temporal change using MERIS satellite data with a resolution of 300m. The satellite provides global imagery every 3 days allowing for high temporal frequency data analysis, with a specific focus on phenology. This allows it to consider forestation issues across very wide areas.

3.1.4 Summary: How many EO based techniques offer potential and what characterises these?

EO and geoinformatic techniques offer the potential to help map and monitor habitats. This section considers the strengths opportunities weaknesses and threats of the main techniques that are in use.

Table 7. Summary SWOT tables for the main types of technique evaluated.

Fieldwork* approach - SWOT	
Strengths	Weaknesses
• Very good at identifying the presence of specific species • Very well understood methodologies • Currently the only way to determine specific sub-surface features e.g. Peat depth	• Very time consuming to cover large areas • Costly in fuel • Intra-surveyor variation • Difficulty in defining ecotones • Resurvey takes as long as initial survey
Opportunities	Threats
• Critical for identifying the presence of small scale features and indicator species	• Tendency to over-map interesting features

(* Field based boundary mapping and classification)

Manual* approach - SWOT	
Strengths	Weaknesses
• Allows more systematic spatial coverage of an area (compared with field work effort) • Reduced fuel costs compared to field survey • Widely available from various monitoring programmes • Use of Very high Resolution data allows a number of habitats.	• User variation in boundary delineation and classification • Time consuming to cover large areas • Collation of training data sets is time consuming • Monitoring requires manual checking of the previously created baseline dataset, comparing extent and classification of each polygon against new imagery.
Opportunities	Threats
• Allows people to become familiar with information content of EO data sources	• Variation in interpretation reduces repeatability

(* Manual digitising and manual interpretation of the imagery)

Semi-automatic* approach - SWOT	
Strengths	Weaknesses
• Rapid way of dividing up the landscape often with accurate boundaries drawn • Ecological knowledge used to interpret from imagery	• Element of user interpretation • Collation of training data is time consuming for large areas • Manual interpretation of imagery is time consuming for large areas
Opportunities	Threats
• Will often be cost effective for smaller specific sites of interest	• More difficult to repeat the classification due to interpretation variation

(* Automatic segmentation with manual interpretation of the imagery)

Automatic* approach - SWOT	
Strengths	Weaknesses
• Systematic approach so objective and rapid. • Can be repeated using the same methods with new imagery with only some additional input	• Anomalies can be difficult to accommodate. • Artefacts in the imagery can lead to mis-classification
Opportunities	Threats
• Validation of the output can feed back into the method to improve it • Repeatability can lead to change detection	• Sourcing consistent imagery • Insufficient ecological training of the system

(* Automatic segmentation and automatic classification of the imagery)

EO and geoinformatic techniques are currently being used for a variety of uses and applications. The increase in computer power, sophistication of algorithms developed and the rigorous methods of image registration have all come together to facilitate the use of the technology. Within the UK there are a number of successful working examples of how EO techniques are being used for habitat mapping and monitoring, within the wider European context there are also many examples of how habitats are being recorded using many different techniques. Other areas are also developing modelling and mapping methods that could provide important pointers as to the way ahead.

3.2 Potential role of emerging techniques

3.2.1 Unmanned Aerial Systems (UAS)

There are a range of unmanned aerial vehicle (UAV) platforms capable of supporting remote sensing sensors as part of UASs. Size and therefore capabilities vary vastly, from Global Hawk (Boeing 737 Wing Span) to lightweight platforms like the Gubua Group's G2, weighing just a few kilos. Many different sensors can be used within UASs, only limited by the weight carrying capacity of the UAV. This includes passive sensors with a variety of channels from true colour through to hyper-spectral and active sensors such as LiDAR, and radar. Atmospheric gas particle sensors have been used to monitor aspects of the atmosphere such as pollution, and magnetometers have been used for oil and gas exploration.

The UK currently benefits from a relatively advanced regulatory position for the operation of small UAS for remote sensing. An approval system has been established allowing competent organisations to gain approvals to conduct "aerial work". The UAS remote sensing sector in the UK is likely to grow to take advantage of the smaller, more cost effective sensors, and better software techniques becoming available along with the supportive regulatory environment. It is also likely that the cost of data for many applications will be lower with UAS versus manned aircraft solutions.

UASs can cover areas in a very systematic way, using programmed routes, which can be repeated. They can fly lower than manned aircraft, with no risk to a pilot, therefore can be used for high resolution image capture. Unmanned aerial systems are used operationally in some sectors and being developed for operational use in others:

Border Security - Extensively employed around the word for border security although no regular operations are thought to be underway in Europe. Relies chiefly upon live day or thermal video.

Agriculture - By far the most established application so far in this sector is airborne spraying in Japan using the Yamaha R-Max UAV helicopter. Numerous UAS based agricultural imaging offerings are being developed, but few if any have progressed to the regular provision of commercial data products. Most of these offerings look towards NDVI and other near infrared derived data products.

Forestry - UAS have been used in Scandinavia and the US for forestry management on a limited basis. Again this application uses RGB and near infrared still imaging.

Mining - Significant recent improvements in photogrammetry software have sparked an embryonic industry using small UAS to produce stock-pile measurements from low-level photography. A small number of operators are currently operating commercially in this sector. It is expected that these techniques will increasingly be used in the environmental monitoring and construction industries.

Archaeology - Photogrammetry and near infrared photography have been used by archaeologists for some time and kite aerial photography has been popular in this sector. UAS are now being used experimentally in this area and a small amount of commercial work has been done.

Coastguard/Fisheries - Several UAS manufactures including one in Europe have specifically targeted this sector. It is not thought that any specific sensor technologies are fielded in this sector.

Infrastructure Management - A likely growth area is utility infrastructure management, such as monitoring of pipelines and inspection or power infrastructure using thermal and UV corona cameras - both use established techniques likely to be increasingly migrated to unmanned systems.

Most UK operators of UAS are either in the defence/security sector or concerned with the collection of photographic and video media for non-scientific use. A handful of operators have carried-out environmental imaging work in visible and near infrared for the production of mosaiced photographs and for a small amount of experimental habitat survey. In terms of areas of potential use for habitat surveillance, UASs could be particularly useful for mapping and monitoring of river courses or railway corridors, for example for monitoring invasive species or gathering data from inaccessible areas such as islands, sea cliffs or inter-tidal areas. They offer the capability for rapid response and deployment for environmental incident support (e.g. pollution tracking or disease control). UASs may also provide a solution to data gathering and "agent" spreading/spraying in difficult to access locations such as wetlands and forest canopies. The UK carries out a large amount of remote sensing for coastal monitoring purposes with manned aircraft. This chiefly consists of LiDAR and photogrammetry. There is scope for higher resolution or more timely work to be done with UAS in this area.

3.2.2 Radar and hyper-spectral sensors

The potential for radar and hyperspectral sensors to add value to existing EO imagery for habitat mapping has not been tested in an operational scenario due to the availability of data, coverage and cost, however a number of research projects are underway to identify advantages they can bring.

TerraSAR-X satellites are providing short-wavelength X-band data at high (< 10 m) spatial resolution. At X-band, the radar signal primarily interacts leaves and small branches in the top of canopies. Communities which exhibit differences in their structure at this scale can be discriminated and considerable potential exists for improving classifications of upland mosaics, marshy grasslands (e.g., Juncus flushes, Phragmites stands) and agricultural crops. Longer wavelength C-band data are provided by RADARSAT and the ENVISAT Advanced SAR (ASAR). While capable of discriminating between some communities, C-band images are generally less sensitive to differences in canopy structure. The Japanese Advanced Land Observing Satellite (ALOS) Phased Arrayed L-band SAR (PALSAR) has demonstrated good capabilities for landcover mapping (Shimada et al., 2010). Operating at long wavelength L-band these data are well suited to understanding forest structure and quantifying the biomass of woody vegetation. As L-band SAR is sensitive to surface moisture, these data may potentially also be used to discriminate between some habitats (e.g., marshy grasslands, bogs).

In addition to measuring backscatter intensity, SAR provides additional information on the three dimensional structure of vegetation through coherence, polarimetry and interferometry.

Interferometric data is of particular interest as it can also provide an indication of vegetation height and the underlying terrain surface, which can assist discrimination of some vegetation types (e.g., based on height differences between, for example, bracken, scrub and broadleaved woodland).

Past research has demonstrated the potential of satellite radar for mapping surface water within fields, multi-temporal radar has been shown to pick up management practices such as grass cutting and cultivation (Schellberg et al., 2008). RADAR has advantages in that it can 'see through' clouds and therefore has more information collected. It looks specifically at the structure of vegetation and could become a very powerful tool especially with the launch of the Sentinel program.

Hyperspectral sensing has long been advocated as a major tool for discriminating plant species as well as retrieving biochemical and biophysical attributes of plants and ground surfaces (Haboudane et al., 2008). Multi-temporal hyperspectral data are particularly valuable to assist better understanding of plant function (e.g., in relation to crop and forest health) and discrimination of plant species (e.g., deciduous trees). Most hyperspectral sensing has been from airborne platforms, which have only been able to provide observations over relatively small areas that are often not repeated. The launch of the spaceborne sensor Hyperion, has provided new opportunities for acquiring hyperspectral data across larger areas and with increased repeat coverage. Worldview-2 also includes some wavelength regions, which are well suited to habitat discrimination. However, these data have not been used to support habitat mapping in the UK, largely because the coverage is still relatively limited and cloud cover reduces the frequency of observation. Currently hyperspectral data are best used to support the interpretation of multi-spectral sensors, focussing on understanding optimal wavelength regions and periods of observation for plant species and community characterisation and discrimination. However, with planned increase in availability of spaceborne sensors, hyperspectral observations and are likely to significantly benefit future monitoring of habitats and associated biodiversity.

The HABISTAT program in the Netherlands and Belgium is using hyperspectral imagery to look at Annex 1 habitats, some interesting results are coming out from this study (GEOBIA, 2010). Much research attention is being focused at the moment on the use of hyperspectral imagery for condition monitoring, this is part of the BIOSOS project which CCW is taking part in that is about to start in Wales.

3.2.3 Developments in geoinformatics

A briefing paper has been produced during this project which is included in PART B - Annexes and technical evidence. Geoinformatics offers tremendous potential for delivering inventory work and rigorous, scientifically based, rule sets which can model situations to assess degrees of classification probability. Increases in computing power and processing speed together with the increase of knowledge within this discipline are going to make it an increasingly important discipline when understanding, modelling and combining datasets.

3.2.4 New approaches to accuracy assessment

Very few of the projects encompassed in this review seem to have undergone robust validation work. Most confirm the accuracy of boundaries by eye in comparison with previous survey work or air photography. Very few projects set a limit for their suitability and scientifically test against this. This more rigorous approach will be needed to support European reporting or monitoring requirements that require statistically valid results.

A paper about how accuracy assessment and fitness for purpose can be built into EO and geoinformatics projects has been prepared as a separate briefing paper and is included in PART B- Annexes and technical evidence. Once projects move towards, inventories and the use of geoinformatics approaches, a whole range of metadata is produced with the projects. This sort of data has not been considered, but is likely to hold some significant information and establishing standard recording techniques would therefore be very valuable.

In addition, for habitat inventories derived from a combination of field survey, localised mapping and manual interpretation of imagery, understanding accuracy can lead to a better QA methodology improving the efficacy of both field survey, interpretation of imagery and developing criteria to make best use of localised surveys. In an object orientated rule-based approach, identification of errors can be used to inform the modification of the rule-base to allow rapid improvement in the classification.

3.3 Evidence of the suitability of EO for habitat monitoring

What evidence is there that these techniques are suitable or have potential to produce reliable habitat measurements for Priority Habitats and Annex I habitats?

3.3.1 Adopting an EO based perspective of habitats - the Crick Framework

EO data and techniques differentiate vegetation types and habitats by identifying specific features that are shown up by different spectral bands or combinations of bands. These include features such as:

- the ratio of living plant material to dead plant material;
- the productivity of the vegetation;
- the wetness of the vegetation;
- the amount of 'woody' material;
- the number of plants with horizontal fleshy leaves as opposed to thin upright leaves etc.

In the same way that some plants are easy to identify because of the colour and shape of their leaves in field survey, so some plants can similarly be easily identified from imagery (e.g. Molinia). Where these plants comprise some of the main cover species of a habitat then this habitat can be picked out with relative certainty. Occasionally two habitats will have similar spectral features but different locations in the landscape, e.g. one is only found on steep slopes and another on wetter flat land. In this case the habitats can be distinguished using spectral data and ancillary datasets. Where habitat features cover small areas (e.g. patches of scrub), a fine spatial scale of imagery is needed. Often it is the difference in growth form between early spring and high summer that helps distinguish one vegetation community from another. Ecological knowledge has been applied to this wide range of interacting factors, to develop a generic classification system (Table 8) that proposes categories (tiers) of habitat groups and the EO /data required to identify them.

Table 8. The Crick Framework describing the role of EO in habitat mapping as a tiered system

Tier					
Tier 1	Likely to be identified solely using EO				
Tier 2[1]	Likely to be identified using EO and ancillary data				
	Tier 2a - Likely to be identified using EO together with ancillary data	Tier 2b - Likely to be identified using VHR EO together with ancillary data	Tier 2c[2] - Likely to be identified using EO data (in some cases VHR) but ID dependent on good geological data	Tier 2d - Likely to be identified using EO methods such as fuzzy membership values	Tier 2e - Likely to be identified using EO including LiDAR to give detailed information about vegetation structure
Tier 3	Likely to be identified using EO and ancillary data but also dependant on availability of timeseries of imagery				
	Tier 3a - Likely to be identified using EO together with ancillary data	Tier 3b- Likely to be identified using VHR EO together with ancillary data	Tier 3c - Likely to be identified using EO data (in some cases VHR) but ID dependent on good geological data		
Tier 4	Currently unlikely to be determined using EO				
	Tier 4a - Habitats distinguished by low frequency or small features	Tier 4b - Habitat hidden from above for most of the year			
Tier 5	Cannot be identified using EO				

[1] Two images always give a more accurate result than single image surveys even if for the same time of year.
[2] Tier 2c vegetation will move into category 4a in the absence of geological data as field work will be necessary to confirm the underlying geology.

Applying ecological knowledge of individual Annex I and BAP priority habitats, the Crick Framework has been used to produce an initial grouping, to assist in establishing the potential contribution EO techniques can deliver for each of the habitats (Table 9). As neither the generic classification system nor the preliminary categorisation of these habitats has been tested, this should be treated as a provisional assessment requiring further consideration and peer review by the ecological and remote sensing community.

Appendix 1 lists the habitat classes provisionally assigned to each of the tiers in the classification system.

Table 9. Number of priority habitats which fall into each habitat tier.

		UK BAP Priority Habitats	EC Habitats Directive Annex I habitats	Total
Tier 1		0	0	0
Tier 2	2a	6	6	32
	2b	7	2	
	2c	2	5	
	2d	1	1	
	2e	1	1	
Tier 3	3a	6	5	41
	3b	9	11	
	3c	4	6	
Tier 4	4a	3	26	50
	4b	12	9	
Tier 5		0	3	3
Total		51	75	126

With regard to the provisional categorisation of these higher priority habitats the following observations are made:

- Habitats which can be distinguished solely on the basis of unmistakable spectral signals (e.g. plantation woodland and other anthropogenic single stand features) form Tier 1 and this category does not contain any BAP priority, or Annex 1 habitats.
- Habitats that have spectral differences, but require additional contextual information to help confirm their occurrence are included in Tier 2a.
- Tier 2b communities occur at fine spatial scales and therefore need data with a pixel coverage of ~1 metre (e.g. saltmarsh).
- Tier 2c habitats are communities such as species-rich grasslands, which require a geology map at a fine enough scale to distinguish calcareous from neutral areas. Where such data is not available, confirmation will have to be by field survey to identify underlying geology.
- Tier 2d are communities that are defined by their mosaics, such as rhos pasture.
- Tier 2e habitats are very structurally distinct communities, such as flushes, which could be more easily distinguishable with the inclusion of LiDAR data.
- Tier 3 habitats are similar to those in Tier 2, but they will also need temporal data as it is the temporal patterns and changing growth form between spring and summer, that distinguish one habitat from another.
- Tier 4a habitats are difficult to determine using EO as they are only distinguishable from other much more common communities by the inclusion of indicator species which are small in size and occur throughout the sward with low frequency; for these habitats field survey is crucial. However, EO can play an extremely valuable role in identifying target areas for field search.
- Type 4b communities tend to occur in hidden locations (e.g. eutrophic water bodies (often occluded from above by vegetation) and sub-tidal vegetation often covered by the tide and EO is therefore not the best means of identification. Nonetheless, with new techniques such as UAS there may be more potential for EO in their identification.
- Tier 5 features such as caves cannot be identified from above, therefore field survey is crucial.

This evaluation of habitats shows that EO and geoinformatic techniques have much to offer in the surveillance and monitoring of habitats. However it will not be the sole answer and its most valuable role will be as part of a holistic approach, utilising it efficiencies to target other effort to the highest degree. The Crick Framework, also has implications for the technique, type of imagery used (field survey/manual/semi-automated and automated techniques) and maybe scale of the job undertaken (e.g. 3b, 2e). The rule-based approach using geoinformatics has the most to offer as can incorporate range of approaches and image types, and work at a range of spatial scales.

3.3.4 From a technical perspective, do EO techniques have potential to provide a full or partial solution (all measures, all habitats, all geographic contexts)?

Adopting an EO based view of habitats demonstrates that EO techniques have potential to provide a large amount of information as part of a wider holistic solution.

All habitats:

Tier 2a, 2c, 3a and 3b, represent 45% of higher priority habitats and a range of the EO techniques reviewed have demonstrated through piloting that they should be fit-for-purpose to play a major role in their identification. These habitats have distinct biophysical properties, e.g. amount of dead to living vegetation, wetness, leaf structure etc. These properties are capable of being well recognised by EO techniques and when added into a rule-base, with geoinformatics and contextual information are capable of being well described, and maybe monitored using EO.

The mapping of Tier 2c and Tier 3c habitats (19 or 15% of habitats) is currently constrained by a lack of fine scale soil or geology data. This largely comprises grassland habitats split by geology or soil type. Where geology data is not available EO can significantly assist targeting of these areas, but final confirmation will then have to be carried out in the field.

Tier 4 habitats, which are difficult to determine using EO, make up over a third of the higher priority habitats (37%). EO can however identify the common communities to target the area of search for follow-up field survey; for example, looking at areas of flush to identify calcareous fens with Cladium mariscus. This use of EO techniques to improve efficiency can be a powerful tool in an integrated approach.

All measures:

The review of recent projects has shown there are various EO techniques that can be applied for mapping the location and extent of a range of habitats including those within dynamic environments. There has been considerable focus on establishing techniques to support the production of baseline habitat inventories and landscape-scale mapping tools. Consideration has been given to determining change in extent and automated techniques appear to be a good option for repeatability and efficiency in this respect, but as yet these studies have not reached the final reporting stage.

Initial research on the potential of EO for assessing condition and condition monitoring has shown promising results. Wetness of habitats, the amount of dead vegetation present and scrub encroachment are all features which can be quantified using EO techniques. This sort of information could significantly help the monitoring effort, which would allow field campaigns to be applied in a more targeted way. This area needs to be investigated in more detail.

Information requirements for ecosystem services are not fully understood. The existing studies undertaken (CCW 2010) show the more detailed and spatially accurate the habitat maps used to underpin the modelling, the better understanding of the services. EO habitat maps therefore have the potential to play a significant part in contributing to our understanding of Ecosystem goods and services.

All geographic contexts:

Technique development reflects the need for different approaches in differing geographical contexts (e.g. monitoring change in an individual SAC versus reporting on the national extent of a habitat) and the use of bio-geographical zones has assisted in improving the overall accuracy of automated techniques.

- When large geographic areas are considered, automated approaches have a number of benefits including the systematic way in which they operate and the ability to re-iteratively improve the method once errors have been identified.
- Automated approaches have been implemented or trialled in western and northern areas of the UK, however there has been limited work in the east of the country. A rule-based automated method should be investigated in this area to assess the ecological facets and imagery needs for identifying habitats by EO.

Summary:

It is clear that a "one-size-fits-all" approach will not deliver information on any habitat measure for the full range of higher priority habitats. This is due to inherent differences in their characteristics from a remote sensing perspective and differences in the scale of approach that is needed for reporting on measures for different purposes. However, there is strong evidence that EO and geoinformatic techniques together have a valuable role to play in an integrated approach, offering a more efficient means of surveillance for many habitats and contributing to targeting of field survey for habitats that will require field survey for their identification.

3.4 Evidence of the economic worth of EO techniques

What evidence is there that these techniques are likely to be cost-effective and provide value for money?

An assessment of the potential value for money that EO techniques can bring, needs to set the costs of earth observation techniques in context. This involves identifying the benefits EO techniques can bring when used as part of a suite of ongoing surveillance and monitoring activities, both in their own right as a solution to meeting current information needs and when considered in the context of the added value they can bring to other activities through improved efficiency. Four approaches to the assessment of value for money are considered; these are presented in order of importance:

1. Value of information to improve the management of ecosystems and biodiversity (Value for Management)
2. Comparisons with the costs of current initiatives – example based on habitat inventories (Cost Comparison).
3. Value for scientific purposes (Science Value)
4. Comparisons with likely infraction fines for failure to meet obligations to protect the highest value designated land in the UK (Avoidance of Fines)

3.4.1 The value of information to improve ecosystem management for biodiversity (Value for Ecosystem Services)

Information that improves our knowledge of the location, status and trends of higher priority habitats is fundamental to ensuring the protection and beneficial management of such habitats and the species that depend upon them, both in a local and strategic context. In the UK, there is an acknowledged gap in the provision of such information for many of the higher priority habitats; the information currently available provides only part of the picture. This in turn leads to uncertainty when evaluating the environmental and societal benefits arising from existing and planned future investments in natural resource protection.

There are a range of policy initiatives with elements that specifically target the management and protection of rare and vulnerable habitats of recognised importance. Most of these initiatives have a broader remit, contributing to the delivery of wider ecological and environmental benefits, such as the WFD, with additional ecosystem goods and services such as water storage, provision and flood mitigation. As a consequence it is often not possible to isolate the actual expenditure on Annex I or BAP priority habitats per se.

However, it is clear that there is substantial expenditure on policy initiatives that target resources towards these habitats and the species that depend upon them (Table 10). Funding for these is provided both by the UK Exchequer and from European funding mechanisms (e.g. the RDPs). The annual costs of meeting biodiversity objectives of the UKBAP alone are estimated at upwards of half a billion pounds (Table 10), with current expenditure estimated to be about £400 million/annum. Note, there is some duplication of the costs presented in relation to Annex I and BAP Priority habitats, for example some of the costs of managing SSSIs may comprise agri-environment payments.

Table 10. Policy costs of some initiatives that include provision for the protection and management of higher priority habitats

Policy mechanism	Annual Cost	Explanation
Meeting UKBAP objectives	£573 - £624 million (England only)	The annual costs of meeting England's BAP objectives have been estimated to be £573 million. Current expenditure on BAP is estimated to be about £400 million, leaving a shortfall of £173 million per year. Another study estimated the annual cost of meeting biodiversity objectives at £624.4 million, taking account of managing SSSIs, BAP priority habitats, certain widespread species assemblages, achieving woodland expansion objectives and buffering wildlife sites.
Cost of managing Sites of Special Scientific Importance (SSSIs)	£54 - £96 million	Defra has estimated that some £395 million was spent managing SSSIs between April 2000 and March 2008. This equates to an average of nearly £54 million per annum at 2008 prices, equivalent to £50 per hectare per year. Of the £395million, £77 million has been from European Union grants and the remainder from central government (Lawton et al., 2010). Defra estimates that by 2010 -11 the ongoing maintenance of sites to maintain or achieve favourable condition could cost the public purse around £96 million a year. Private businesses, non-government organisations, local government and individuals also contribute to the maintenance of sites, but there is no complete overview of the costs involved.
Agri-environment schemes: Higher Level Scheme (England)	£241 million (England only)	Agri-environment schemes, implemented and funded under the Rural Development Plan, are a primary means of targeting and promoting environmentally sensitive land management in the countryside. In England Environmental Stewardship (ES) is the key scheme. Equivalent schemes aimed at habitats of recognised importance operate in other parts of the UK. The Higher Level Scheme of ES aims to deliver significant environmental benefits in high priority situations and areas. It involves more complex environmental management and whilst its remit extends beyond higher priority habitats, it specifically targets such land and forms a key delivery mechanism for the protection and enhancement of these habitats. It is of particular importance outwith protected areas. Costs shown are for 2009 and include annual payments to farmers, plus the cost of administration costs to Natural England (NE) and the Rural Payments Agency (RPA) in operating the scheme. HLS accounts for over half of total expenditure on ES.
Local Wildlife Sites	£62 million (England only)	Estimated costs of managing important biodiversity sites outside the statutory protected sites, assuming costs for LWS are similar per unit area to SSSIs (i.e. £89 per ha). (Lawton et al., 2010)
BAP habitat in National Parks and AONBs	£30.5 million	BAP habitats in National Parks and AONBs, to manage to SSSI standard, estimate based on area of BAP habitat within NPs and AONBs which is outside SSSIs (= 343,000 ha) and assumes costs are similar per unit area to that of SSSIs (i.e. £89 per ha) is £30.5 million annually (Cao,Y et al., 2008).

Considerable effort is now being put into valuing ecosystem services by Defra both in the UK (Defra 2007) and internationally through UK contributions to The Economics of Ecosystems & Biodiversity (TEEB) project. A recent study (Cao et al., 2009) has estimated the combined cost of meeting environmental objectives for water management (flood risk and water quantity measures), climate change mitigation (protecting the major carbon stores in peat and woodland), soil quality, resource protection (including improving water quality) and public access at £517.3 million. These estimates do not include any costs associated with regulatory compliance and demonstrate the additional costs that need to be taken into account when habitats are considered and managed for the wider goods and services they provide beyond their inherent ecological benefits.

There is an increasingly recognised need to view ecological management of habitats in a wider context, and an aspiration to plan for a coherent and resilient managed ecological network with habitat management delivered at the landscape scale. Taking a forward look, the Lawton report (2010) estimates that the annual cost of establishing a coherent and resilient ecological network in England, a framework that will be necessary for the long-term sustainability of higher priority habitats, is likely to lie somewhere between £600 million to £1.1 billion. The report recognises the need to plan for the medium and longer term stating that “the sooner we act, and the better we are at focussing our actions to enhance the Network, the lower the eventual cost will be"; an important acknowledgement that no or delayed action will result in higher costs overall due to a loss of environmental goods and services.

Earth Observation already makes a substantial contribution to identifying, mapping and understanding the importance of managing land for a range of ecosystem services; LCM2007 for example will provide key information on the more commonly found Broad Habitats for the UK National Ecosystem Assessment. Further investment in EO techniques will enable improved identification and monitoring of higher priority habitats for a range of purposes. Improved mapped inventories, in particular, will improve the efficacy and make more cost-effective a wide range of current policy measures directed at natural resource protection. They will also facilitate work to value UK ecosystem goods and services and inform the early stages of policy development in relation to initiatives to improve ecological networks. If the costs of EO technique development will be of the order of £1m this would represent a very small percentage (< 0.0001 %) of upwards of £500bn in policy costs of existing funded initiatives. In this context investment in EO techniques appears to represent very good value for money.

3.4.2 Comparisons with the costs of current initiatives (BAP inventories/ Annex I) - Cost Comparison

A very specific initiative is the mapping and monitoring of moorland burning. Unsustainable moorland burning is an issue important enough to attract legislation and several strategic policy implications. Much of the data currently used is gathered from sample field surveys and carries with it the limitations inherent in those systems. In many cases, whilst current data will still be valuable, remote sensing data can provide more information, both spatially and temporally and can add to the ability for more detailed research, analysis and interpretation.

A recent report by Cranfield University (Yallop et al., 2008) has tried to estimate the cost of the current method of data collection. It suggests that the number of staff looking at habitat condition in the uplands is about 90 FTE (full-time equivalents). This equates to a figure of approximately £3 million per annum, if costs such as salaries, management, overheads and site expenses are included. From discussions with Natural England it was estimated that a quarter of staff time is involved with inspecting burned areas, or looking for evidence of burning, which equates to a proportional cost of about £750k each year. Should EO be utilised as far as possible in this mapping and monitoring process, then it was calculated that the current cost will diminish to a quarter initially and then as the new processes improve and are more integrated into working practices over time it is estimated that this will reduce by ten percent every year over a period of ten years.

Under EC Habitats Directive regulations, there is a requirement to report at a UK level on the selection, designation and management of Natura 2000 sites. In Wales, Phase 1 mapping was completed, over the period 1979 to 1997 at an estimated cost of around £10 million. There is currently an on-going programme to revise this national mapping using EO techniques, in a much shorter timescale and for a fraction of the costs (CCW, pers. comm.).

Another recent study examined the time and resource requirements for a range of EO options for filling gaps in the mapping of habitats to Phase 1 standards, for the Tweed Consortium. The options included traditional manual aerial photography interpretation, automated digitising manual AP classification, automated digitising semi-automated AP classification and implementation of an automated digitising and 'time series and rule based' classification system (Medcalf and Williams, 2010). The study concluded that, purely in terms of time and resource requirement, a single experienced operator could map approximately 40ha per day using manual API, to over 4,000ha per day for a rule-based classification system, once the start-up phase is complete. This compares with 10-40ha per day for field survey, not including map preparation and travel to and from sites.

3.4.3 Comparing cost for different techniques

There is no published work on the cost comparison of different techniques. Studies have shown approximate indicators for timings taken to complete field studies, or broad scale comparative figures. Requests for cost information were made as part of this project, with different organisations clearly recording cost and accounting for their projects in very different ways. Therefore, it is extremely difficult to make inter-project comparisons. In addition cost can vary because the hidden, start-up and miscellaneous costs, plus in some cases commercial sensitivities, are an issue in trying to identify and quantify project activity. Finally, there are many different ways of running a project and each will have its own efficiencies and issues. For example, where field teams use hand held GPS devices to collect data a large amount of spatial data project time can be saved as a separate cartographic exercise is negated or reduced and accuracy can often be enhanced because errors of transcription are avoided (Dauwalter et al., 2006).

In order to achieve a framework of comparative costs information has been compiled from various sources including ad-hoc discussions, published and unpublished literature and varied anecdotal experiences over running a broad range of projects. The following has therefore been suggested as a first stage of considering the different orders of magnitude from approach to approach. The results are presented with increasing levels of automation and the savings that these realise. Increased levels of automation have the most profound cost saving effect on resurvey of a monitoring programme, where the existing data can be re-used.

It is essential to acknowledge that increased automation does not imply a corresponding decrease in ecological skill needed to undertake any mapping or analysis. All forms of habitat mapping and monitoring requires expert ecological knowledge. Without this inherent understanding of the manifestation ecological features and ecosystem processes, all mapping mechanisms, regardless of the level of automation will not provide a suitable result.

Cost comparisons

Typical comparative costs are presented below for field-based methods, semi-automated EO-based methods and automated EO-based methods. Costs have been estimated based on the following overall requirement:

- A complete habitat inventory of a 60km x 60 km block (the size of a SPOT 5 image), including identifying smaller Annex 1 and BAP habitats.
- There is a requirement for both baseline and resurvey.

- All survey work to be completed within a single fieldwork season.
- The costs for the semi-automated and automated methods have been drawn from data gathered from a number of projects.
- To include all relevant management, quality assurance (including accuracy assessment) and project support time, as well as any travel and subsistence.
- Ultimately a map for the whole area is desired to fulfil ecosystem services requirements, in addition to habitat mapping and that surveillance activity requires a complete resurvey over the whole area. It should be noted that there are alternative options for resurvey, including risk based targeting.

This cost analysis is not intended to be comprehensive, neither does the table show consideration for issues with running surveys in different areas, but rather it is a hypothetical example supposing an area of half uplands and half agricultural lowlands/ forestry to provide a standard for comparison. Also it is a slightly artificial example assuming a completely comprehensive ‘ ideal’ survey rather than a financially expedient programme, tailored to a specific budget.

Field-based methods

Project start-up	Baseline	Re-survey [3]	Total
Field map production (1:5,000) and screening of habitat areas: £10K-£20K	Contracted out Field survey to include staff time and travel: £250K-£450K Digitisation: £30K-£50K Field Team In house Field survey to include staff time and travel:£200K-£300K	Contracted out Re-survey for monitoring: £290,000-£520,000 Field Team In house £240,000-£370,000	Contracted out £680,000 - £1,140,000 Field Team In house £250,000-£690,000

Assumptions:

a) Mapping is based on full field survey, supported by the use of aerial imagery.
b) Access is fully available for field survey and does not require significant land owner contact.
c) The mapping ‘in house’ figures do not contain any of the cost associated with building and maintaining an in house team of field ecologists.
d) We assume a certain amount of targeting (using a combination of manual air photo interpretation and existing data) has been undertaken and that, coniferous forestry areas and agricultural land are not surveyed in detail. This would mean that field survey on an upland area may be required on around 30km by 30km (i.e. 25% of the survey area). Maps would be produced for the whole 60km by 60km area using the field survey and other data (e.g. coniferous forestry) that is already available.
e) Interpretation and targeting will need to be done either by very experienced staff who have a thorough knowledge of air photo interpretation (through experience of using stereo pairs of photos) or by an ecologist using stereo pairs. This is because and the micro-relief provides fundamental knowledge for the identification of vegetation communities.

[3] Assumes a full resurvey for all three methods, so that information is available on all land use ecosystems services applications as well as BAP and Annex 1 mapping. Note that other options should also be considered for monitoring e.g. risk based sampling.

f) Costs for start-up cover either the production of printed maps or the inclusion of setting up electronic field data collection devices (not the cost of devices and associated information systems).
g) Assumes that mapping can be achieved for all habitats based on a rate of approximately $3km^2$ (300ha) per day.

Semi-automated EO-based methods

Project start-up	Baseline	Re-survey	Total
Image acquisition (those outside of PGA2 agreement), and design of segmentation. Production of field maps:	Attribution and manual editing of polygons: Field checking, including for habitats identified as Tier 4 habitats: Saving of approximately £150/ km^2 to £425/ km^2	Resurvey for monitoring: Saving of approximately £150/ km^2 to £425 /km^2	A total saving of £300/km^2 to £850/ km^2

Assumptions:
a) Mapping is based on an initial automatic segmentation, with subsequent manual attribution and editing of polygons and with limited field checking as part of the quality assurance process.
b) Field checking is highly targeted using information from the semi-automated analysis e.g. area of search for calcareous fen, based on wet areas identified within an area of known calcareous geology, significantly reducing the area of search.
c) CIR and RGB photography is available for the area in question under PGA2. No additional data costs have been considered.
d) The organisation carrying out the work has all software licenses to run the specialist software to automatically digitise (segment). Early field work is carried out to provide training data for the interpretation team.

Automated EO-based methods

Project start-up	Baseline	Re-survey	Total
Production of image stack, gathering and collating ancillary data layers (those outside PGA2 agreement) Including satellite acquisition (1-4 scenes), pre-processing and rule base development:	Rule base refinement and processing. Field checking, including for habitats identified as Tier 4 habitats: Saving of approximately £220/ km^2 to £500/ km^2	Resurvey for monitoring: Saving of approximately £250 /km^2 to £550/ km^2	Saving of approximately of £500/km^2 to £1050/ km^2

Assumptions:
a) Mapping is based on a fully automatic rule-based approach, with limited field checking as part of the quality assurance process.

b) Field checking is highly targeted using information from the automated analysis e.g. area of search for calcareous fen based on wet areas identified within an area of known calcareous geology, significantly reducing the area of search.
c) CIR photography is available through PGA2. SPOT 5 imagery cost has been assumed here, but it is anticipated that imagery from ESA Sentinel 2 satellites will become the base satellite imagery and either replace (to deliver a cost saving) or allow for supplementary imagery to be acquired.
d) The organisation carrying out the work has all software licenses to run the specialist software to automatically digitise and develop either supervised or rule based approach.

3.4.4 Value for scientific purposes - Science Value

The use of EO for identifying and evaluating habitat and species data, and other contextual data, is a rapidly expanding area of science, with rapidly advancing approaches to information processing and improved technology, especially linked to GPS and an array of new sensors. Investments taking forward techniques developed for habitat surveillance and monitoring of higher priority terrestrial and freshwater habitats, are likely to provide scientific spin-off into new areas which have cost and value for money implications.

Of particular importance is the control of invasive species. It is becoming increasingly evident that certain invasive species are causing damage to ecosystems, native habitats and species in the UK. In 2008, a strategy was developed (Fera, 2008) to meet the challenge posed by invasive non-native species in Great Britain. Of particular concern are plant species such as Japanese Knotweed, Himalayan Balsam and Giant Hogweed, and more recently the fungal pathogen phytophthora, which is causing extensive damage to Larch plantations and other trees and shrubs. The cost of controlling these invasive species can be enormous. The National Trust has estimated that the cost of eradicating Japanese Knotweed alone from the UK would be in excess of £1.5bn (National Trust), or £2.3bn per year to control all non-native species (Biodiversity is life 2010). The Forestry Commission, in 2009, committed an extra £100K to phytophthora control in just two very small areas of Wales and the problem has become substantially worse since then (Horticulture Week 2009) £120,000 has been spent by just one water company on modifications to cope with Zebra Mussels, which foul filtration systems (Defra). EO has the potential to contribute to the identification of the distribution of these invasive species and targeting appropriate control treatments. An EO approach has been piloted to identifying the likely distribution of Japanese Knotweed in Caerphilly CBC; the approach is now being rolled out across all key areas of Wales, together with a further pilot for Himalayan Balsam and Giant Hogweed.

There are likely to be other opportunities for scientific spin-off into new areas. Broad based stakeholder groups such as UK Forum for Earth Observation Applications provide an opportunity for knowledge transfer to identify these. For example, techniques and approaches developed for habitat surveillance and monitoring of higher priority terrestrial and freshwater habitats may provide techniques that are applicable to the environmental monitoring of marine environments, which can be difficult and potentially dangerous to survey from the ground, and are subject to increasing EU regulations.

3.4.5 Avoidance of fines for failure to meet obligations to protect the highest value designated land in the UK - Avoidance of Fines

Infraction proceedings can be taken by the European Commission against Member States for failure to comply with an obligation under an EU treaty. The failure to properly transpose and enforce an EU obligation can eventually lead to a fine. The penalty represents a material loss to the UK Exchequer and falls outside of Parliament's intentions in relation to the proper administration of European funding.

EU infraction fines have been imposed in the UK in Northern Ireland for 'non-compliance' with single payment scheme regulations for the 'failure to ensure tight controls on the eligibility for SPS payments' (essentially allowing the wrong interpretation of rules on the identification of land eligible for financial support). Although subject to challenge and appeal, the costs of the fine, if confirmed, could be as much as €132M (Farmers Guardian 2010). This illustrates the serious costs involved if non-compliance is shown. This case is of relevance from an EO perspective because EO has potential for use as a rapid and cost-effective solution, once incorrect interpretation has been highlighted.

In other sectors, in 2008-09 Defra incurred disallowance penalties of £92.2 million on a range of matters: the Arable Area Payments Scheme, Fruit and Vegetable grant schemes relating to 2003 to 2006, Export Funds, Cross Compliance 2006, Exceptional Measures and Livestock Premium, Bovines and Ovines 2003 and 2004. These disallowance penalties were due to identified weaknesses in control systems within Defra and its agencies.

To date no fines have been imposed on the UK government for non-compliance with aspects of Directives relating to the protection of higher priority habitats. In other EU member states, Ireland has been referred to the Court of Justice for the continuing failure to protect sensitive peatlands from peat extraction; similarly Spain has been given a written warning (a precursor to pursuing an infraction fine) for failing to protect Natura 2000 sites by allowing opencast mining developments.

Concerns have been expressed by UK wildlife organisations that current spending cuts on environmental protection could lead to damage to habitats and destruction of protected species, and a situation arising where non-compliance (and hence infraction fines) for failing to protect habitats from damage could be more likely (Belfast Telegraph 2011) The next review of habitat condition under the Habitats Directive is due in 2013.

To summarise the situation with regard to infraction fines, there is a risk, and even when not subject to fine, the resolution of infraction proceedings are both stressful and resource intensive. These risks would certainly be reduced by demonstrating that improved evidence-based surveillance and monitoring systems have been developed and put in place to report with more confidence on the status and trends of these habitats.

3.5 Moving to an operational scenario

Statutory organisations with responsibility for delivering nature conservation in the UK differ in terms of:

- the amount and nature of information they have already gathered for the habitat measures of interest.
- their experience of working with the range of EO data and techniques available;
- approaches that may be considered fit-for-purpose and potentially cost-effective now or in the near future by one organisation are not necessarily the right solution for other organisations.

With the exception of work on Dartmoor, activity in England has followed a thematic approach with mapping of selected, mainly terrestrial, UKBAP Priority habitats. In Wales, activity has focussed on country wide mapping to a Phase 1 classification. Specific Annex I and BAP priority habitat extent, and condition data are now being added as other ongoing research. Northern Ireland are also piloting Phase 1 mapping of NSSI's using a different approach. By contrast, in Scotland there are projects that evaluate a range of approaches, including thematic mapping, landscape scale mapping and modelling of existing habitat data to provide information on both priority habitats and Annex I habitats. There is also current work concerned with characterising bog woodland in Scotland and a programme of targeted field survey providing NVC mapping and condition data for saltmarsh sites.

Progress and differing approaches to the production of national habitat mapping activities (Table 10) by SNCOs illustrates the situation well.

Table 14. Differing current approaches to habitat mapping of SNCOs

Country	Approach	Delivery
Northern Ireland	Manual techniques for digital habitat mapping from aerial photographs are still being piloted. Focus on continued identification of sites for designation under Habitats Directive and SSSI legislation.	This work is being delivered by NIEHS staff.
Wales	Following significant investment in research and applications development, CCW have developed an automatic classification technique which is in operational use for Phase 1 mapping for the whole of Wales. Now focussing other on applications of the core data and rule base from which the map was derived. Specific Annex 1 and BAP habitat extent, and condition data are now being added as other ongoing research.	This required the skills of ecologists, remote sensing and geoinformatic specialists. Skills sourced from within CCW, from research institutes and specialist consultants.
Scotland	Manual interpretation of aerial imagery and field survey in operational use for the production of digital maps and inventories for selected habitats. Preparing for production of national mapped inventories. Ongoing research to establish the potential role of geoinformatic approaches, manual, semi-automatic and automatic classification techniques for the production of inventories for both Annex I and BAP habitats.	This work delivered by SNH staff. Use of external expertise to seek the most appropriate techniques
England	For the production of thematic based habitat BAP habitat inventories, a combination of field survey and manual interpretation techniques. Many draft BAP PH inventories prepared and refined. Beginning to focus on potential role of EO for producing measures of condition, including measures of habitat composition and structure relating to species requirements and underpinning processes.	Much of the work is carried-out in-house but some is outsourced to specialist consultancies. Applications development work draws on supply of EO data (aerial photography, CASI, LiDAR) and remote sensing skills from the EA, Geomatic Unit, under a formal partnership arrangement.

Looking beyond the work of the SNCOs on national habitat mapping the results of the research and pilot projects reviewed demonstrate that some techniques are near operational, being fit-for purpose for assessing the status of some priority habitats if the ecological, remote sensing and geoinformatic skills are available to organisations.

3.5.2 If they are potentially cost-effective, what technical, organisational or other barriers need to be overcome to make them operational?

To translate a technique into a potentially cost-effective tool, requires the organisation adopting it to have access to the right skills, experience and technology. This is particularly the case for the more complex techniques. Without a framework in place to either provide access to these skills (e.g. via specialist units) or to facilitate the rapid transfer of best practice between organisations techniques can only be considered to be “theoretically” cost-effective or ready for deployment across the UK.

One of the major needs in terms of EO is for people to understand how it works and to become comfortable with its benefits, limitations and usability. Ecologists and policy makers have an inherent grasp of the issues that may be apparent when a map created by field work is used, similar knowledge needs to be gained for EO derived products. This forms the driver for a number of the capacity building pathfinder projects, such as 1.1, 1.2, 1.4, 2.1 and 2.2.

3.5.3 How would they fit within the current framework of habitat surveillance?

The need for habitat surveillance is strong and indeed growing with increasing interest in ecosystem services mapping. Habitat surveillance has always suffered in the past by the requirement for expensive, resource intensive field survey, both at baseline and again for each resurvey. This is part of the reason why there are so many gaps in the provision of data and understanding. In the current economic climate of budget cuts and cost efficiencies, the prospect of funding major field-based habitat surveys becomes ever more daunting. In this situation the role of rapid and cost-effective EO-based methods in seamlessly extending the existing habitat surveillance framework, providing they can produce data of equal quality and with known accuracy, can only become more important and relevant.

4. Key findings and recommendations for future work

4.1 Key Findings

This review analysed 23 UK-specific projects, many of which are ongoing, in order to identify the role that Earth Observation (EO) and geoinformatic approaches can provide in supporting habitat surveillance and monitoring activities in the UK. A series of headline questions were addressed; the first of these covered the need for information to cover known gaps in provision. Gaps have been identified in terms of:

- knowledge of location and extent (distribution) of Annex I and BAP sites, especially outside protected areas, and habitat context (e.g. surrounding vegetation);
- measures to support assessment of habitat condition;
- tracking and monitoring change;
- understanding ecosystems services;
- describing dynamic environments;
- suitable information to help ecologists and environmental professionals understand the role and value of EO techniques.

The second headline question considered the EO techniques available and how and in what context they had been used. Several different approaches have been used with varying degrees of success. The techniques considered to have most potential to support current UK surveillance and monitoring are characterised as follows:

- use a scale of imagery suitable for the features that needed to be identified;
- use a systematic method of analysis;
- use a range of data sources coupled with sound ecological thinking;
- involve interdisciplinary teams;
- combine geoinformatic and EO approaches to allow modelling and incorporation of many different types of data;
- are not costly to repeat or improve upon and can be adapted to differing bio-geographical zones;
- can deal with some temporal variability in the imagery, using this to help classify or characterise habitats and habitat features;
- can accurately describe areas of certainty and uncertainty, ecotones and mosaics.

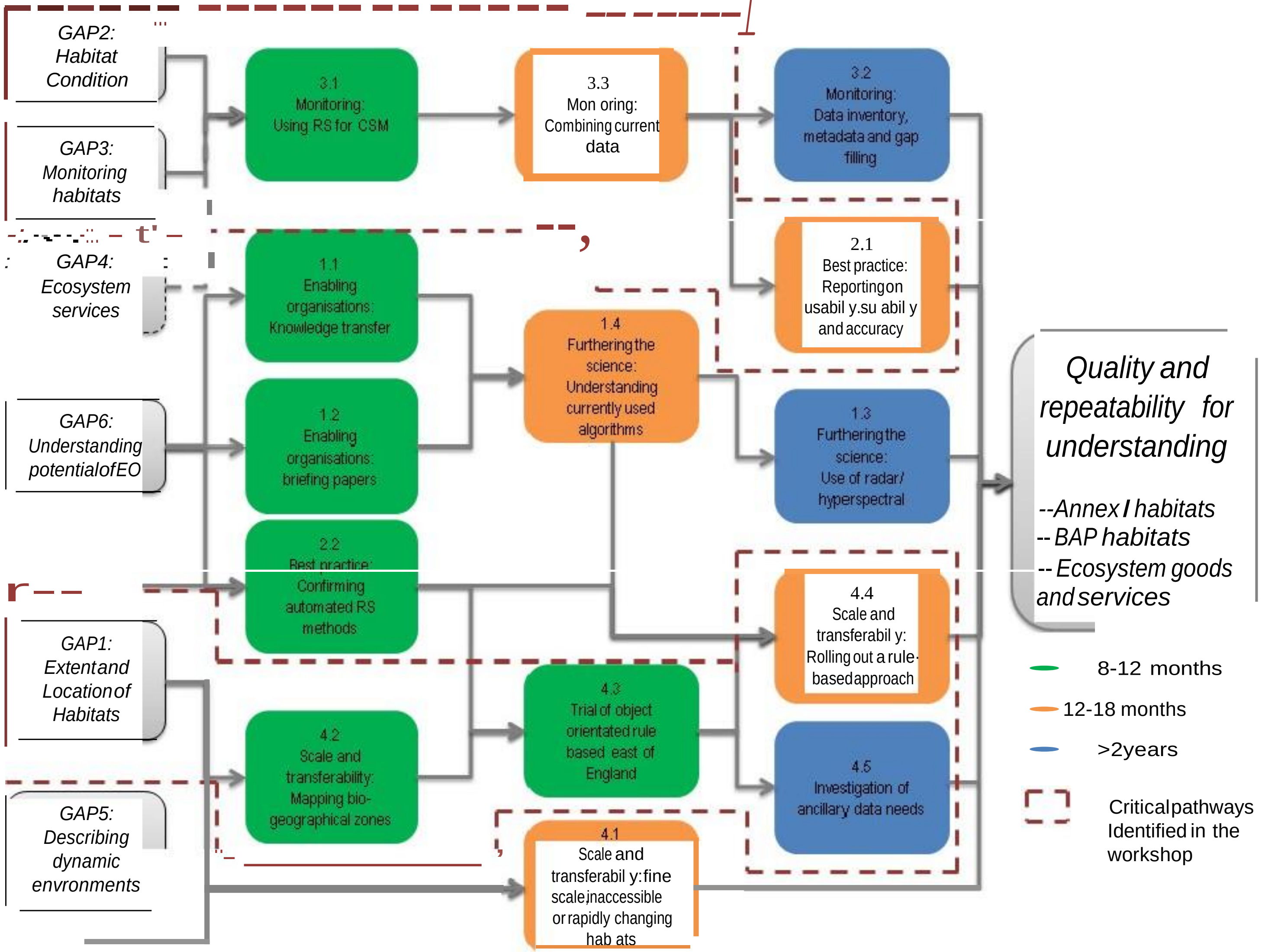
The third headline question addressed the suitability of techniques from a technical perspective for wider application and roll-out. Those techniques with most possibility for wider roll-out, which will also give the possibility for repeat survey for monitoring, and the identification of features that can be equated with habitat condition assessment were based around the object-orientated rule base approach. There were several manifestations of this approach, but all had in common the identification of areas on the ground that were then described using both spectral information from the imagery and other information such as the position in relation to fields, in a rule-based analysis (using geoinformatic concepts, although these were not always acknowledged using this terminology). Several different software solutions were used. Research from across Europe has shown that the advantages of object-based methods in terms of data content is only matched by the use of hyperspectral data combined with sophisticated classification techniques.

The cost-effectiveness of these techniques was examined using a value for money approach. Key messages arising are:

- The potential cost of development of EO techniques represents a very small percentage of funds (>£500bn) currently invested in initiatives for the protection and management of higher priority habitats. In this context investment appears to represent very good value for money.
- Products derived from investment in a single EO technique, have fulfilled multiple policy requirements. This has provided solutions to a range of habitat surveillance needs and has addressed issues from other policy areas. This potential for re-use ensures rapid recovery of costs, but not necessarily just from one budget line or department.
- Savings over solely field-survey based methods were substantial in the case-studies assessed. Where the techniques offer potential for repeat monitoring, the savings increase making the systems good value for money in the longer term.

The following section of the report addresses the issues that will need to be faced when moving to an operational scenario. Figure 2 below shows the road map of how EO techniques could be taken forward. Projects shown in green should deliver results in the short-term, those in orange may take more development to bring to fruition, and those in blue involve longer-term research because they require technique development and piloting.

Figure 2. Roadmap showing the relationship between gaps in provision identified, and the 'pathfinder projects' needed to address these with an EO program



4.2 Recommendations

4.2.1 Raising awareness of the value of remote sensing for habitat surveillance and monitoring

Habitat classification has, until recently, relied mainly upon manual interpretation of imagery, and with some success, particularly in support of the production of thematic-based habitat inventories. For over a decade, ecologists and remote sensing specialists have been developing automated techniques for habitat classification and there is now considerable activity in this field. These techniques are based on object identification and rule-based classification, and whilst they are still being developed, there is evidence that they are fit-for-purpose in supporting the production of habitat inventories and a range of other resources. They bring advantages of relatively rapid delivery of habitat information across wide areas, they can produce products that are information rich, and can be readily improved upon. The rule bases that have been developed can be adapted for further use in other areas or for resurvey. To increase understanding of the role of the various EO techniques now and in the future we suggest the following:

Recommendation1: Develop projects for environmental professionals with the specific purpose of improving understanding of the capabilities and value of remote sensing data for habitat surveillance and monitoring. This will enable organisations to make informed choices about the EO techniques to ensure that they are fit-for-purpose for their needs. These projects should:

- set out the capabilities and value of remotely sensed data for habitat surveillance and monitoring, including techniques under development;
- explain and demonstrate the benefits of incorporating quality metadata into products derived from EO data; this will promote understanding and re-use of the data;
- include workshops, webinars, training courses or awareness sessions that provide opportunities to explain the relative merits of the available techniques and technology and encourage their use;
- use successful case studies to promote best-practice and demonstrate the operational applicability or potential of particular techniques;
- include “briefing papers” to increase understanding of concepts, techniques and common definitions.

The requirements for the Pathfinder Projects arising from this recommendation are:

PATHFINDER PROJECT: 1.1
Establishing a program of active engagement; enabling organisations to make informed choices about the use of EO techniques
A series of webinars, workshops or seminars should be established to communicate the value and benefit of remote sensing to ecologists, planners and policy makers. During these seminars, techniques could be discussed; capacity of the data, and the work coming from remote sensing science, should be explained. Metadata standards should be introduced that build on existing requirements (e.g. INSPIRE) but can be extended to handle the rich information content (e.g. per pixel or object information) that these approaches will generate. Case studies should be presented.

PATHFINDER PROJECT: 1.2
Enable organisations to make informed choices about the use of EO techniques through provision supporting documentation
Further briefing papers should be produced to add to those prepared as part of this project. It is suggested that these address the questions such as: "What habitat-related information can be identified from remote sensing?" Other papers may need to be compiled to explain other features and techniques. Briefing papers should also be produced to compliment the subjects covered in the seminars and webinars outlined above.

Maintaining an active engagement with research, applied research projects and the professional communities

Several projects funded through the GIFTSS program were specifically designed to be user-led and bring remote sensing technology to bear on questions of importance to ecologists and partner organisations. These projects have invariably led to better understanding by both parties. Given the fast-paced change of remote sensing science, the exponential growth in computing technologies and the planned implementation of new satellites, this type of enabling programme will continue to be of value.

<u>Recommendation</u> <u>2</u>: Maintain active engagement with researchers and professionals in the remote sensing community and promote dissemination of information regarding emerging techniques and exemplar projects. This can be achieved by:

- continued funding for research programs that focus on both the basic science and applied research;
- using collaborative groups, such as the UK Forum for Earth Observation Applications, to aid open communication between stakeholders;
- closely monitor emerging techniques and exemplar projects to ensure rapid uptake and rollout of successful practical applications of remote sensing.

The requirements for the Pathfinder Projects arising from this recommendation are:

PATHFINDER PROJECT: 1.3
Explore the potential to extend the range of imagery used to address habitat surveillance and monitoring needs
There have been limited applied research projects which assess the potential of some image types, such as radar (with a potential role in wide area mapping) and hyperspectral data (for more site specific activity) for habitat surveillance and monitoring. However, there is good evidence from theoretical research that these image types could help address known needs. This work should build on any previous and ongoing relevant research, such as the BioSOS project. In particular, wider trials are needed to establish how radar can be used, in conjunction with other data, to derive measures relating to habitat structure and other bio-physical properties in order to support assessment of habitat condition in a range of environments.

4.2.2 Confirming science

Many of the projects reviewed provide maps and measures of habitat extent, and/or condition, based on the use of remote sensing algorithms (e.g. NDVI). Although in some cases the final maps have been checked and are considered fit-for-purpose, there seems to be less understanding of the biophysical characteristics being manifested through the algorithms and how these function in ecological communities. It is suggested that:

Recommendation 3:. Defining and characterising the biophysical features of vegetation types to allow a better understanding of the way in which habitats can be identified by EO.

Recommendation 4: Establish an understanding of how commonly used remote sensing algorithms describe biophysical features of vegetation types such as those defined in recommendation 3.

PATHFINDER PROJECT: 1.4

Allowing the ecology to lead the remote sensing science

A more complete understanding of how certain remote sensing classifications work, will allow the methods to become more efficient. Projects should be established to;

- characterise the biophysical features of vegetation types
- investigate the relationships between commonly used remote sensing algorithms and the way they describe biophysical characteristics of the vegetation

These will increase understanding of how habitat features manifest in EO, ensuring transferability and spatially robust results, which will in turn improve the ability to describe condition features.

Assessing and understanding accuracy and uncertainty

Assessing and understanding accuracy and uncertainty, whilst challenging, is a critical step in establishing and describing both the merits and limitations of products derived in whole or part from remote sensing and establishing the credibility of the ensuing product(s). Identification of errors brings with it an understanding of how and why the errors occurred and this can be used to inform the modification of procedures to improve the product to ensure it is fit-for-purpose.

Recommendation 5: Best practice for assessing and understanding accuracy and uncertainty should be developed and widely disseminated. This should involve:

- the use of exemplar projects to demonstrate the need for a clear specification of the purpose of the product being developed and a description of what must be achieved to meet this purpose. Pull-through benefits identified from ancillary uses of mapping can make up key components of a business case, but they should not confuse the core specification and production process. Project reporting should describe how well the product that was produced meets the original specification;
- advocating the use of geoinformatic approaches to provide valuable information on the uncertainty in maps and the distribution of errors;

- developing a series of descriptions of how to systematically report accuracy, uncertainty, error distribution and map / inventory suitability to assist in describing the uncertainty associated with different surveys (this must be sufficiently generic to be applied to the broad range of techniques)

Recommendation6: It is recommended that maps / inventories have rigorous quality checks applied and error correction stages built into the production processes. Remote sensing projects, like any other mapping projects, are best when thorough checks and corrections, manual and automated, are part of the whole mapping process, resulting in as 'clean' a product as possible that is understood in relation to fit-for-purpose.

PATHFINDER PROJECT: 2.1

Establishing best practice for reporting on usability, suitability and accuracy

To promote the widest possible adoption of EO-based data and map products, work is needed to further report on uncertainty, accuracy, usability and suitability. This work package is likely to consist of the following areas:

- Design of uncertainty and accuracy reporting methods that are both robust and understandable.
- Design of some standardised specifications for use in EO projects to outline how error and uncertainty should be dealt with.
- Design of a quality assurance method for confirming that errors have been adequately dealt with in inventory projects before they are accepted by organisations.

Maintaining an active engagement with local authorities, interest groups and volunteers

Utilising other field survey datasets and volunteer effort to enhance remote sensing projects has been shown to enhance results. In addition, agencies across the UK have access to a range of botanical survey and condition assessment data that provide rigorous field data. This data would be a very valuable comparative resource for further examining and understanding remote sensing techniques. It is therefore recommended that:

Recommendation7: Existing datasets and volunteer efforts, as well as any field campaigns in the area of interest, should be considered for incorporation into remote sensing projects to enhance the final output, its accuracy and its comparison to existing datasets. Exemplar projects could demonstrate the potential benefits of such an approach, such as the field validation provided by volunteers in the Tweed catchment (Medcalf and Williams, 2010).

Recommendation8: Automated / semi-automated remote sensing techniques, which can be expanded in scope to cover countrywide areas, should first be trialled in areas with existing rigorous field campaigns so that comparisons can be made.

PATHFINDER PROJECT: 2.2

Confidence in automated EO mapping by comparison trials

In order to assess the results of automated remote sensing methods with field trials, projects should be set up to allow comparison with field survey and also build confidence in the techniques. These trials should be conducted with the best possible access to EO data, as confidence building is an important component. It is suggested the work package comprises:

- A comparison of at least two proven automated or semi-automated approaches, trialled on areas with existing field campaigns.
- Currently areas of the UK have patchy coverage of high resolution satellite, or CIR airborne imagery. Both of these datasets have been identified as important for collecting habitat information at appropriate spatial detail. New techniques are available to merge datasets, which enhances spatial accuracy, this means that habitat information could be established in areas with less than ideal data coverage. Further trials on what can be achieved with remote sensing data of sub-optimal resolution for the habitats in question is therefore suggested.

Recommendation 9: Issues relating to the rapid development of operational remote sensing techniques need to be considered. In the early stages of development of operational products, intellectual property considerations arise and partners need to take account of these when seeking to share or exploit knowledge. Scientific aspects of remote sensing are evolving at a very rapid pace; it is now often the case that by the time that the reporting of research occurs, new opportunities are available to enhance the techniques.

- It is recommended that reviews are regularly carried out on new techniques and technologies, and that any work stream be left flexible enough for these to be incorporated into it. Careful consideration needs to be made of those techniques which are operational vs pre-operational.

4.2.3 Monitoring – condition and vegetation structure

The use of remote sensing techniques for monitoring

Recommendation 10: Establish a series of projects based on selected CSM habitat groups (e.g. coastal grasslands) to identify the features and processes that can be identified using EO techniques and relate these to the needs of common standards condition monitoring. This will require the combined skills of ecologists and remote sensing specialists.

PATHFINDER PROJECT: 3.1

Establishing remote sensing techniques to aid established monitoring programmes

A series of projects based on selected CSM habitat groups to identify the features and processes that can be distinguished using EO techniques should be established. These should be related specifically to the needs of common standards condition monitoring. In particular those features indicative of positive and negative condition could be translated into algorithms calculable from imagery.

Recommendation 11: It is recommended that for any remote sensing habitat work, a multidisciplinary project team be assembled, often led by an environmental professional. This is the only way to ensure the complete understanding of the mapping target that will facilitate the development of a technologically and ecologically sound method and output.

Recommendation12: Incorporation of different types of remote sensing data for monitoring; Earth observation provides an extremely efficient and cost effective way of mapping remote areas, such as uplands, and would provide an ideal mechanism for monitoring these regions. The most successful studies to date have used a range of different-scaled EO data and a range of different data types.

- It is recommended that an inventory of data be established over the main upland blocks and that when available, the GMES Sentinel data acquisition programme be examined to assess the likelihood of coverage of areas lacking current coverage.
- A plan should then be drawn up to acquire imagery for poorly covered areas in alternative ways. This should include manned and unmanned aerial systems.

PATHFINDER PROJECT: 3.2

Preparation of monitoring of remote areas based on EO data availability

The following elements are needed:

- An inventory of available imagery from all scales of EO sensors, including LiDAR and aerial photography, for extensive upland areas and an evaluation of the potential future provision under GMES of coverage for these areas.
- An associated metadata register of agency data held, specifying dates and times (crucial pieces of knowledge in assessing usefulness) of data capture including aerial photography and colour infrared photography, digital terrain models, LiDAR coverage and existing vegetation and monitoring information.
- A targeted plan for additional acquisition (including tasking) where necessary.
- Further research into change detection techniques to identify the most suitable for establishing change in priority habitats.

Recommendation13: Establishing baseline methodologies. In the past, monitoring has relied heavily on baseline map production. One issue with this is that as methodologies change, map products improve in their spatial expression of habitat extent and number and type of classes they cover. In the past, each step change in methodology would have necessitated a new baseline map. Geoinformatic techniques offer the possibility of combining and describing map datasets against each other and therefore potentially can be used as change detection products.

- A project should establish mechanisms for combining datasets to produce baselines to then potentially be used for monitoring. This has the potential to provide significant cost savings over time and to monetise value in historical survey data.

PATHFINDER PROJECT: 3.3

Establishing geoinformatic baseline methodology

A project should be undertaken to look at how to use geoinformatic techniques to provide the best possible baseline data by combining different spatial accuracy and different habitat classes in a statistically rigorous structure. It is important that the geoinformatic techniques employed are capable of incorporating additional data when it is available, and therefore providing information suitable for change detection, which can then be used for the basis of further monitoring.

4.2.4 Scale and transferability

Understanding how to work with datasets captured at different scales

Whilst some habitats (such as upland moorland) can be successfully mapped using a combination of 10m and 23m resolution satellite imagery, others (for example water bodies on a bog surface) would require 1m resolution data or finer. The use of multiple scales of imagery has been demonstrated (Lucas et al. 2011) as an efficient means of mapping extensive areas. UAS has been shown to have potential, particularly for monitoring and mapping areas of habitat which are very fine-scaled, very difficult to access (such as cliff ledges) or which would benefit from frequent re-visit due to their temporal flexibility in repeat flying. When mapping a range of habitats within a landscape there is likely therefore to be a requirement for a range of scales of data.

Recommendation14: the scale of the EO data used should reflect the scale of the feature of interest and that the use of multi-scale imagery should be the 'norm' for remote sensing projects; each project should address imagery needs at the outset by means of a "data scale plan".

Recommendation15: Use of Unmanned Aerial Systems is recommended as it has been shown to have potential particularly for monitoring and mapping areas of habitat which are very small scaled, very difficult to get to such as cliff ledges or which would benefit from frequent re-visit due to their dynamic nature.

PATHFINDER PROJECT: 4.1

Mapping fine scale, inaccessible or rapidly changing habitats

Demonstrate Unmanned Aerial Systems image capture and analysis as a means of mapping and monitoring of fine scale, inaccessible or rapidly changing habitats.

Recommendation16: It is recommended that smaller scale surveys using LiDAR and CASI should be continued to allow rigorous understanding of the landscape ecology. Such work can be built into a rule-based approach and the extra structural information could increase the capacity to distinguish between habitats which appear similar using other EO data. Such data could also be used to validate existing classifications using other EO data sources.

Strategic roll out

This study identified that there is still insufficient information on extent of a number of habitats, to determine condition and change features. From the body of work reviewed in this project an object orientated rule based approach has the most potential to address such issues at a national scale.

An object orientated rule based approach has considerable advantages for country wide roll out, over manual approaches:

- Once rules are developed it is extremely cost effective and rapid to re-run the process, conversely manual approaches require a similar input of effort to re-map the area for monitoring.
- Rules can be easily modified to take field validation or manual quality control work into account.
- The object orientated rule based approach also allows field campaigns to be specifically targeted to areas with high likelihood but low certainty of being habitats of interest, in order to identify tier 4 habitats.
- Manual approaches require rigorous collection of image catalogues to guide manual classification from all the different phenotypic manifestations of communities across the area of interest; at a national level this would be a daunting task (Stahl et al, 2011).

It has been shown in several studies, that in order to roll out any EO approach across the whole UK or an individual country, it is necessary to understand the biogeographical zones and the physical manifestations of the vegetation communities across these. Understanding these biogeographical zones in an object oriented rule based approach is important to efficiently adapt the rules to incorporate these variations. As rules are built, combining ecological knowledge with facets of the imagery and supporting datasets, not solely reliant on 'recognising' sections of the imagery, this task only needs to be completed once and then in following years the mapping process can benefit from the use of these established rules.

<u>Recommendation17:</u> It is recommended that a project be undertaken to define specific bio-geographical zones of the UK, areas which have different landscape ecology and phenotypic manifestations of vegetation communities.

PATHFINDER PROJECT: 4.2
Establish biogeographical zones
Building on existing knowledge and maps, describe and map the biogeographical zones across the UK looking in particular at the phenotypic manifestations of the communities of interest in relation to EO. This will be critical for any object orientated rule base approach, to transfer the ecological manifestation of the habitats across regions.

<u>Recommendation18:</u> an object orientated rule based approach should be trialled on an eastern area of the UK, where little work of this nature has been undertaken. The ecological manifestation of habitats in EO data can then be developed for lowland / eastern conditions. This work would prove the adaptability of the technique to incorporate enough ecological variation to support a more strategic rollout at a national or UK wide scale.

PATHFINDER PROJECT: 4.3

Feasibility of rolling out an object based approach

A strategic mapping pilot should be undertaken to assess the transferability of object orientated rule base mapping to an area where the habitats and context in which they are found are very different, for example on the east coast of Great Britain.

PATHFINDER PROJECT: 4.4

Rolling out an object based approach

A plan for a strategic rollout across the UK of object orientated, rule-based mapping would build on existing work (e.g. Pathfinder 4.3) and establish how well such an approach can deal with all the manifestations of habitat across the UK.

4.2.5 Incorporation of different types of data

Making full use of current data and improving data accessibility between organisations:

For geoinformatics based, or object orientated rule-based approaches, ancillary datasets are required to allow the classification of some Annex I habitats. In particular, there is a need for soil and geology data mapped at a very fine resolution (e.g., 1:5000). It may be that some of this data already exists for key areas in PhDs and other specific studies; but some new data may need to be gathered.

Recommendation 19: clarify ancillary data requirements and investigate the availability of existing information and the cost of providing additional ancillary data where none exists.

PATHFINDER PROJECT: 4.5

Gaps in ancillary data

A thorough investigation of the gaps in ancillary data and how to fill them should be undertaken. This should also include a timescale for the needs.

4.3 Project workshop

4.3.1 Workshop Objectives

A workshop was held on March 15th 2011, at the JNCC offices at Peterborough, to check and validate the project findings before they were finalised and discuss actions needed to realise the potential of EO techniques. This was attended by ecologists, GI and remote sensing specialists from a range of organisations (SNCOs, FC, Defra, JNCC, EA, LRCs), with representation from all countries of the UK. The workshop agenda and list of attendees is provided in Appendix 3. The workshop objectives were to:

- establish a greater understanding of where agencies are in terms of their use of remote sensing and geoinformatic techniques
- convey the potential benefits of using EO;
- test the recommendations of the review and check pathfinder projects are logical and suitable for taking habitat monitoring and surveillance forwards by the users.

4.3.2 Findings from the workshop

Discussions at the workshop confirmed that there is wide variation in the use, knowledge and capacity of organisations to adopt the range of EO techniques currently available or under development. The implication is that there is no one clear way forward. However, all the organisations present are actively working to develop EO and geoinformatic techniques to meet immediate priority information needs, particularly for cost-effective habitat mapping. Using the skills of ecologists, GI and remote sensing specialists was viewed as key to the effective uptake of remote sensing techniques by many organisations. Joint working across agencies, data sharing and the use of specialist units or contractors were reported as effective strategies where used. In some cases, this included making good use of local resources, for example, using Local Records Centres or voluntary organisations to maintain and check the content of centrally produced draft habitat inventories.

Following presentations of the recommendations and pathfinder projects, the group were in general agreement that these reflected user needs and were of the view that pathfinder projects that support the cost-effective mapping of habitats were of the highest priority. There was also widespread support for pathfinder projects that support the use of EO for condition assessment, with this being considered an area that EO can bring potentially large cost savings over current methods as well as helping address the need for cost-effective methods to monitor condition over the wider countryside (i.e. outwith statutory sites).

These priorities are largely reflected by ongoing and planned activity that individual organisations have for financial year 2011/12; encompassing development of techniques for habitat monitoring (Phase 1, Annex I and BAP) and with uplands, coastal, wetlands, rush/molinia pastures and woodlands being the key environments where EO techniques are considered by users to offer potentially the most cost-effective option. There is also planned research to understand and gather evidence on the links between biophysical measures and habitat condition. This reflects a shift in the way of looking at, and recording of ecological features with evidence of a possible transition in focus from taxonomy to condition features. However, this activity is disparate and it was agreed a framework for future activity would be beneficial because organisations are working to resolve common issues and reporting pressures.

Delegates considered that habitat mapping needs to be completed before operational progress can be made to assess change in the status of habitats or the provision of information for ecosystem services; there is little planned research activity on these topics but there was interest in carbon-peatlands-water as a potential “use-case” to show the relationship between biodiversity and habitats.

It was felt that pathfinder projects could be linked to existing European initiatives (e.g. pathfinder 4.3 and 4.4 and SEIS-NESIS] and that there should be a concerted effort to identify and influence how GMES could support UK activity (e.g. by GMES meeting specified image processing requirements). With regard to demonstrating cost-effectiveness it was felt that the East of England pilot (pathfinder 4.3) could compare selected techniques to demonstrate cost-benefit and provide firm evidence for best practice.

There was discussion of issues relating to ways of defining habitats. The proposed grouping of habitats within the Crick Framework, based on their potential for identification using EO was considered a novel and valuable way of identifying appropriate techniques for their surveillance and monitoring.

Delegates felt that there would be benefit in organisations working together to:

- identify which organisations have an interest in particular pathfinder projects;
- decide which pathfinder work packages should be scoped further and which need to be new projects;
- considering how the pathfinder projects should be co-ordinated, delivered and led.

It was agreed that the current project Steering Group should begin this activity with a view to achieving co-ordinated delivery, taking account of specific organisational needs and knowledge, and developing opportunities for partnership working and for wider engagement with key initiatives such as LWEC and GIFTSS and organisations such as NCEO.

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Other appendices to be found in PART B - Annexes and technical evidence

Appendix 1 - Provisional assessment of how habitats may fit into the classification system

		BAP Priority habitats	Annex I habitats	
Tier 1		none	none	
Tier 2	2a	Blanket Bog	H1140	Mudflats and sandflats not covered by seawater at low tide
		Intertidal mudflats	H4030	European dry heaths
		Lowland Raised Bog	H4060	Alpine and Boreal heaths
		Native Pine Woodlands	H6150	Siliceous alpine and boreal grasslands
		Upland Heathland	H7110	Active raised bogs
			H7130	Blanket bogs
	2b	Coastal saltmarsh	H1310	Salicornia and other annuals colonising mud and sand
		Calaminarian Grasslands	H6130	Calaminarian grasslands
		Coastal Sand Dunes		
		Estuarine rocky habitats		
		Hedgerows		
		Inland Rock Outcrop and Scree Habitats		
		Lowland Heathland		
	2c	Limestone Pavements	H8240	Limestone pavements
		Lowland Beech and Yew Woodland	H4040	Dry Atlantic coastal heaths with Erica vagans
			H7230	Alkaline fens
			H8110	Siliceous scree of the montane to snow levels
			H8120	Calcareous and calcshist screes
	2d	Purple Moor Grass and Rush Pastures	H4010	Northern Atlantic wet heaths with Erica tetralix
	2e	Lowland Fens	H2190	Humid dune slacks
		Upland Flushes, Fens and Swamps		
Tier 3	3a	Arable Field Margins	H1130	Estuaries
		Saline lagoons	H1150	Coastal lagoons
		Lowland Meadows	H6510	Lowland hay meadows
		Upland Hay Meadows	H6520	Mountain hay meadows
		Lowland Mixed Deciduous Woodland	H91C0	Caledonian forest
		Coastal and Floodplain Grazing Marsh		
	3b	Coastal Vegetated Shingle	H1210	Annual vegetation of drift lines
		Mountain Heaths and Willow Scrub	H1220	Perennial vegetation of stony banks
		Reedbeds	H1420	Mediterranean and thermo-Atlantic halophilous scrubs
		Upland Birchwoods	H2110	Embryonic shifting dunes
		Upland Mixed Ashwoods	H2120	Shifting dunes along the shoreline (`white dunes`)
		Upland Oakwood	H2130	* Fixed dunes with herbaceous vegetation (`grey dunes`)
		Machair	H21A0	Machairs
		Wet Woodland	H2330	Inland dunes with open Corynephorus and Agrostis grasslands
		Wood-Pasture & Parkland	H3160	Natural dystrophic lakes and ponds
			H91D0	Bog woodland
			H6410	Molinia meadows
	3c	Aquifer Fed Naturally Fluctuating Water Bodies	H3180	Turloughs
		Lowland Calcareous Grassland	H6170	Alpine and subalpine calcareous grasslands
		Lowland Dry Acid Grassland	H6210	Semi-natural dry grasslands
		Upland Calcareous Grassland	H6230	Species-rich Nardus grassland
			H9130	Asperulo-Fagetum beech forests
			H9190	Old acidophilous oak woods on sandy plains
Tier 4	4a	Oligotrophic and Dystrophic Lakes	H1320	Spartina swards
		Open Mosaic Habitats on Previously Developed Land	H1330	Atlantic salt meadows
		Traditional Orchards	H1340	Inland salt meadows
			H2140	* Decalcified fixed dunes with Empetrum nigrum
			H2150	* Atlantic decalcified fixed dunes
			H2160	Dunes with Hippophaë rhamnoides
			H2170	Dunes with Salix repens
			H2250	* Coastal dunes with Juniperus spp.
			H3140	Hard oligo-mesotrophic waters with Chara spp.
			H4020	Temperate Atlantic wet heaths with Erica ciliaris and Erica tetralix
			H4080	Sub-Arctic Salix spp. scrub
			H5110	Buxus sempervirens formations
			H5130	Juniperus communis formations
			H6430	Hydrophilous tall herb fringe communities
			H7120	Degraded raised bogs
			H7140	Transition mires and quaking bogs
			H7150	Depressions on peat substrates of the Rhynchosporion
			H7210	Calcareous fens with Cladium mariscus
			H7220	Petrifying springs with tufa formation

			H7240	Alpine pioneer formations
			H8210	Calcareous rocky slopes with chasmophytic vegetation
			H8220	Siliceous rocky slopes with chasmophytic vegetation
			H9180	Tilio-Acerion forests
			H91A0	Old sessile oak woods with Ilex and Blechnum in the British Isles
			H91E0	Alluvial forests with Alnus glutinosa
			H91J0	Taxus baccata woods of the British Isles
	4b	Sabellaria alveolata reefs	H1170	Reefs
		Maritime Cliff and Slopes	H1230	Vegetated sea cliffs of the Atlantic and Baltic coasts
		Intertidal chalk	H3110	Oligotrophic waters containing very few minerals of sandy plains
		Mesotrophic Lakes	H3130	Oligotrophic to mesotrophic standing waters
		Eutrophic Standing Waters	H3150	Natural eutrophic lakes
		Rivers	H3170	Mediterranean temporary ponds
		Seagrass beds	H3260	Water courses of plain to montane levels
		Sheltered muddy gravels	H9120	Atlantic acidophilous beech forests with Ilex
		Ponds	H9160	Oak-hornbeam forests
		Intertidal underboulder communities		
		Peat and clay exposures		
		Blue mussel beds		
Tier 5		none	H1160	Large shallow inlets and bays
			H8310	Caves not open to the public
			H8330	Submerged or partially submerged sea caves

Appendix 2 - Annex I and BAP Priority Habitats

LEVEL 1		LEVEL 2		LEVEL 3	
UK BAP Broad habitat	Relationship	UK BAP Priority habitats	Relationship	Annex I code	EC Habitats Directive Annex I habitats
Broadleaved, mixed and yew woodland	contains	Lowland beech and yew woodland	contains	H9130	Asperulo-Fagetum beech forests
				H9120	Atlantic acidophilous beech forests with Ilex and sometimes also Taxus in the shrublayer (Quercion robori-petraeae or Ilici-Fagenion)
			overlaps with	H91J0	Taxus baccata woods of the British Isles
		Other broadleaf, mixed and yew woodlands	contains	H5110	Stable Buxus sempervirens (box) formations
		Lowland mixed deciduous woodland	contains	H9160	Sub-Atlantic and medio-European oak or oak-hornbeam forests of the Carpinion betuli
			may overlap with	H9180	Tilio-Acerion forests of slopes, screes and ravines
				H91E0	Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)
			overlaps with	H9160	Sub-Atlantic and medio-European oak or oak-hornbeam forests of the Carpinion betuli
				H9190	Old acidophilous oak woods with Quercus robur on sandy plains
		Upland birchwoods	may overlap with	H91A0	Old sessile oak woods with Ilex and Blechnum in the British Isles
		Upland mixed ashwoods	overlaps with	H9180	Tilio-Acerion forests of slopes, screes and ravines
				H8240	Limestone pavements
				H91J0	Taxus baccata woods of the British Isles
		Upland oakwood	is probably equal to	H91A0	Old sessile oak woods with Ilex and Blechnum in the British Isles
			overlaps with	H91D0	Bog woodland
		Wet woodland	contains	H91E0	Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)
				H91D0	Bog woodland
				Other wet woodland (no equivalent or contained Annex I type)	
	partially contains	Lowland wood-pastures and parkland	overlaps with	H9160	Sub-Atlantic and medio-European oak or oak-hornbeam forests of the Carpinion betuli
				H9190	Old acidophilous oak woods with Quercus robur on sandy plains
		Traditional orchards	is partially contained in	H6210	semi-natural dry grasslands and scrubland facies on calcareous substrates (Festuco-Brometalia).
Coniferous woodland	contains	Native pinewoods	contains	H91C0	Caledonian forest
			overlaps with	H91D0	Bog woodland
Boundary and linear features	contains	Ancient and/or species rich hedgerows	No equivalent or contained Annex I types		
Arable and horticultural	contains	Cereal field margins	No equivalent or contained Annex I types		
Improved grassland	contains	Coastal and floodplain grazing marsh	overlaps with	H6510	Lowland hay meadows (Alopecurus pratensis, Sanguisorba officinalis)
			overlaps with	H6410	Molinia meadows on calcareous, peaty or clayey-silt-laden soils (Molinion caeruleae)
	contains	Other improved grassland [no equivalent or contained Priority Habitat or Annex I types]			
Neutral grassland	contains	Lowland meadows	contains	H6510	Lowland hay meadows (Alopecurus pratensis, Sanguisorba officinalis)
			contains	Other lowland meadows (no equivalent or contained Annex I types)	
		Upland hay meadow	is equal to	H6520	Mountain hay meadows
		Other neutral grassland [no equivalent or contained Priority Habitat types]		H1340	Inland salt meadows
Calcareous grassland	contains	Lowland calcareous grassland	overlaps with	H5130	Juniperus communis formations on heaths or calcareous grasslands
			overlaps with	H6210	Semi-natural dry grasslands and scrubland facies on calcareous substrates (Festuco-Brometalia)
				H6211	Semi-natural dry grasslands and scrubland facies on calcareous substrates (Festuco-Brometalia) (important orchid sites)
		Upland calcareous grassland	overlaps with	H6210	Semi-natural dry grasslands and scrubland facies on calcareous substrates (Festuco-Brometalia)
				H6230	Species-rich Nardus grassland, on siliceous substrates in mountain areas (and submountain areas in continental Europe)
			contains	H6170	Alpine and subalpine calcareous grasslands
				H5130	Juniperus communis formations on heaths or calcareous grasslands
Acid grassland	contains	Lowland dry acid grassland	contains	H2330	Inland dunes with open Corynephorus and Agrostis grasslands
Fen, marsh and	contains	Upland fens, flushes	contains	H7240	Alpine pioneer formations of the Caricion bicoloris-atrofuscae

swamp		and swamps	overlaps with	H7140	Transition mires and quaking bogs
				H7220	Petrifying springs with tufa formation (Cratoneurion)
		Lowland fens	contains	H7210	Calcareous fens with Cladium mariscus and species of the Caricion davallianae
				H7230	Alkaline fens
			overlaps with	H7220	Petrifying springs with tufa formation (Cratoneurion)
				Other springs [no equivalent or contained Annex I types]	
		Purple moor grass and rush pasture	contains	H6410	Molinia meadows on calcareous, peaty or clayey-silt-laden soils (Molinion caeruleae)
			overlaps with	H6510	Lowland hay meadows (Alopecurus pratensis, Sanguisorba officinalis)
			contains	Other purple moor-grass and rush pastures [no equivalent or contained Annex I types]	
		Reedbeds	[No equivalent or contained Annex I types]		
Bogs	contains	Blanket bog	contains	H7130	Blanket bog
			overlaps with	H7140	Transition mires and quaking bogs
				H7150	Depressions on peat substrates of the Rhynchosporion
		Lowland raised bog	contains	H7110	Active raised bogs
				H7120	Degraded raised bogs still capable of natural regeneration
			contains	Other lowland raised bogs [no equivalent or contained Annex I types]	
			overlaps with	H7150	Depressions on peat substrates of the Rhynchosporion
		Other bog types (no equivalent or contained Priority Habitat types)		H7140	Transition mires and quaking bogs
Dwarf shrub heath	contains	Lowland heathland	contains	H4020	Temperate Atlantic wet heaths with Erica ciliaris and Erica tetralix
				H4040	Dry Atlantic coastal heaths with Erica vagans
			overlaps with	H7150	Depressions on peat substrates of the Rhynchosporion
				H4010	Northern Atlantic wet heaths with Erica tetralix
				H5130	Juniperus communis formations on heaths or calcareous grasslands
				H4030	European dry heaths
		Upland heathland	overlaps with	H4010	Northern Atlantic wet heaths with Erica tetralix
				H5130	Juniperus communis formations on heaths or calcareous grasslands
				H4030	European dry heaths
Montane habitats	contains	Mountain heaths and willow scrub	contains	H4060	Alpine and Boreal heaths
				H6150	Siliceous alpine and boreal grasslands
				H4080	Sub-Arctic Salix spp. Scrub
Standing open water and canals	contains	Aquifer fed naturally fluctuating water bodies	contains	H3180	Turloughs
			overlaps with	H3150	Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation
		Eutrophic standing waters	contains	H3150	Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation
			overlaps with	H3140	Hard oligo-mesotrophic waters with benthic vegetation of Chara spp.
		Mesotrophic lakes	overlaps with	H3140	Hard oligo-mesotrophic waters with benthic vegetation of Chara spp.
				H3130	Oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and/or of the Isoëto-Nanojuncetea
		Oligotrophic and dystrophic lakes	contains	H3160	Natural dystrophic lakes and ponds
			overlaps with	H3110	Oligotrophic waters containing very few minerals of sandy plains: Littorelletalia uniflorae
				H3140	Hard oligo-mesotrophic waters with benthic vegetation of Chara spp.
				H3130	Oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and/or of the Isoëto-Nanojuncetea
		Ponds	contains	H3170	Mediterranean temporary ponds
			overlaps with	H3110	Oligotrophic waters containing very few minerals of sandy plains: Littorelletalia uniflorae
				H3130	Oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and/or of the Isoëto-Nanojuncetea
				H3140	Hard oligo-mesotrophic waters with benthic vegetation of Chara spp
				H3150	Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation
				H3160	Natural dystrophic lakes and ponds
Rivers and streams	contains	Rivers	contains	H3260	Water courses of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion vegetation
Inland rock	contains	Limestone pavements	is equal to	H8240	Limestone pavements
		Calaminarian grasslands	is equal to	H6130	Calaminarian grasslands of the Violetalia calaminariae
		Inland rock outcrop and scree habitats	contains	H8220	Siliceous rocky slopes with chasmophytic vegetation
				H8210	Calcareous rocky slopes with chasmophytic vegetation
				H8110	Siliceous scree of the montane to snow levels (Androsacetalia alpinae and Galeopsietalia ladani)
				H8120	Calcareous and calcshist screes of the montane to alpine levels (Thlaspietea rotundifolii)
				H6430	Hydrophilous tall herb communities
		Other rock types (no equivalent or contained Priority Habitat types)		H8310	Caves not open to the public

Supralittoral rock	contains	Maritime cliff and slope	is equal to	H1230	Vegetated sea cliffs of the Atlantic and Baltic coasts
Supralittoral sediment	contains	Coastal sand dunes	contains	H2250	Coastal dunes with Juniperus spp.
				H2190	Humid dune slacks
				H2170	Dunes with Salix repens ssp. argentea (Salicion arenariae)
				H2160	Dunes with Hippophae rhamnoides
				H2150	Atlantic decalcified fixed dunes (Calluno-Ulicetea)
				H2140	Decalcified fixed dunes with Empetrum nigrum
				H2130	Fixed dunes with herbaceous vegetation ("grey dunes")
				H2120	Shifting dunes along the shoreline with Ammophila arenaria ("white dunes")
				H2110	Embryonic shifting dunes
		Coastal vegetated shingle	contains	H1220	Perennial vegetation of stony banks
				H1210	Annual vegetation of drift lines
		Machair	is equal to	H21A0	Machair
Littoral sediment	contains	Coastal saltmarsh	contains	H1330	Atlantic salt meadows (Glauco-Puccinellietalia maritimae)
				H1420	Mediterranean and thermo-Atlantic halophilous scrubs (Sarcocornetea fruticosi)
				H1320	Spartina swards (Spartinion maritimae)
				H1310	Salicornia and other annuals colonising mud and sand
			overlaps with	H1130	Estuaries
		Saline lagoons	is contained within	H1150	Coastal lagoons
		Mudflats	is probably contained in	H1140	Mudflats and sandflats not covered by seawater at low tide
			overlaps with	H1130	Estuaries
				H1160	Large shallow inlets and bays
		Sheltered muddy gravels	overlaps with	H1160	Large shallow inlets and bays
				H1140	Mudflats and sandflats not covered by seawater at low tide
		Blue mussel beds on sediment	is probably contained in	H1130	Estuaries
				H1160	Large shallow inlets and bays
				H1140	Mudflats and sandflats not covered by seawater at low tide
		Peat and clay exposures with piddocks	is probably contained in	H1160	Large shallow inlets and bays
				H1140	Mudflats and sandflats not covered by seawater at low tide
	overlaps with	Seagrass beds	is contained in	H1140	Mudflats and sandflats not covered by seawater at low tide
				H1150	Coastal lagoons
Littoral rock	contains	Estuarine rocky habitats	is contained in	H1130	Estuaries
		Sabellaria alveolata reefs	overlaps with	H1170	Reefs
		Intertidal underboulder communities	[No equivalent or contained Annex I types]		
	overlaps with	Intertidal chalk	overlaps with	H1170	Reefs
		Other rock types (no equivalent or contained Priority Habitat types)		H8330	Submerged or partially submerged sea caves
Built up areas and gardens	contains	Open mosaic habitats on previously developed land	[No equivalent or contained Annex I types]		

Appendix 3 - Workshop

Agenda

<u>Workshop on 'Making Earth Observation work for UK habitat conservation: Phase I'</u>

15 March 2011, JNCC offices, Peterborough

Chair for the day: Mark Crick, JNCC

Reporter for the day: Jacqueline Parker, Team Projects

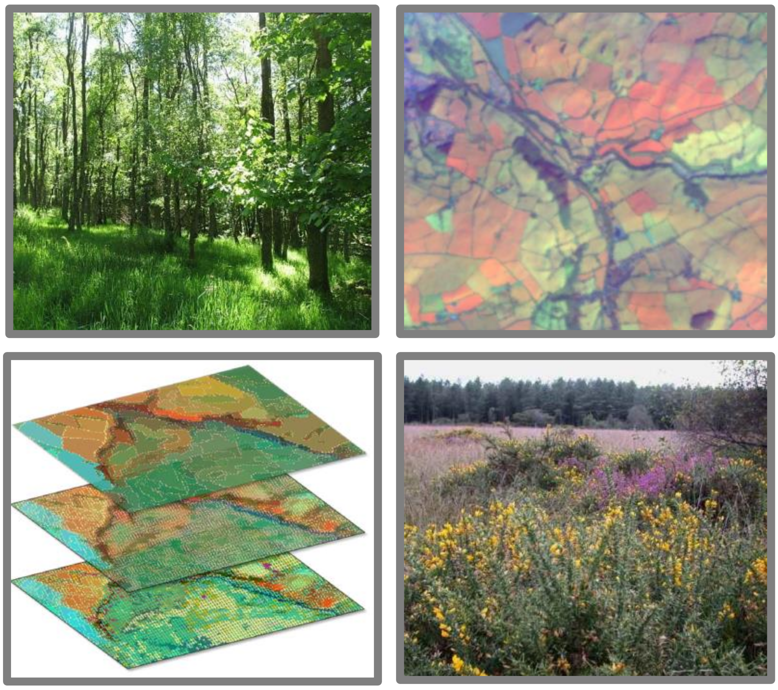
Time		Responsibility/ Speaker
10am	Arrival and coffee	
10:30am	Introduction to the day	Mark Stevenson, Defra
10:40	Background to the project	Mark Crick, JNCC
10:50	Environment Systems approach to the project	Katie Medcalf, Environment Systems
11:00-12:00	Session 1 : How do we gather habitat data now? • Results of review by Environment Systems • Split into groups for facilitated discussion	Katie Medcalf Facilitators: Liz Fox, Susan Watt, Mark Crick
12-12:45	Lunch	
12-45-13.00	Feedback from Session 1 • 5 mins per group for presenting back to all, and sumupoffindings	Jacqueline Parker
13.00 - 13:45	Session 2: How could we approach gathering habitat data differently? • Initial recommendations from Environment Systems study • Split into groups for facilitated discussion	Katie Medcalf Facilitators: Andrew Richman, Sally Johnson, Stewart Snape
13:45-14:45	Session 3: What do we need to do next to realise the potential of these techniques? • Initial suggestion of priorities from Environment Systems study • Split into groups for facilitated discussion.	Steve Keyworth Facilitators: Alan Brown, Keith Porter,MarkCrick
14:45-15:00	Tea break	
15:00-15:30	Feedback from sessions 2 and 3 • 5 mins per group per session for feedback	Summing up by Katie/ Jacqueline/ Nicki Turton, Environment Systems
15:30-15:50	Where next? • Wider discussion session - opportunity for delegates to identify what they think has been missed or overlooked in the study.	Mark Crick
15:50-16:00	Concluding remarks • Whatwillhappenaftertodayandintonext FY	Mark Stevenson/ Mark Crick

List of delegates

Alan Brown	CCW
Annelie Mattisson	SNH
Andrew Richman	EA
Susan Watt	SNH
Graham Weaver	NE
Mark Stevenson	Defra
John Cornell	CPERC
Keith Kirby	NE
Keith Porter	NE
Liz Fox	Defra
Mark Crick	JNCC
Mark Wright	DOENI
Paul Robinson	JNCC
Stewart Snape	FC
Sally Johnson	SNH
Linda Birkin	JNCC
Steve Keyworth	ES
Katie Medcalf	ES
Jacqueline Parker	Team projects
Nicki Turton	ES

Making Earth Observation Work for UK Biodiversity Conservation – Phase 1

Part B—Annexes and technical evidence



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This Part B document supports the Part A, Final Report document compiled for JNCC and Defra. This document includes all the evidence and analysis that the main report document draws upon.

The evidence presented in this part B document, was based on a systematic assessment of current projects and follow-up structured interviews with professional staff.

The following sections are included:

- **Section 1** addresses the proposed habitat classification system based on the features that EO can detect of the vegetation
- **Section 2** looks at the policy drivers, which are underpinning the current need for improved and more efficient information collection, for habitat monitoring
- **Section 3** includes a review of relevant habitat mapping initiatives in the EU and at a global level
- **Section 4** comprises the UK habitat initiatives included in the detailed review, including both field-survey based and EO-based projects.
- **Section 5** contains the 2 briefing papers created during the project for the steering group to further information on technical issues

Section 1 - habitat classifications

1.1 - Provisional assessment of how habitats may fit into the Crick Framework

		BAP Priority habitats	Annex I habitats	
Tier 1		none	none	
Tier 2	2a	Blanket Bog	H1140	Mudflats and sandflats not covered by seawater at low tide
		Intertidal mudflats	H4030	European dry heaths
		Lowland Raised Bog	H4060	Alpine and Boreal heaths
		Upland Flushes, Fens and Swamps	H6150	Siliceous alpine and boreal grasslands
		Upland Heathland	H7110	Active raised bogs
			H7130	Blanket bogs
			H7140	Transition mires and quaking bogs.
	2b	Coastal saltmarsh	H1310	*Salicornia* and other annuals colonising mud and sand
		Coastal Vegetated Shingle	H6130	Calaminarian grasslands.
		Estuarine rocky habitats		
		Hedgerows		
		Inland Rock Outcrop and Scree Habitats		
		Lowland Heathland		
		Coastal Sand dunes		
		Seagrass beds		
	2c	Limestone Pavements	H8240	Limestone pavements
		Peat and clay exposures	H4010	Northern Atlantic wet heaths with *Erica tetralix*
		Calaminarian Grasslands	H4060	Dry Atlantic coastal heaths with Erica vagans.
			H7230	Alkaline fens
			H8110	Siliceous scree of the montane to snow levels
			H8120	Calcareous and calcshist screes
	2d	Lowland Fens	H2190	Humid dune slacks
Tier 3	3a	Arable Field Margins	H1150	Coastal lagoons
		Saline lagoons	H6510	Lowland hay meadows
		Lowland Meadows	H6520	Mountain hay meadows
		Upland Hay Meadows	H91C0	Caledonian forest
		Native Pine Woodlands		
		Coastal and Floodplain Grazing Marsh		
		Purple Moor Grass and Rush Pastures		
	3b	Mountain Heaths and Willow Scrub	H1210	Annual vegetation of drift lines
		Reedbeds	H1220	Perennial vegetation of stony banks
		Machair	H1420	Mediterranean and thermo-Atlantic halophilous scrubs
		Wet Woodland	H2110	Embryonic shifting dunes
		Wood-Pasture & Parkland	H2120	Shifting dunes along the shoreline (`white dunes`)
			H2130	* Fixed dunes with herbaceous vegetation (`grey dunes`)
			H21A0	Machairs
			H2330	Inland dunes with open *Corynephorus* and *Agrostis* grasslands
			H3160	Natural dystrophic lakes and ponds
	3c	Aquifer Fed Naturally Fluctuating Water Bodies	H3180	Turloughs
		Lowland Calcareous Grassland	H6170	Alpine and subalpine calcareous grasslands
		Lowland Dry Acid Grassland	H6210	Semi-natural dry grasslands
		Upland Calcareous Grassland	H6230	Species-rich *Nardus* grassland
			H9130	*Asperulo-Fagetum* beech forests
			H6410	*Molinia meadows.*
			H3170	Mediterranean temporary ponds
Tier 4	4a	Oligotrophic and Dystrophic Lakes	H1130	Estuaries
		Open Mosaic Habitats on Previously Developed Land	H1320	*Spartina* swards
		Traditional Orchards	H1330	Atlantic salt meadows
		Lowland Beech and Yew Woodland	H1340	Inland salt meadows
		Lowland Mixed Deciduous Woodland	H2140	* Decalcified fixed dunes with *Empetrum nigrum*
			H2150	* Atlantic decalcified fixed dunes
			H2160	Dunes with *Hippophaë rhamnoides*
			H2170	Dunes with *Salix repens*
			H2250	* Coastal dunes with *Juniperus* spp.
			H3140	Hard oligo-mesotrophic waters with *Chara* spp.
			H4020	Temperate Atlantic wet heaths with *Erica ciliaris* and *Erica tetralix*
			H4080	Sub-Arctic *Salix* spp. scrub
			H5110	*Buxus sempervirens* formations
			H5130	*Juniperus communis* formations
			H6430	Hydrophilous tall herb fringe communities
			H7120	Degraded raised bogs
			H7140	Transition mires and quaking bogs
			H7150	Depressions on peat substrates of the *Rhynchosporion*

			H7210	Calcareous fens with *Cladium mariscus*
			H7220	Petrifying springs with tufa formation
			H7240	Alpine pioneer formations
			H8210	Calcareous rocky slopes with chasmophytic vegetation
			H8220	Siliceous rocky slopes with chasmophytic vegetation
			H9180	*Tilio-Acerion* forests
			H91A0	Old sessile oak woods with *Ilex* and *Blechnum* in the British Isles
			H91E0	Alluvial forests with *Alnus glutinosa*
			H91J0	*Taxus baccata* woods of the British Isles
			H9190	Old acidophilous oak woods on sandy plains
			H6211	*Semi-natural dry grasslands - important orchid sites.*
			H91D0	*Bog woodland*
	4b	Sabellaria alveolata reefs	H1170	Reefs
		Maritime Cliff and Slopes	H1230	Vegetated sea cliffs of the Atlantic and Baltic coasts
		Intertidal chalk	H3110	Oligotrophic waters containing very few minerals of sandy plains
		Mesotrophic Lakes	H3130	Oligotrophic to mesotrophic standing waters
		Eutrophic Standing Waters	H3150	Natural eutrophic lakes
		Rivers	H3260	Water courses of plain to montane levels
		Sheltered muddy gravels	H9120	Atlantic acidophilous beech forests with *Ilex*
		Ponds	H9160	Oak-hornbeam forests
		Upland Oakwood	H1160	Large shallow inlets and bays
		Upland Birchwoods	H4020	Temperate Atlantic wet heaths with *Erica ciliaris* and *Erica tetralix*
		Blue mussel beds		
		Upland Mixed Ashwoods		
Tier 5		Intertidal underboulder communities	H8310	Caves not open to the public
			H8330	Submerged or partially submerged sea caves

1.2 - Annex I and BAP Priority Habitats

LEVEL 1		LEVEL 2		LEVEL 3	
UK BAP Broad habitat	**Relationship**	**UK BAP Priority habitats**	**Relationship**	**Annex I code**	**EC Habitats Directive Annex I habitats**
Broadleaved, mixed and yew woodland	contains	Lowland beech and yew woodland	contains	H9130	*Asperulo-Fagetum* beech forests
				H9120	Atlantic acidophilous beech forests with *Ilex* and sometimes also *Taxus* in the shrublayer (*Quercion robori-petraeae or Ilici-Fagenion*)
			overlaps with	H91J0	*Taxus baccata* woods of the British Isles
		Other broadleaf, mixed and yew woodlands	contains	H5110	Stable *Buxus sempervirens* (box) formations
		Lowland mixed deciduous woodland	contains	H9160	Sub-Atlantic and medio-European oak or oak-hornbeam forests of the *Carpinion betuli*
			may overlap with	H9180 H91E0	*Tilio-Acerion* forests of slopes, screes and ravines Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae)*
			overlaps with	H9160	Sub-Atlantic and medio-European oak or oak-hornbeam forests of the *Carpinion betuli*
				H9190	Old acidophilous oak woods with *Quercus robur* on sandy plains
		Upland birchwoods	may overlap with	H91A0	Old sessile oak woods with *Ilex* and *Blechnum* in the British Isles
		Upland mixed ashwoods	overlaps with	H9180	*Tilio-Acerion* forests of slopes, screes and ravines
				H8240	Limestone pavements
				H91J0	*Taxus baccata* woods of the British Isles
		Upland oakwood	is probably equal to	H91A0	Old sessile oak woods with *Ilex* and *Blechnum* in the British Isles
			overlaps with	H91D0	Bog woodland
		Wet woodland	contains	H91E0	Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae)*
				H91D0	Bog woodland
				Other wet woodland (no equivalent or contained Annex I type)	
	partially contains	Lowland wood-pastures and parkland	overlaps with	H9160	Sub-Atlantic and medio-European oak or oak-hornbeam forests of the *Carpinion betuli*
				H9190	Old acidophilous oak woods with *Quercus robur* on sandy plains
		Traditional orchards	is partially contained in	H6210	semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*).
Coniferous woodland	contains	Native pinewoods	contains	H91C0	Caledonian forest
			overlaps with	H91D0	Bog woodland
Boundary and linear features	contains	Ancient and/or species rich hedgerows	No equivalent or contained Annex I types		
Arable and horticultural	contains	Cereal field margins	No equivalent or contained Annex I types		
Improved grassland	contains	Coastal and floodplain grazing marsh	overlaps with	H6510	Lowland hay meadows (*Alopecurus pratensis, Sanguisorba officinalis)*
			overlaps with	H6410	*Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*)
	contains	Other improved grassland [no equivalent or contained Priority Habitat or Annex I types]			
Neutral grassland	contains	Lowland meadows	contains	H6510	Lowland hay meadows (*Alopecurus pratensis, Sanguisorba officinalis)*
			contains	Other lowland meadows (no equivalent or contained Annex I types)	
		Upland hay meadow	is equal to	H6520	Mountain hay meadows
		Other neutral grassland [no equivalent or contained Priority Habitat types]		H1340	Inland salt meadows
Calcareous grassland	contains	Lowland calcareous grassland	overlaps with	H5130	*Juniperus communis* formations on heaths or calcareous grasslands
			overlaps with	H6210	Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*)
				H6211	Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (important orchid sites)
		Upland calcareous grassland	overlaps with	H6210	Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*)
				H6230	Species-rich *Nardus* grassland, on siliceous substrates in mountain areas (and submountain areas in continental Europe)
			contains	H6170	Alpine and subalpine calcareous grasslands
				H5130	*Juniperus communis* formations on heaths or calcareous grasslands
Acid grassland	contains	Lowland dry acid grassland	contains	H2330	Inland dunes with open *Corynephorus* and *Agrostis* grasslands

Fen, marsh and swamp	contains	Upland fens, flushes and swamps	contains	H7240	Alpine pioneer formations of the *Caricion bicoloris-atrofuscae*
			overlaps with	H7140	Transition mires and quaking bogs
				H7220	Petrifying springs with tufa formation (*Cratoneurion*)
		Lowland fens	contains	H7210	Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*
				H7230	Alkaline fens
			overlaps with	H7220	Petrifying springs with tufa formation (*Cratoneurion*)
				Other springs [no equivalent or contained Annex I types]	
		Purple moor grass and rush pasture	contains	H6410	*Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*)
			overlaps with	H6510	Lowland hay meadows (Alopecurus pratensis, Sanguisorba officinalis)
			contains	Other purple moor-grass and rush pastures [no equivalent or contained Annex I types]	
		Reedbeds	[No equivalent or contained Annex I types]		
Bogs	contains	Blanket bog	contains	H7130	Blanket bog
			overlaps with	H7140	Transition mires and quaking bogs
				H7150	Depressions on peat substrates of the *Rhynchosporion*
		Lowland raised bog	contains	H7110	Active raised bogs
				H7120	Degraded raised bogs still capable of natural regeneration
			contains	Other lowland raised bogs [no equivalent or contained Annex I types]	
			overlaps with	H7150	Depressions on peat substrates of the *Rhynchosporion*
		Other bog types (no equivalent or contained Priority Habitat types)		H7140	Transition mires and quaking bogs
Dwarf shrub heath	contains	Lowland heathland	contains	H4020	Temperate Atlantic wet heaths with *Erica ciliaris* and *Erica tetralix*
				H4040	Dry Atlantic coastal heaths with *Erica vagans*
			overlaps with	H7150	Depressions on peat substrates of the *Rhynchosporion*
				H4010	Northern Atlantic wet heaths with *Erica tetralix*
				H5130	*Juniperus communis* formations on heaths or calcareous grasslands
				H4030	European dry heaths
		Upland heathland	overlaps with	H4010	Northern Atlantic wet heaths with *Erica tetralix*
				H5130	*Juniperus communis* formations on heaths or calcareous grasslands
				H4030	European dry heaths
Montane habitats	contains	Mountain heaths and willow scrub	contains	H4060	Alpine and Boreal heaths
				H6150	Siliceous alpine and boreal grasslands
				H4080	Sub-Arctic *Salix* spp. Scrub
Standing open water and canals	contains	Aquifer fed naturally fluctuating water bodies	contains	H3180	Turloughs
			overlaps with	H3150	Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation
		Eutrophic standing waters	contains	H3150	Natural eutrophic lakes with *Magnopotamion* or Hydrocharition-type vegetation
			overlaps with	H3140	Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.
		Mesotrophic lakes	overlaps with	H3140	Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.
				H3130	Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*
		Oligotrophic and dystrophic lakes	contains	H3160	Natural dystrophic lakes and ponds
			overlaps with	H3110	Oligotrophic waters containing very few minerals of sandy plains: *Littorelletalia uniflorae*
				H3140	Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.
				H3130	Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*
		Ponds	contains	H3170	Mediterranean temporary ponds
			overlaps with	H3110	Oligotrophic waters containing very few minerals of sandy plains: *Littorelletalia uniflorae*
				H3130	Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*
				H3140	Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp
				H3150	Natural eutrophic lakes with *Magnopotamion* or Hydrocharition-type vegetation
				H3160	Natural dystrophic lakes and ponds
Rivers and streams	contains	Rivers	contains	H3260	Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation
Inland rock	contains	Limestone pavements	is equal to	H8240	Limestone pavements
		Calaminarian grasslands	is equal to	H6130	Calaminarian grasslands of the *Violetalia calaminariae*
		Inland rock outcrop and scree habitats	contains	H8220	Siliceous rocky slopes with chasmophytic vegetation
				H8210	Calcareous rocky slopes with chasmophytic vegetation
				H8110	Siliceous scree of the montane to snow levels (*Androsacetalia alpinae and Galeopsietalia ladani)*
				H8120	Calcareous and calcshist screes of the montane to alpine levels (*Thlaspietea rotundifolii*)

				H6430	Hydrophilous tall herb communities
		Other rock types (no equivalent or contained Priority Habitat types)		H8310	Caves not open to the public
Supralittoral rock	contains	Maritime cliff and slope	is equal to	H1230	Vegetated sea cliffs of the Atlantic and Baltic coasts
Supralittoral sediment	contains	Coastal sand dunes	contains	H2250	Coastal dunes with *Juniperus* spp.
				H2190	Humid dune slacks
				H2170	Dunes with *Salix repens* ssp. *argentea* (*Salicion arenariae*)
				H2160	Dunes with Hippophae rhamnoides
				H2150	Atlantic decalcified fixed dunes (*Calluno-Ulicetea*)
				H2140	Decalcified fixed dunes with *Empetrum nigrum*
				H2130	Fixed dunes with herbaceous vegetation ("grey dunes")
				H2120	Shifting dunes along the shoreline with *Ammophila arenaria* ("white dunes")
				H2110	Embryonic shifting dunes
		Coastal vegetated shingle	contains	H1220	Perennial vegetation of stony banks
				H1210	Annual vegetation of drift lines
		Machair	is equal to	H21A0	Machair
Littoral sediment	contains	Coastal saltmarsh	contains	H1330	Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)
				H1420	Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosi*)
				H1320	*Spartina* swards (*Spartinion maritimae*)
				H1310	*Salicornia* and other annuals colonising mud and sand
			overlaps with	H1130	Estuaries
		Saline lagoons	is contained within	H1150	Coastal lagoons
		Mudflats	is probably contained in	H1140	Mudflats and sandflats not covered by seawater at low tide
			overlaps with	H1130	Estuaries
				H1160	Large shallow inlets and bays
		Sheltered muddy gravels	overlaps with	H1160	Large shallow inlets and bays
				H1140	Mudflats and sandflats not covered by seawater at low tide
		Blue mussel beds on sediment	is probably contained in	H1130	Estuaries
				H1160	Large shallow inlets and bays
				H1140	Mudflats and sandflats not covered by seawater at low tide
		Peat and clay exposures with piddocks	is probably contained in	H1160	Large shallow inlets and bays
				H1140	Mudflats and sandflats not covered by seawater at low tide
	overlaps with	Seagrass beds	is contained in	H1140	Mudflats and sandflats not covered by seawater at low tide
				H1150	Coastal lagoons
Littoral rock	contains	Estuarine rocky habitats	is contained in	H1130	Estuaries
		Sabellaria alveolata reefs	overlaps with	H1170	Reefs
		Intertidal underboulder communities	[No equivalent or contained Annex I types]		
	overlaps with	Intertidal chalk	overlaps with	H1170	Reefs
		Other rock types (no equivalent or contained Priority Habitat types)		H8330	Submerged or partially submerged sea caves
Built up areas and gardens	contains	Open mosaic habitats on previously developed land	[No equivalent or contained Annex I types]		

Section 2 - Policy drivers for surveillance and monitoring of Annex I and BAP Priority habitats

2.1 - Primary policy drivers for surveillance and monitoring of Annex I and BAP Priority habitats

Policy / legislative driver	*General description of requirements*	*Specific obligations/ actions arising as a result of the policy/directive*	*Information needs expressed in terms of surveillance and monitoring measures*	*Government bodies involved in meeting requirement*
UKBAP	Reporting rounds show how the UKBAP contributes to the UK"s progress towards the significant reduction of biodiversity loss called for by the CBD and a range of other national, European and international agreements. Habitat Action Plans (HAPs) have been produced for priority habitats identified in 1995-97. HAPS for priority habitats identified subsequently are being produced at country level. Recent work has identified the habitat requirements of all UKBAP species relevant to priority habitats in England. For species conservation to be effectively integrated into a habitat-based approach much greater emphasis needs to be placed on creating the component niches and resources required by BAP species, rather than managing habitats generically. The UKBAP advocates an ecosystem approach.	1) national <u>strategic planning</u> and <u>target setting</u> for delivery of the UK Biodiversity Action Plan. 2) assessment of the national, regional and local status of habitats for <u>reporting</u> on UK BAP (as well as contributing to reporting on EU directives and CBD targets) 3) reporting on relevant <u>indicators</u> published by the UK Biodiversity Partnership and in country biodiversity, and environment strategies 4) information to support <u>local</u> decisions on development planning, habitat management and recreation. 5) HAPs - define the habitat (in terms of constituent sub-types e.g. NVC, Annex I); identify associated habitats and species; describe its distribution and extent; identify <u>factors</u> affecting the habitat and management needs; provide objectives for management and protection; identify any barriers to achieving these. 6) development of a habitat-based approach to species management. 7) promotion of public enjoyment of wildlife and involvement in its protection, in particular to raise awareness of the most threatened habitats in the UK. 8) Identify the state of and changes to ecosystem functions and services provided by the habitats	1) ideally a digital mapped <u>inventory</u> of BAP priority habitats (**location, extent**) and information on their **condition** and scope for setting targets on restoration and **re-creation** of the habitat. Such inventories need to be of consistent quality and of a repeatable nature. 2) ideally a digital mapped <u>inventory</u> of BAP priority habitats (**location, extent**) and measures of **condition** and **change** in these. 3) for the UK indicator "Status and trends in UK BAP Priority Habitats", **extent** of habitats and measures of **condition** status. For "habitat connectivity" indicator - **location** and **extent,** taking account of surrounding habitats and **change** to both BAP and surrounding habitats. 4) ideally a digital mapped <u>inventory</u> of priority habitats (**location, extent**) and measures of **condition** relating to particular sites 5) ideally a digital mapped ~~inventory~~ of BAP priority habitats (**location, extent**) and information about its **composition** (constituent sub-habitat types e.g. NVC, Annex I) and surrounding habitats; measures of **condition** (relating to quality but also other measures of suitability for plant and animal species – e.g. structural diversity, vegetation heterogeneity, productivity, wetness) and in some contexts (uplands, coastal, woodlands) the measures of **dynamic processes** (erosion, burning). Identify suitable sites for **re-creation** of the habitat 6) as above (5) e.g. structural variation within and between habitats is often important, both because different species require different structural states and because many species rely on many different states to complete their life cycles. In wetlands, hydrology, water quality and the transitional zone between aquatic and terrestrial habitats are all critical components of priority species requirements. 7) ideally a digital mapped <u>inventory</u> of BAP priority habitats (**location, extent**) and measures of **condition** and **change** in these. 8) ideally a digital mapped <u>inventory</u> of BAP priority habitats (**location, extent**) set in the context of surrounding habitats. Because this information allows the **functionality** of the habitat to be quantified including the treats, and interactions with surrounding land use and species	The UK Biodiversity Partnership has very wide membership and for statutory bodies extends from national to local level and across various sectors. BAP implementation is largely a devolved matter led by the country administrations a nd their statutory conservation agencies.

Policy / legislative driver	General description of requirements	Specific obligations/ actions arising as a result of the policy/directive	Information needs expressed in terms of surveillance and monitoring measures	Government bodies involved in meeting requirement
EU Habitats Directive	Every six years the UK must report on measures taken and their outcome in terms of the conservation status of species and habitats listed on the Directive"s Annexes. The UK has completed two reporting rounds for the Habitats Directive, (periods 1994-2000 and 2001-2006). The first report concentrated on the process of designating SACs. The second included assessments of the conservation status of each of the habitats and species. The third report is due in 2013 and cover the period 2007-2012. It is expected to request information on the conservation measures taken by Member States.	1) designation of a network of SACs to ensure adequate protection of Annex I habitats. 2) periodic assessment of the conservation status of the habitats (both protected sites and wider countryside). 3) provision of feedback on the success of management of protected sites (conservation measures), in a form suitable for use in reviewing and modifying existing management 4) report on trends relating to the range, area and condition of all Annex 1 habitats (both protected sites and wider countryside). 5) assessment of conservation status and trends of species listed in the Directive"s annexes (protected sites and wider countryside).	1) ideally a digital mapped inventory of Annex 1 habitats (**location, extent**) to inform on designation, establish how the network of sites relate to the wider countryside and to the bio-geographic range of the habitat. 2) a range of direct or proxy measures of **condition** status that together can be used to establish whether the habitat is in favourable condition 3) **location** and **extent** of Annex 1 habitats within the individual SAC and any **change** to these. Location and extent of habitats surrounding the SAC – as contextual information to understand and help demonstrate appropriateness of management. 4) a range of direct or proxy measures of **condition** status that together can be used to establish whether the SAC is in favourable condition. 5) evidence of **change** in the **location**, **extent** or **condition** (or proxy measures of condition) of the Annex 1 habitats. 6) information on the **location**, **extent** and **condition** of Annex I habitats to inform assessment of status of particular species.	All country administrations and their statutory nature conservation agencies, JNCC, Defra.

2.2 - Other policy drivers for the surveillance and monitoring of higher priority habitats

Policy / legislative driver	*General description of requirements*	*Specific obligations/ actions arising as a result of the policy/directive*	*Information needs expressed in terms of surveillance and monitoring measures (relating to higher priority habitats)*	*Government bodies involved in meeting requirement*
SSSI /ASSIs	Sites/Areas of Special Scientific Interest (SSSIs/ASSIs); form the fundamental statutory mechanism for protecting sites of ecological interest in the UK. There are over 6000 SSSIs/ASSIs in the UK covering over 2.4million hectares. The UK has also entered into international commitments to establish a network of protected wetland sites under the Ramsar Convention (Ramsar sites). Special Protection Areas (which protect the habitats of migratory birds) and Special Areas of Conservation (SACs) are required to be established under the EC Birds and Habitats Directives respectively. Together these sites are known as Natura 2000 sites. In many cases, the same area of land is protected by more than one designation; the basic building block is the SSSI or ASSI, which underpins the vast majority of the international site designations. The basis of the common standards for site monitoring is that those special features for which the site was designated are assessed to determine whether they are in a satisfactory condition. The nature conservation component which is assessed is therefore not the site itself, but the feature (e.g. habitat, species, or earth science feature) for which it was designated. Sites may have one, two, or several interest features on them.	1) Identify key attributes of the feature are set targets set for each. Each attribute is then measured and compared against the target value set (a condition assessment). If all the targets are met, the feature is in favorable condition. 2) Human activities and other factors which are likely to be affecting the site adversely, and the conservation measures taken to maintain or restore the site, are also recorded.	1) For each individual site, information on the **location**, **extent**, and **condition** (quality as assessed by recording a range of specific measures of attributes) and **supporting processes** of habitat(s) or species for which site designated (usually NVC types) and any **change** to these. 2) Presence, location and extent of these activities and factors.	JNCC and the SNCOs

Policy / legislative driver	*General description of requirements*	*Specific obligations/ actions arising as a result of the policy/directive*	*Information needs expressed in terms of surveillance and monitoring measures (relating to higher priority habitats)*	*Government bodies involved in meeting requirement*
UK and country level environmental frameworks	The UK NEA has been set up to give new information on the changing natural environment in terms of our countries existing ecosystems and the diverse range of services that they provide to people. Both the UK and country governments have as strong themes in their approach to this legislation: • developing a stronger evidence base for our ecosystems • valuing ecosystems • updating regulatory and management approaches • and redesigning partnership mechanisms with stakeholders The frameworks objective are to secure sustainable and integrated management of land and water by making the long-term health of ecosystems, and the goods and services they provide, central to decision making aiming to ensure the natural and cultural capital assets are maintained.	Each of the countries framework is at a slightly different stage and has its own characteristics and emphasis, However they will all be subject to public consultation and targets to be set will be in line with the emerging thought at the end of the processes.	These new approaches need to be underpinned by science, monitoring and information. There is considerable scope for increasing the level of monitoring of the environment through the introduction of technology like GIS and remote sensing (e.g. earth observation).	Various
Non-statutory site protection	There a large number of surviving patches of important wildlife habitat scattered across England outside of SSSIs. Local authorities often adopt sites that are important to local wildlife. These may be called Local Wildlife or Geological Sites, County Wildlife Sites, Sites of Importance for Nature Conservation, Sites of Biological Interest or other names. These are often in brownfield and urban areas. There is a recognised need to take steps to improve the protection and management of these remaining wildlife habitats (JNCC, 2010). Protection is usually best achieved through incentive based mechanisms, such as the agri-environment schemes, but at times may require designation. Whilst local authority site designation does not provide statutory protection, it is taken into account in the planning process.		Ideally a digital mapped inventory on the **location** and **extent** of semi-natural habitats, including higher priority habitats and the **condition** of these expressed in terms of BAP priority habitats, Annex I habitats or classifications that are referable to these (Phase 1, NVC).	Local Authorities
Water Framework Directive	The WFD commits EU member states to achieve good ecological status of all water bodies by 2015 through river basin planning, management and monitoring. This includes surface freshwaters (including lakes, streams and rivers), groundwater, ecosystems such as some wetlands that depend on groundwater, estuaries and coastal waters. Integral to the delivery of the Directive is creating better habitats for wildlife that lives in and around water. Current activity has focused on classifying water bodies and assessing risks. River Habitat Surveys provide information to meet aspects of WFD reporting on quality of water bodies.	1) report on river basin planning, management and monitoring by 2015 2) River Habitat Survey (RHS) is used to assess the physical character of river habitats that are important to a wide range of invertebrates and other animals. This generic monitoring program looks at the health, condition and threats to rivers. RHS methodology has been in use since 1994 with data on almost 20,000 surveys held to date	We consider that the following information would assist with delivering these requirements but it is not known whether these have been identified as an explicit requirement. **1)** maps of the **location** and **extent** of all habitats, incl. higher priority habitats within river basins. Any **change** in these. 2) maps of the **location, extent** and **condition** of all habitats within the natural range of the wildlife species of interest and any **change** in these.	Environment Agency
Agri-environment schemes	Agri-environment schemes, implemented and funded under country Rural Development Plans, are a primary means of targeting and promoting environmentally sensitive land management in the countryside throughout the UK. Separate schemes operate in each country but all have elements that target "higher level" habitats and that aim to deliver significant environmental benefits in high priority situations and areas. AE schemes are a key delivery mechanism for management of higher priority habitats outwith protected areas.	1) target uptake of agreements to land of high nature conservation value 2) monitor environmental outcomes of the scheme	1) **Location** of habitats of high conservation value 2)Information on **location** and **condition** of habitats to inform sampling for monitoring programme. 3) **change** in **extent** and **condition** of habitats on both agreement and non-agreement land to inform on scheme success	Devolved Government

Policy / legislative driver	*General description of requirements*	*Specific obligations/ actions arising as a result of the policy/directive*	*Information needs expressed in terms of surveillance and monitoring measures (relating to higher priority habitats)*	*Government bodies involved in meeting requirement*
National Ecosystem Assessment	The UK National Ecosystem Assessment was commissioned in 2010 and will provide the first analysis of the UK"s natural environment in terms of the benefits it provides to society and future economic prosperity. Covering terrestrial, freshwater and marine ecosystems, the assessment will create a compelling and easily understood explanation of the state and value of the UK"s changing natural environment and ecosystem services	1) assess the **status** and **trends** of the UK"s ecosystems and the services they provide at multiple spatial scales from country to catchment levels. 2) describe the key factors (drivers of change) affecting the UK"s ecosystems, including changes in land-use, infrastructure development, pollution and climate change 3) include plausible futures for the UK"s ecosystems and the services they provide 4) outline society's options to secure continued delivery of the UK"s ecosystem services 5) value the contribution of ecosystem services to human	Will mainly involve producing a synthesis of available information. Information on the **location**, **extent** and **condition** of UK"s higher priority habitats. **Changes** to these habitats will be needed to be recorded to give a contextual basis for the range of assessments to be undertaken.	
Strategic and local planning	Development plans and planning controls afford protection to sites with both statutory and non-statutory designations. Current national policy and guidance are set out in a range of documents and increasingly these have facilitated the delivery of ecological enhancement through the planning system. Combined with the local initiatives, such as the preparation of Local Biodiversity Action Plans these instruments provide the tools for a planning authority to achieve meaningful ecological gain within their area. Strategic Environmental Assessment (SEA) should ensure that plans and programmes take into consideration the environmental effects they cause and includes a requirement to avoid or mitigate any potentially adverse impacts on the site and monitor their impacts. Strategic Environmental Assessment Directive is intended to integrate environmental considerations into strategic decision-making. The EIA Directive requires Member States to assess the significant environmental effects of certain public and private projects, by carrying out an Environmental Impact Assessment (EIA). EIA is mandatory for the projects listed under Annex I of the Directive and discretionary for projects listed under Annex II. Special attention is directed at EIA in environmentally sensitive locations. A Shoreline Management Plan (SMP) is a large-scale assessment of the risks associated with coastal processes and helps reduce these risks to people and the developed, historic and natural environments. Coastal processes include tidal patterns, wave height, wave direction and the movement of beach and seabed materials.	1) Carry out SEAs of e.g. regional and local, development, waste and transport plans and EIAs of projects. 2) Produce local development plans 3) Produce shoreline management plans 4) Implement planning controls, mitigating any potentially adverse impacts as necessary 5) Monitor impacts 4) Seek opportunities and deliver environmental gains 5) Manage and monitor LA sites	Ideally a digital mapped inventory on the **location** and **extent** of semi-natural habitats, including higher priority habitats and the **condition** of these.	Various Departments and agencies, Local Authorities

Section 3 - Global and European habitat mapping work

Name	Country	Motivation	Data used	Techniques	Reference
Global Land Cover (GLC2000)	Global	Production of global land cover map	SPOT/VEGETATION from 2000	26 classes (mapped into seven categories identified on the basis of forest management and global change science requirements. Application of unsupervised classification algorithm ISODATA to seasonal mosaics and subsequent allocation of clusters to land cover classes.	Mayaux, P. et al. (2006), Validation of the global land cover 2000 map, *IEEE Transactions Geoscience and Remote Sensing*, 44(7), 1728 – 1739.
Global Land Cover by National Mapping Organisations (GLCNMO)	Global	Production of global land cover map	MODIS acquired over eight periods (16 day composites) in 2003 trained for supervised classification using Landsat imagery, MODIS NDVI seasonal change patterns and other data sources.	20 classes; 14 derived by supervised classification and six classified independently using other data sources (e.g., DMSP) relating to urban, open tree cover, mangrove, wetlands, snow/ice and inland water	R. Tateishi, Bayaer, M. A. Ghar, H. AL-BILBISI et al., (2008). A New Global Land Cover Map, GLCNMO, *Proceedings, 21st congress of the International Society for Photogrammetry and Remote Sensing (ISPRS)*, No. 21, pp 1369-1372 Beijing, China
Geoland2	Europe	Provides up-to-date cross-border harmonised geo-information at global and local scales on the changing conditions of our natural resources. Two parts – Core Mapping Services (Euroland, BioPar and SATChMo) and Core Information services.	Euroland – very high spatial resolution optical data. Continental component includes calibrated NDVI. BioPar – Bio-geophysical parameters in near-real time and off-line mode. SATChMo - medium to high resolution.	Euroland: Local Component – information on land use for urban agglomerations. 19 Thematic classes, with a minimum mapping unit of 0.25ha for urban classes and 1 ha for non-urban classes. Continental Component – 5 high resolution quantitative thematic land cover parameters and a HR change layer with information on impervious areas, forests, grasslands, wetlands and small water bodies. BioPar – Variables which describe the continental vegetation state, the surface radiation budget and the water cycle. SATChMo – uses algorithms. VHR/HR Area frame sampling over permanent samples representative for all European and African environmental/ecological conditions. Forest Monitoring (Core information Service) – Information will be represented in a high-resolution forest layer with a 1 ha minimum mapping unit, containing information on forest area by type and area change.	http://www.gmes-geoland.info/project-background/project-tasks/core-information-services.html
CORINE Land Cover	Europe	To provide a harmonized single map of land cover for Europe. Editions for 1990, 2000 and 2006 and is based on interpretation of satellite images. MMU of 25 m.	Primarily Landsat sensor data	The CORINE nomenclature is hierarchical and has five classes in level 1: artificial surfaces, agricultural areas, forest and semi-natural areas, wetlands and water bodies. These are subdivided to 15 classes in level 2 and 44 classes in level 3. Classes not always appropriate for stakeholders needs at regional and local scales because of their development at the European scale.	http://www.eea.europa.eu/publications/COR0-landcover

European Landscape Map (LANMAP)	Europe	A result of an initiative started at Alterra in 2002 to produce a pan-European landscape classification which aims to provide a new hierarchical European Landscape Classification that can be used as a framework for indicator reporting and environmental sampling.	High resolution optical data.	Segmentation and classification, with four hierarchical levels that use also digital data on climate, altitude, permanent material and land use; 350 landscape types are identified with a minimum mapping unit of 11 km^2.	Caspar A. Mücher, Jan A. Klijn, Dirk M. Wascher and Joop H.J. Schaminée (2010). *Ecological Indicators*, 10(1), 87-103.
SIOSE	Spain	Aims to produce a land cover/land use database for Spain that is periodically updated for national and regional administrations. Nominal scale of 1:25,000 and a MMU ranging from 0.5 to 2 ha depending on the land cover. Currently underway with aim to provide repeat national coverage.	Multi-resolution and temporal data (e.g., SPOT-5) Reference topographic data: BCN (hydrography, roads, railway network), Cadastre (urban limits, street axes), Agricultural (National Crop Map -MCA) and Forest (National Forest Map - MFE) thematic data. Thematic LC/LU databases in the Spanish Autonomous Communities	Integration of reference topographic data to build the spatial base skeleton. Automated aerial photography interpretation API using SPOT 5 followed by manual API.	Valcarcel, N., Villa, G., Arozarena, A., Garcia-Asensio, L., Caballlero, M., Porcuna, A., Domenech, E., Peces, J., SIOSE, A successful test bench towards harmonization and integration of Land Cover/ Use information as environmental reference data. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. Vol. XXXVII. Part B8. Beijing 2008
DeCover	Germany	DeCOVER 2 seen as a national extension to the GMES activities providing LULC information services to decision makers at different scales and supports the current German appaoch to establish a national harmonized digital landscape model (DLDME). First implementation of DeCover Core Service to start in July 2010 for validation in 2011.	RapidEYE 5m RGB NIR TerraSAR-x The DLMDE is based on the topographic reference data model ATKIS/Basis-DLM© using remote sensing information	Multi-temporal satellite data used to detect changes based on existing reference geometries. In addition to the DeCOVER Core Service, thematic services related to agricultural and environmental monitoring needs are to be developed and demonstrated on selected test sites To provide the support for GMES and national LULC initiatives, a multistep change detection process chain is being developed and demonstrated over selected test sites in Germany.	http://www.decover.info
COS2007	Portugal	To produce a Land Use and Land Cover Map of Continental Portugal for 2007 (COS2007) based on visual interpretation of aerial photography with the use of some seasonal satellite imagery. Aimed to provide a large scale map product with a high level of thematic and positional accuracy, harmonised with global and European policies, but capable of addressing interests and	Orhtorectied digital aerial images for 2007 (RGB and NIR) at 50 m spatial resolution. AWiFS spring and summer images.	Visual interpretation of aerial photography assisted through reference to AWiFs. Up to 193 classes at five hierarchical classification levels, with the first three in line with the nomenclature of the CORINE Land Cover MMU of 1 ha	Caetano, M., Nunes, V. and Pereira, M. Land use and land cover map of continental Portugal for 2007 (COS:2007): Project presentation and technical specifications development. *Proceedings, 3rd Workshop of the EARSeL Special Interest Group on Land Use / Land Cover*, CD.

		needs of Portuguese users.			
HABISTAT	Europe	Undertaken by Belgian and Dutch research teams and focusing on how remote sensing techniques could be used for Natura 2000 habitats monitoring, with a pilot study on heathlands.	Range of specialised platforms (e.g., hyperspectral, Chris-Proba).	Semi-automated monitoring with focus on mapping recent distributions with uncertainty of < 20 %. Focus on classification using advanced remote sensing technologies; focus understanding variability of biophysical parameters and how these can be retrieved. Multi-scale and temporal approach.	http://habistat.vgt.vito.be/
EPA rule-based mapping	Ireland	To provide detailed maps of habitats for Ireland.	Medium spatial resolution optical satellite data	Rule-based classification.	Keyworth, S., Jarman, M., and Medcalf, K., 2009, Provision of assistance to the Environmental Protection Agency in establishing suitability of rule-based feature extraction and classification processing methods to a habitat mapping solution for a study area in Ireland. Rule-Based Method Assessment for the EPA
MEDWET	Mediterranean wetlands	Seeks to halt the loss and degradation of Mediterranean wetlands which is undertaken within the Ramsar Convention on Wetlands. A forum of 27 Mediterranean countries, specialised wetland centres and international environmental organisations. Inventory, assessment and monitoring of Mediterranean wetlands	No direct use of remote sensing data indicated.		http://www.medwet.org/
Global Observation Research Initiative in Alpine Environments (GLORIA)	Alpine environments	To establish a long-term observation network to obtain standardised data on alpine biodiversity and vegetation patterns on a global scale. Its purpose is to assess risks of biodiversity losses and the vulnerability of high mountain ecosystems under climate change pressures.	No direct use of remote sensing data indicated.	Field based technique of looking at several summits within each target region, which are characteristic of the area to monitor change in biota in a standardised sampling design in the summit region.	http://www.gloria.ac.at/
NILS	Sweden	To generate habitat mapping for Sweden	CIR air photography External databases such as watercourses, roads and houses. 631 sample units across Sweden, 20% sampled each year in a 5-year cycle. A 1 km^2 patch is air photo interpreted and each contains 12 circular	Development of rule base with dichotomous key for API to make the polygon delineation as interpreter-independent as possible. A total of 67 variables are estimated for each delineated polygon.	Stahl, G., Allard, A., Esseen, P., Glimskar, A., Ringvall, A., Svensson, J., Sundquist, S., Christensen, P., Torell, A., Hogstrom, M., Lagerqvist, K., Marklund, L., Nilsson, B., Inghe, O., *2011*, National Inventory of Landscapes in Sweden (NILS) - scope, design, and experiences from establishing a multiscale biodiversity monitoring system, *Environ. Monit. Assess.* **173**, pp. 579-595

			field sample points and 12 transects		
Biosphere reserve of Terras do Mino case study	NW of the Iberian peninsula	To monitor change in the landscape over 12 years (1990-2002) to establish the impact of the European agricultural policy.	Landsat TM (July 1990), Landsat ETM+ (August 2002), DEM, slope, proximity to rivers, contrast, NDVI, NDII, MLC algorithm	Classification of Landsat data into an ecological system based on EUNIS, CORINE with a sub-regional classificatory system built on ecological units. 15 types of ecological unit defined in 2002, 13 in 1990. Classification of landscape pattern change indicators: dominance, contagion, fragmentation, patch type diversity and complexity of patch shape.	Martinez, S., Ramil, P. and Chuvieco, E., *2010*, Monitoring loss of biodiversity in cultural landscapes. New methodology based on satellite data. *Landscape and Urban Planning* **94** pp.127-140.
The European Biodiversity Observation Network (EBONE)		An EU FP7 project that provides the European contribution on terrestrial monitoring to the Group on Earth Observations Biodiversity Observation Network (GEO BON). Aims to develop a cost effective system of biodiversity data collection at regional, national and European levels. To develop a coherent data collection and distribution system for internationally comparable and coordinated assessments and to support the CBD and European SEBI indicators. To establish a common habitat classification system and to qualitatively compare in-situ and remote sensing data.	Reference primarily to optical remote sensing data	Rule base for translating EBONE output into Annex I habitats.	Bunce, R., Bogers, M., and Evans, D., 2010, *European Biodiversity Observation Network Design of a plan for an integrated biodiversity observing system*. D 4.2 Rule based system for Annex I habitats EBONE-D4.2-2.6
CLC2006 Finland	Finland	To provide land cover maps for Finland.	IRS P6 LISS 2006 Spot 4/5 LANDSAT 7 ETM 2000 Finnish LPIS Orthophotos Vegetation zones Topographic data Building and dwelling database Finnish National Forest Inventory	Spring and summer imagery are resampled to 20 m spatial resolution, a dichotomous key is used for classification and manual digitising is used for areas not automatically classified. Automated interpretation of satellite images and data integration with existing digital map data applied. Specific classes were interpreted manually with the aid of IMAGE2006 and ancillary data. In order to detect changes between 2000 and 2006 two approaches were combined: a) Differences between high resolution land cover data sets 2000 and 2006 were evaluated together with b) the changes detected using satellite data only (i.e., IMAGE2000 and IMAGE2006).	CLC2006 Finland, Final Technical Report. Finnish Environment Institute, November 2009.
Biodiversity Multi-SOurce Monitoring	Europe	To develop tools and models for consistent multi-annual monitoring of	High and very high resolution optical remote sensing	Focus on the identification of indicators of change from remote sensing data, with classification aligned with General	www.biosos.nur.wl

System: From Space To Species (BIO-SOS)		NATURA 2000 sites and their surroundings. The emphasis of the project is on NATURA 2000 sites in the Mediterranean part of Europe, the Netherlands and the UK. The latter is a contribution to global issues as are carried out in GEO.	datasets (e.g., IKONOS, Quickbird, Worldview, SPOT HRG, Landsat), including those acquired by airborne hyperspectral sensors.	Habitat Categories.	
Multi-Scale Service for Monitoring NATURA 2000 Habitats of European Community Interest	Europe	Aims to develop a standardised monitoring system using remote sensing to observe and manage the state of NATURA 2000 sites which reflects the specifics and variety of habitats in the different bio geographical regions. The multi-scale concept reflects the specific requirements for sensitive sites-related reporting, monitoring and management. Ties in closely to GMES and INSPIRE	Remote sensing and geospatial data	Algorithm development and integration	http://cordis.europa.eu/fetch?CALLER=FP7_PROJ_EN&ACTION=D&DOC=49&CAT=PROJ&QUERY=012ae733e531:be09:04e5b01e&RCN=96950 http://www.vito.be/VITO/EN/HomepageAdmin/Home/WetenschappelijkOnderzoek/Aardobservatie/Ms.Monina.htm

Section 4 - UK habitat mapping method analysis

4.1 - SWOT tables

		SWOT	
1. SNH Coastal Vegetated Shingle Inventory	Draft interim report detailing the current progress and method for developing a shingle inventory for Scotland using pre-existing surveys, aerial photography, and base mapping as support material for field visits, which will feed back into the API procedure.	**Strengths:** 1. uses a combination of boundary delineation by API and ground validation with any queries from the API addressed, and the field validation feeding back into the API. 2. Field validation spread around 4 different geographical zones to account for common issues from the API which are regionally based.	**Weaknesses:** 1. Little information given about the consistency of the imagery 2. Only the sites which have had field visit have any idea of how well the API has picked up the habitat.
		Opportunities: 1. Testing the limits of API of vegetated shingle 2. Compilation of a robust baseline of shingle habitats will allow for a better ability to monitor and determine trends within areas of the habitat.	**Threats:** 1. Availability of funding to complete the field survey. 2. Acquiring imagery data that is consistently from the same time of year.

		SWOT	
2. NE Coastal Vegetated Shingle work	Series of work over approximately a decade, initially pulling together all the previous survey material and updating the information with aerial photography and rules for subsequent digitising and fieldwork.	**Strengths:** 1. Inventory has been compiled over 10 years so issues have been encountered and overcome. 2. The inventory is considered to be a good indication of location of all patches of shingle over 0.1ha. 3. The work has drawn from many different sources and methods to determine a proposed data capture and mapping protocol for this habitat. 4. as it has used pre-existing survey data it has been a fairly effective use of current resources to improve the inventory product.	**Weaknesses:** 1. Information has come from a range of disparate sources and then compared to air photography from several years later, so errors may have crept in. 2. The 2007 inventory did not include any additional ground-truthing 3. Manual digitising and checking of the polygons against the air photos and master map is time consuming 4. This has provided a snapshot of the current resource with no indication of trends and system dynamics
		Opportunities: 1. Baseline dataset allows change to be established and quantified 2. Specification for information collection and digitisation allows for new information to be seamlessly integrated into the current dataset 3. Areas where there were discrepancies have been flagged for checking therefore targeting the field survey	**Threats:** 1. Shingle is a dynamic environment which cannot be picked up by a snapshot of an inventory so trends and processes could be missed

		SWOT	
3. NE Maritime Cliff and slope inventory 2004/5	This work aimed to continue the earlier inventory work, by assessing subsequent surveys against the survey, digitisation and attribution standards set out in the earlier work. This work specifically looks at identifying soft cliff habitats.	**Strengths:** 1. Uses pre-existing resources 2. Sets out specifications for standard digitisation criteria of cliff surveys which have been tested and evolved	**Weaknesses:** 1. The original specifications were not followed in the subsequent survey work 2. There is limited knowledge on the exact extent of soft cliff habitats 3. There is no clear way to map extent and condition of cliff habitats due to their 3D nature.
		Opportunities: 1. Specifications for standardisation of survey techniques and digitisation allow for new data to seamlessly be incorporated into the pre-existing data	**Threats:** 1. Cliff habitats are difficult to access due to health and safety and the often fragile nature of the cliffs, therefore visiting them can degrade the habitat. 2. Dataset is not very robust as it is formed from such a number of disparate surveys with different scales and classifications.

<table>
<tr><td rowspan="3">4. Validation of Upland Hay Meadows, lowland Meadows and Purple Moor-Grass & Rush Pastures Habitat Inventories in parts of North West England in 2010</td><td rowspan="3">This project's a field validation of 193 sites - mostly identified from modelling work on the BAP priority grassland habitats where certainty of the habitat was low. They were located in specific areas of North Lancashire and Cumbria. The project mostly focused on upland hay meadow but also looked at a few sites of lowland meadow and purple moor grass & rush pasture. Due to cutting & access issues, a large number of roadside verges were included in the selected sites.</td><td colspan="2">SWOT</td></tr>
<tr><td>Strengths:
1. Field description gives the most detailed evaluation possibly</td><td>Weakness:
1. It is easy for field recorders to be ambiguous with their recording which means that the data is then impossible to analysis statistically</td></tr>
<tr><td>Opportunities:
1. Some fusion between field survey and remote sensing to target field effort would be very useful</td><td>Threats:
1. Very costly and only a very small number of sites have been considered</td></tr>
</table>

<table>
<tr><td rowspan="3">6. Saltmarsh work in England</td><td rowspan="3">It has created a complete saltmarsh inventory for England and Wales from 3 sets of saltmarsh mapping work using air photography in a range of techniques from manual interpretation through to automated segmentation and classification. It looked at using the 1989 saltmarsh survey data for detection of meaningful change.</td><td colspan="2">SWOT</td></tr>
<tr><td>Strengths:
1. Provides a baseline dataset for most areas of saltmarsh across England and Wales
2. As 3 funding channels were used, this spreads the cost between organisations who will benefit from the information</td><td>Weaknesses:
1. By only mapping areas of discrete vegetation individual species variation within the saltmarsh will not be picked up and likewise the extent of the pioneer species is not included.
2. As the data came from 3 different methods there is variability in the output
3. One method relied totally on expert interpretation of the air photography which can be subjective</td></tr>
<tr><td>Opportunities:
1. a robust baseline extent of discrete saltmarsh vegetation can allow determination of change in extent and potentially infer some processes information.</td><td>Threats:
1. Difficulty attaining national imagery at the same tidal state.
2. Over simplification of the mapping output to try and make the output nationally consistent.</td></tr>
</table>

<table>
<tr><td rowspan="3">7. Scotland saltmarsh survey work</td><td rowspan="3">This Saltmarsh mapping project is 1 year into a 3 year program to visit every saltmarsh site in Scotland and complete an NVC survey and CSM review. It has not been reported on yet and all comments below are from a telephone interview with Stewart Angus.</td><td colspan="2">SWOT</td></tr>
<tr><td>Strengths:
1. NVC survey goes into good enough detail to be able to determine Annex I categories
2. Combination of habitat mapping and CSM for every site allows a greater suite of information and view of the situation including processes to be attained</td><td>Weaknesses:
1. Field survey is time consuming
2. Field survey has an element of subjectivity
3. Sites will be visited at varying times of the year therefore not necessarily comparing like with like</td></tr>
<tr><td>Opportunities:
1. Will provide a baseline dataset which has all been collected within a 3 year window using the same methodology which will allow for change to be determined</td><td>Threats:
1. some areas are potentially difficult to reach or damaging to the habitat to reach, therefore may have difficulty in species determination</td></tr>
</table>

<table>
<tr><td rowspan="3">11. Welsh Phase 1 mapping</td><td rowspan="3">The Wales Habitat Inventory project is a Wales-wide inventory of Phase 1 Habitat types designed for viewing at c.1:25,000 scale. BAP and Annex I habitats are only considered where they match Phase 1 Habitat types. The project is designed to operate as a baseline to further monitor change and will ultimately be compared to the 1990's field based Phase 1 Habitat mapping. A novel approach has been designed and implemented in upland and lowland habitat areas where fuzzy membership has been used to indicate spatial variation and ecotones. Some features with hard boundaries have been mapped as Boolean classes.</td><td colspan="2">SWOT</td></tr>
<tr><td>Strengths:
1. Good potential to scale up from objects to sub-habitats and to habitats of interest (BAP, Annex I).
2. Technique development operational.
3. Known to accommodate regional variations in habitat characteristics.
4. Flexible model allows re-iterations of processing building on knowledge to improve mapping accuracy.</td><td>Weaknesses:
1.Time and knowledge needed to develop new rule-base for Annex 1 and BAP PHs.</td></tr>
<tr><td>Opportunities:
1. Scale of current work (all Wales) suggests method transferable.
2. May be opportunities to adapt current rule base.</td><td>Threats:
1. Knowledge transfer.
2. Users not familiar with concept of fluid mapping - where update is an inherent characteristic of the map.
3. Sufficient in-house knowledge for agencies to replicate.</td></tr>
</table>

12. Tweed catchment Phase 1 from aerial photography	The Tweed catchment was mapped predominantly using aerial photography. Automated segmentation and semi-automatic classification techniques were used to produce a phase 1 habitat map, which was later used for habitat network analysis.	**SWOT**	
		Strengths: 1. Technique gives high quality of ecological classification. 2. Maintained by volunteers and local wildlife centre	**Weaknesses:** 1. Inconsistency in habitat attribution.
		Opportunities: 1. Can easily be transferred to other areas on other scales.	**Threats:** 1. Reliant on high resolution imagery and skilled ecologists. 2. Inconsistency in the imagery

13. Developing Inventories of Upland BAP and Annex I habitats in Scotland	Interim report looking at using a knowledge and rule-base to pull together existing habitat data and modelling the likelihood of the presence of BAP and Annex I habitats in the Uplands of Scotland.	**SWOT**	
		Strengths: 1. Uses existing data sets, hence the inventory will be generated cost effectively in comparison to alternative classification methods. 2. Uses expert knowledge. 3. Habitats with good existing inventories and specific determining features have been located well. 4. identifies areas with insufficient habitat information to target future work	**Weaknesses:** 1. Some of the historical datasets are unknown quantities in terms of quality and robustness of the method 2. Datasets captured at different scales are combined. 3. Some habitats have very limited pre-existing data so have not been able to be well modelled.
		Opportunities: 1. The provided statistical validation is supportive, 2. The scale of current work suggests the method could be transferable to other large upland regions.	**Threats:** 1. Issues combining datasets comprising different accuracies and scales.

14. Scotland Inventory of Upland BAP and Annex I habitats	Interim report on How to fill gaps in knowledge of Upland habitats in Scotland testing 3 approaches, heads up digitising, automated digitising and object-orientated rule-based approach. In the interim report there is little information on the specific approaches used within the second 2 approaches however the object based approach seems to have been the most successful and efficient method so far.	**SWOT**	
		Strengths: 1. Uses a three pronged approach to assess the relative merits of each.	**Weaknesses:** 1. Issues encountered transferring rules between bio-geographical regions
		Opportunities: 1. will potentially create a baseline upland habitat inventory, or provide a method for determining these habitats	**Threats:** 1. Cloud cover 2. Issues of availability of consist data

16. LCM 2007	Land Cover Map 2000 (LCM 2000) and the current LCM 2007 which is in production are both land cover data sets to identify broad categories of land cover type. LCM 2007 uses remote sensing analysis techniques, combining automated segmentation and a pixel based „maximum likelihood" classification based primarily on IRS satellite imagery. LCM 2007 incorporates more cartographic layers that LCM 2000 to build up a field by field picture. This is a broad scale project with a minimum mapping unit of 0.5ha there is a relationship to the Broad Priority Habitat Groups and features such as heathland that are identified which is also an Annex I habitat feature. LCM 2007 is imminently due for release.	**SWOT**	
		Strengths 1. Nationally repeated 2. Systematic	**Weaknesses** 1. The generalisation leads to features not identified. 2. It has been used for projects where more detail was required and has therefore come up against issues that it was not designed to deal with and lost a little bit of credibility.
		Opportunities 1. There is an existing set of skills and knowledge to be built upon 2. There is a strong brand associated with the product	**Threats** 1. It has a low user base in the UK because of its strategic nature 2. Lost many staff and so continuing effort is difficult to realise.

		SWOT	
17. Geomatics Group (2011) Dartmoor National Park Authority Remote Sensing Project	The project was designed specifically to assess the extent and condition of key habitat types and features of archaeological and landscape interest such as hedges, woods and below ground archaeological features. It uses a range of automated, semi-automated and manual interpretation approaches and assesses specific condition and change features of habitats within a trial area in Dartmoor using specifically flown CASI and LiDAR data.	**Strengths** 1. Very accurate data with good spatial and spectral resolution 2. Clear thinking about how the data could relate to condition of upland habitats 3. Some good ideas about how change in the extent of upland habitats can be simply described 4. Collect once use many approach for the data, spreads the cost of expensive data capture	**Weaknesses** 1. Because some of the techniques rely on expert interpretation there is a possibility for error 2. Manual visual interpretation will be time consuming over larger areas 3. Flying areas for frequent updates could be costly but should be considered against field collection
		Opportunities 1. Methods could be refined and further automated using some of the more sophisticated remote sensing techniques to give a robust repeatable method, which could be applicable over wider areas 2. Potential error arising from reliance on expert interpretation can be mitigated by the reference images and the different bands of imagery available for assessment and semi-automated methods	**Threats** 1. Difficulty and cost of flying over more extensive uplands may make the technique prohibitively expensive 2. Each upland area will require its own set of training reference data sets to ensure robustness and comparability between operatives

		SWOT	
18. Remote sensing of Dune habitats at Kenfig NNR	Mapping of Dune system habitats at the Kenfig NNR in South Wales in the late 1990s, using high resolution airborne data. Supervised classification using ground control points, to determine vegetation types solely by spectral signal.	**Strengths:** 1. Good quality air born data used 2. Young dune features are easily identified	**Weaknesses:** 1. Technique is prone to error as all the image is identified and no certainty can be placed on any of the figures
		Opportunities: 1. High resolution data is clearly suitable for this type of study 2. This project looked at the advantages of using multi channel data	**Threats:** 1. Simplistic classification techniques that rely on spectral results only and do not use hyperspectral data can give unsatisfactory outcomes and perhaps mislead people about the worth of remote sensing data.

		SWOT	
19. English Nature, the development of remote sensing techniques for marine SAC monitoring, 2003	Methods for mapping a series of intertidal habitats were tested across candidate SACs around England. Most methods used CASI, LiDAR and aerial photography with ground control points, where available. In most cases two different year sets of data was used in order to compare the method and potentially detect change. The projects had varying degrees of success.	**Strengths:** 1. a range of intertidal habitat types were evaluated and tested using 2 different classification systems 2. It was established that remote sensing was able to pick up the broad habitat type well	**Weaknesses:** 1. The classifications were only trialled at one site per habitat, therefore issues of geographic transferability were not considered.
		Opportunities: 1. This study systematically looked at a start point for using remote sensing for monitoring in SACs.	**Threats:** 1. issues were encountered through the ground survey information not being of good enough quality for comparison with the RS data. 2. have to be careful in comparing like for like seasonal imagery to get a robust change analysis

<table>
<tr><td rowspan="3">20. Remote sensing of bog surfaces JNCC</td><td rowspan="3">Three lowland raised bogs were mapped using a variety of remotely sensed imagery, bog features were identified in a maximum likelihood supervised classification. It was found that the Ikonos satellite sensor data were found to be highly suited to the task of lowland raised bog habitat classification, able to identify the major raised bog land cover classes well.</td><td colspan="2">SWOT</td></tr>
<tr><td>Strengths:
1. Technique operational and widely used. Easy to implement.
2. Easily repeatable, only limited by data quality.
3. Major raised bog classes were identified well using Ikonos data.</td><td>Weaknesses:
1. Inconsistent data sets use across the three sites.
2. More advanced techniques commercially available.</td></tr>
<tr><td>Opportunities:
1. Could be applied to other sites across the UK. The use of higher resolution data which has been specifically captured for a project would greatly increase the applicability for ecological assessment purposes.</td><td>Threats:
1. The availability of suitable quality data
2. Suitably experienced users in ecology and remote sensing</td></tr>
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<table>
<tr><td rowspan="3">21. Scottish Government Peat Erosion pilot</td><td rowspan="3">This was a GIFTSS project to evaluate satellite earth observation as a cost-effective method of assessing the extent and severity of erosion in the upland organic soils of Scotland. The spatial extent of exposed peat, intact peat, vegetated bog surfaces and pools is a highly important component in regards to the potential modelling of the carbon budget of peatland and global climate change. By mapping the peat extent using object orientated rule-based approach, the risk of erosion could be established.</td><td colspan="2">SWOT</td></tr>
<tr><td>Strengths:
1. Classification rules can be driven by ecologists.
2. Incorporation of multi-temporal imagery together with ancillary data sets to improve classification. Object based classification approach.</td><td>Weaknesses:
1. Considerable time and knowledge needed to develop new rule-base.</td></tr>
<tr><td>Opportunities:
1. Mapping of peat extent leading to the modelling of this carbon store.
2. Mapping landcover in remote mountainous areas.
3. Monitor changes to landcover condition.</td><td>Threats:
1. Persistence of cloud cover may limit availability of spaceborne imagery.
2. Established but complex processing routines involving expensive preparatory software.
3. Need for aerial photography to be captured at similar dates to the spaceborne imagery.</td></tr>
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<table>
<tr><td rowspan="3">22. The application of remote sensing to identify and measure changes in the area of moorland which has been burned as part of a management system NE</td><td rowspan="3">This work occurred in 2 phases, development and implementation. It uses a semi-automated system allowing VHR imagery to pick out areas of vegetation in the uplands that have been burned as part of management practices. Originally for SSSI monitoring but also useful tool for compliance and regulation of improper burning, and then targeting restoration.</td><td colspan="2">SWOT</td></tr>
<tr><td>Strengths:
1. Improved spatial resolution to better identify illegal burning practices and for defining thresholds for prosecution.
2. Improved temporal resolution to provide a better estimation of what burning practices have occurred through time.
3. System has been designed to work with VHR satellite imagery and airborne based systems</td><td>Weaknesses:
1.Still currently only a trial, needs more work and funding to get it to an operational stage
2. Needs repeat imagery</td></tr>
<tr><td>Opportunities:
1. Reliable monitoring data may alter peoples actions with threat of penalty for inappropriate burning management
2. If data is routinely collected a better understanding of temporal dynamics can be attained through analysis and modelling.
3. Targeting bog restoration effort</td><td>Threats:
1. Cost of attaining repeat imagery</td></tr>
</table>

<table>
<tr><td rowspan="3">23. Random Forest characterization of upland vegetation and management burning from aerial imagery</td><td rowspan="3">RGB and CIR aerial photography was classified using the Random Forest ensemble machine learning algorithm. Training points from fieldwork and API were used to inform three classifications: main classification into one of 7 upland land covers, subsequent classification of the 'heather' class into one of four growth phases, and then reclassification of misclassified 'newly burnt heather' class. Classification was based on reflectance values and ratios, and misclassified areas were selected according to parameters of landscape context (e.g. % edge pixels). This facilitated subsequent multivariate analyses of the occurrence of heather management by burning. Advocated as potential monitoring tool for burning of sensitive areas/within agri-environment schemes.</td><td colspan="2">SWOT</td></tr>
<tr><td>Strengths:
1. Achieves accurate classification and mapping of upland land-covers from aerial photography
2. Classification of heather growth phases and management by burning achievable over large area and incorporating landscape context</td><td>Weaknesses:
1. Requires training points from fieldwork on the ground or API</td></tr>
<tr><td>Opportunities:
1. Could be used to monitor heather management by burning as part of monitoring of remote upland habitats, especially within agri-environment schemes or known sensitive areas
2.Repeated analyses could facilitate monitoring of change in heather management practices</td><td>Threats:
1. Failure to obtain sufficient training points from fieldwork or API would seriously hinder this approach</td></tr>
</table>

<table>
<tr><td rowspan="3">24. Integrated Assessment of Countryside Survey data to investigate Ecosystem Services in Great Britain</td><td rowspan="3">This project aims to provide a long term large scale integrated dataset which will be essential for a scientific understanding of effective management for Ecosystem Services. The method adopted is trying to demonstrate potential approaches to quantify current status and trends, understand and quantify past change in a selection of ecosystem services and uses this to understand possible futures.</td><td colspan="2">SWOT</td></tr>
<tr><td>Strengths:
1. Multi temporal.
2. UK-wide.
3. Strong statistical framework.
4. Developed with CS as a central component, correlating services spatially.
5. Analyses interactions between ecosystem service indicators e.g. quantifying and predicting in terms of Broad Habitats present in 1km.</td><td>Weaknesses:
1. Data collected at a broad 1km scale. 2. Rationale behind the specific surveys
3. Data availability at global and national scale limits the analysis which can be undertaken.
4. The coarseness and compatibility of data available (varies between UK countries)
5. Difficulties in obtaining temporal local scale data.</td></tr>
<tr><td>Opportunities:
1. CS is a long running and rigorous survey which has great advantages as a data set to be used as a field comparator with RS techniques, however the data is very tightly controlled and any comparison work would need to be done by CEH in a joint project.
2. Methods used should be regarded as innovative examples of what can be done, rather than definitive.</td><td>Threats:
1. Unable to detect the positive outcomes of agri-environment schemes on habitat extent and condition due to the limited amount of spatially coherent GB scale spatial datasets on agri-environment scheme status e.g. location, history and other scheme details.</td></tr>
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<table>
<tr><td rowspan="3">Phenology And Vegetation Earth Observation Service (PHAVEOS)</td><td rowspan="3">This project looks at making use of the MERIS data, from pre-processing through to creation of biophysical maps and phenology curves. Using MERIS data, vegetation change can be monitored using a variety of measures with spatial-temporal resolutions of 300m every 2-3 days. Products from PHAVEOS, can provide temporally continuous data at a much finer spatial resolution than existing satellite derived products, enabling researchers to monitor phenological variables more accurately and precisely.</td><td colspan="2">SWOT</td></tr>
<tr><td>Strengths:
1. Wide scale temporal product produced.
2. Utilise spectral information across the whole spectrum with a high revisit time.
3. Suitable for numerous approaches such as coastal monitoring, deforestation, forest degradation, monitoring of drought, insurance claim verification.</td><td>Weaknesses:
1. Output coverage weather dependent.
2. Technique relies on expert implementation of published algorithms, along with ESA MERIS data, therefore large scale RD needed to generate and comparable product.
3. Still a need to refine and characterise vegetation parameters in relation to noise within the imagery if data products are to be successfully utilised and taken up globally.</td></tr>
<tr><td>Opportunities:
1. Only if access to time series could be gained.
2. Potential to use datasets of varying spatial and spectral detail with increased use of the concept expected when Sentinel 2 20m resolution imagery is incorporated.</td><td>Threats:
1. IP=The aim is to make the temporal data available through and web mapping service. There is no indication on end user access cost.
2. The launch of the American Veers instrument which is a replacement for MODIS and will be launched before Sentinel 2 will offer comparable imagery to MERIS, 400m resolution and more bands, but which sample of less finer intervals and so could allow for other data products to be produced be competitors.</td></tr>
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<tr><td rowspan="3">Support to Defra EO Strategy Development on Land Observations - 'hub' and 'spoke' project</td><td rowspan="3">This project looked at the concept of a central data repository with 'spokes' delivering online products to users. It looks at a range of data applications including woodland change, land cover determination and change, flood management and animal disease outbreaks.</td><td colspan="2">SWOT</td></tr>
<tr><td>Strengths:
1. It is a very strong concept, providing EO data for a wider range of decision makers to improve policy making.
2. Central storage of the data means that each department does not need to invest time and money in developing EO derived products.</td><td>Weaknesses:
1. Insufficient information about the classification methods. Automatic or manual?</td></tr>
<tr><td>Opportunities:
1. Significant opportunities for a range of government departments at central and local level.</td><td>Threats:
1. Classification methods need to be transparent to provide reliable products. Need to engage the user community in this process.</td></tr>
</table>

4.2 - Characterisation of techniques

1. SNH Coastal Vegetated Shingle Inventory

Measure	Location	Extent	Condition	Change	Dynamic environment issues	Ecosystem services
Characteristics of the method & evidence of likely applicability	Project still underway, mapping vegetated shingle extent from air photography with field validation in 4 different geographic locations have been field visited to identify common regional AP issues. The surveyors recorded overall extent of the vegetated shingle, shingle community types and extents target notes, took georeferenced photographs, and recorded other site characteristics such as wrack/leaves on the drift line, clast size and backshore transitions. Hope to have definition down to Annex I or IHS level from field visits. The information from the field visits is informing the desk based, API capture process for the Scottish coast. Due to the resolution of the imagery, it is difficult to determine Annex I features from AP alone. Due to these issues, the project intends to only classify areas that are known with any certainty and then map any potential shingle sites from the AP with a caveat of being in need of validation by field visit. An estimate of how much it will cost to complete the field work is currently underway.		Not addressed by this technique	Sneddon and Randall 2002 vegetated shingle surveys are also being digitised as part of this work, and will be completed when the air photography is made available. These could possibly then be compared to the contemporary air photographs to determine localised change.	This technique looks more at creating a baseline inventory and therefore a snapshot of the vegetated shingle situation without considering the dynamic processes involved.	Not addressed by this technique
Data / information sources used	Aerial photography 0.25m, False colour IR aerial photography (where available), Phase 1, NVC, RR Solway report and Sneddon and Randall. OSMM including MHW. OS 1:10,000 scale base mapping.		Not addressed by this technique	Sneddon and Randall 2002 vegetated shingle surveys	Not addressed by this technique	Not addressed by this technique
Indicative accuracy / Fitness-for-purpose	Possibly too early to tell, should give a fairly good product although the sites which haven't been visited will have less information especially on species.		Not addressed by this technique	Hasn't been completed yet	Not addressed by this technique	Not addressed by this technique
Scale of work	Intending on creating a Scotland wide inventory.					
Characteristics of the technique - and stage of development of each	**Heads up digitising from aerial photography** Delineation of boundaries using air photos - well established **Fieldwork** Validation and classification of pre-digitised polygons - well established, fieldwork feeding back into the air photo interpretation process - established.		Not addressed by this technique	Hasn't been completed yet	Not addressed by this technique	Not addressed by this technique
Known gaps in provision	Project currently still underway, only a few sites have been field validated in this part of the project, it is hoped that field survey will be completed of the other sites if funds become available.		Not addressed by this technique	Hasn't been completed yet	Not addressed by this technique	Not addressed by this technique

Potential Issues	Sites which have not been visited will have a lesser amount of detail, especially on species. Therefore there will be inconsistency within the dataset. There is no indication of the capture dates and consistency of the imagery so there may be issues regarding this.	Not addressed by this technique	Inconsistency across mapping methods. Sneddon and Randall dataset is not a complete inventory, just survey of known sites, also lack of reference points at some sites which makes registration difficult.	Not addressed by this technique	Not addressed by this technique
Future potential uses	By rolling out the field survey the inventory will become more robust.	A robust baseline of this habitat type will allow better management and basis for monitoring.	A robust baseline of this habitat type could give a base for evaluation of change	Not addressed by this technique	Not addressed by this technique
Development of the technique	Incorporation of other high resolution imagery may aid remote determination of boundaries and species.	Not addressed by this technique	Not addressed by this technique	Not addressed by this technique	Not addressed by this technique

2. NE Coastal Vegetated Shingle work

Measure	**Location**	**Extent**	**Condition**	**Change**	**Dynamic environment issues**	**Ecosystem services**
Characteristics of the method & evidence of likely applicability	Several stage process of development of inventory a robust baseline dataset for identifying change in coastal vegetated shingle. Starting with field surveys from the late 1988-1990 digitised and at a later stage checked against air photos. The polygons were then amended where it was considered that they were mis-located. A habitat survey methodology and mapping rule base is proposed for the capture and creation of updated inventory information from field based survey and mapping standards. Digitise to recent OSMM MHW unless recent drastic change. Include shingle structure where there is indication of vegetation even if not currently veg. Landward limit OSMM topographic features unless very different from reality in which case use AP and 1:2,500 nominal scale. MMU of 0.1ha (unless as part of a fragmented linear feature where whole feature is greater than 0.1ha). priority list of allowable overlaps. These protocols have been tested within the field survey of twelve selected shingle sites during this project for which individual site profiles have been developed.		Condition of shingle relates to its use, structure and change over time so this method does not provide any evidence of being able to assess condition, however with a repeatable system the condition of the system may be established.	This evidence base provides the basis for environmental change analysis and more robust shingle status assessment, especially related to long-term climate change and sea level rise. As a standard set of rules for data capture and fieldwork have been used in the latter stages of this method, it is therefore repeatable which would allow for change to be established.	Issues of overlapping habitat inventories, Sand dune in particular, due to highly mobile nature of the environment. Also mapping structure features and change in structures provides an added difficulty.	Not considered in this work
Data / information sources used	**Creation of 2008 inventory:** Sneddon and Randall (2002) series of vegetated shingle field based mapping. Other subsequent shingle surveys, such as BRANCH. Over the course of the project all shingle surveys that have been accessible have been considered for inclusion. **Validation of digitised field surveyed:** Aerial photography 2002 and 2005 False colour infrared images for selected sites Recent OS MasterMap. LiDAR where available - South coast **Expert knowledge:** Shingle geomorphology and ecological - essential knowledge of the sites used for checking - essential		Not considered in this work	New aerial photography can be used to update and assess for change	Not considered in this work	Not considered in this work

Indicative accuracy / Fitness-for-purpose	Many areas still in need of validation due to variability in methods used as the base sources of information used to create inventory, but considered by NE staff as a good view of the extent of the resource. The rule-base for data-capture and mapping is considered robust to allow new information to be standardised so it is useable and updatable.	Not considered in this work	As a baseline dataset for detecting change it has potential	Not considered in this work	Not considered in this work
Scale of work	English coastline, 12 sites re-visited to develop field and mapping method.				
Characteristics of the technique - and stage of development of each	**Amalgamation of field survey material** digitising well established, but need expert knowledge for shingle and standard practice of inclusion/exclusion of bare shingle **Validation and quality checking** established use of Air photography and OS MM **Development of rule-base for field work and mapping** Moving towards more joined up thinking with standard rules for data capture is well established	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Known gaps in provision	Where information from the original surveys was not corroborated by the air photos, and without any clear reason for the change (e.g. poor orthorectification) then they were flagged as in need of checking.	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Potential Issues	Originally field survey carried out between 1988 and 1990, (classified by Sneddon and Randall) limitations due to lack of gaps, AP, and inaccessible areas. Some of these areas were digitised in 2004 and limitations of poorly mapped extent etc were made apparent. 2007 inventory update, purely desk based with no additional field survey work undertaken. Digitised polygons were double-checked against the original field maps to check for misclassification during digitising, then topographically checked using OS and AP, realistic changes were left in, unrealistic changes were amended. It highlighted areas thought to have changed dramatically in order to target future work.	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Future potential uses	The specification for standard field survey data collection and digitisation allow for new surveys to add to existing information without issues of conformity.	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Development of the technique	Standard field and capture protocols can evolve and change as necessary.	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work

3. NE Maritime Cliff and slope inventory 2004/5

Measure	Location	Extent	Condition	Change	Dynamic environment issues	Ecosystem services
Characteristics of the method & evidence of likely applicability	Pre-2000 hard and soft coastal cliff survey data was compiled in a project in 2002, however there were issues relating to poorly mapped extents of the surveys (such as ellipses or polylines). This project also set out guidelines for standard digitisation criteria. The Draft Maritime Cliff and Slope Inventory for England and the JNCC Maritime Cliff Database (1986-1989) were used to estimate areas of soft cliff in England to form a draft BAP cliff dataset. These datasets were also then used to infer areas of soft cliff with no known survey by using the geology information to stratify the areas of cliff into hard cliff, soft cliff, intermediate or unknown. Since then surveys to fill gaps in knowledge, mostly on soft cliffs have been commissioned, which the 2004/5 report looks at. This aimed to get a better view of coverage of soft cliff habitats. Biological surveys have been completed for approximately 80% of National Trust land, a large number of which are on the coast, surveys between 1979 and 2005 have now been digitised and used within this work. All surveys completed post-2000 were subject to rigorous assessment against the 2002 survey criteria. It was evident that the previous specification was not followed in a consistent manner, with wide discrepancies between datasets in terms of format, quality and attribution.		This technique does not take into account issues of condition	Due to the different types of dataset used to create the draft BAP habitat layer, extent is very inconsistently defined, sometimes just as start and end points of the cliff therefore it is not a robust enough dataset to be used to determine change.	This work does not look at processes associated with the dynamacism of the environment	This technique does not consider issues relating to ecosystem services
Data / information sources used	Pre existing maritime cliff surveys from a variety of sources including Natural England commissioned NVC surveys and National Trust commissioned Phase 1 surveys. JNCC cliff database. OS base-mapping		Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Indicative accuracy / Fitness-for-purpose	The inventory is not at a complete level. Information has come from many disparate sources, using vastly different mapping scales and mapping systems. Many maritime cliff and slope habitats are inaccessible due to health and safety issues, or fragile which makes mapping difficult. Where not actually known, it indicates where there is potentially soft cliff habitats.		Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Scale of work	Pulling together all surveys completed in England to create a national inventory.		Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Characteristics of the technique - and stage of development of each	**Collation of surveys** **Development of standards** Survey, digitisation and attribution standards set out in previous work were tested and refined **Identifying gaps** Using information from the JNCC cliff database, such as geology, to stratify the coastline to identify where there is potentially soft cliff habitats		Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Known gaps in provision	Inconsistency across data sets used in the data collation. Lack of specific knowledge about scale and extent of the habitat, the location		Lack of knowledge about condition of the habitat.	Not considered in this work	Not considered in this work	Not considered in this work

	of the majority of important cliff habitats is known.				
Potential Issues	Inconsistency across data sets. Lacking a robust way to display 3d data on a 2d map. Health and safety and fragile environment issues relating to accessibility of the cliffs for fieldwork.	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Future potential uses	As standards have been refined and adapted it means that any new survey data will fit into the current inventory without any issues of incompatibility. With the completion of the 2nd round of the shoreline management plans digital information on coastal defence works should give a good idea of how much of the coastline is unmanaged	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Development of the technique	Use of pre-existing survey data will always form a part of validation of monitoring, and having robust set of specifications for future survey work will help to make the data updateable and more easily combinable.	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work

4. Validation of Upland Hay Meadows, lowland Meadows and Purple Moor-Grass and Rush Pastures Habitat Inventories in parts of North West England in 2010

Measure	**Location**	**Extent**	**Condition**	**Change**	**Dynamic environment issues**	**Ecosystem services**
Characteristics of the method & evidence of likely applicability	Location and extent of the habitats were not considered in this field validation. As many of the fields had been cut assessment was often carried out on field boundaries only. This project was mostly about checking the condition and evaluation of set meadows under the scheme. The main methodology is therefore described in the box below relating to condition.		Condition of the grassland sites was assessed using a modification of the CSM and HLS monitoring regime: The following changes were made: - More indicators species were added to the list particularly where these were specific to North Lancashire and Cumbria. - 'W' walk was replaced by linear walk along verges of cut hay fields - Quadrat size was increased to 2m squared - Number of stops per habitat / field was reduced to 10 (very small patches had only 5 or even 1 sample taken) - DAFOR descriptions of vegetation abundance were used despite the difficulty of using this method for describing the abundance of patch forming species such as melancholy thistle	No specific features relating to change were described in this survey.	Not considered in this work	The quality and presence of indicator species can be applied to ecosystem goods and service modelling, but no attempt to consider this issue has been made in the report of this project
Data / information sources used	Field survey BAP Inventory model produced by Natural England		Field survey condition assessment - modified methodology	Not considered in this work	Not considered in this work	Not considered in this work

Indicative accuracy / Fitness-for-purpose	No location or extent measurements were made or recorded in this field work study	14% of the meadows were not assignable to a BAP class 4% were actually improved grassland 7% were only semi-improved grassland and not a BAP grassland category 9% were better described as another BAP habitat rather than upland hay meadow 22% were recorded as poor upland hay meadow as they failed in one indictor or percentage cover feature Leaving only 44% that fully fulfilled upland hay meadow condition requirement However as the report made no attempt to compare the meadows and the certainty form the BAP records it is hard to make any statement about where these figure represent fitness for purpose?	Not considered in this work	Not considered in this work	Not considered in this work
Scale of work	field scale trial scattered over specific areas of Lancashire and Cumbria	field scale trial scattered over specific areas of Lancashire and Cumbria	Not considered in this work	Not considered in this work	Not considered in this work
Characteristics of the technique - and stage of development of each	CSM / HLS condition monitoring is a well documented field descriptive method, however the extent features of the grasslands were not captured in this project.	CSM / HLS condition monitoring is a well documented field descriptive method, the inclusion of more specific indicator studies is also a well reported variation on the monitoring - see Wales agri-environment monitoring.	Not considered in this work	Not considered in this work	Not considered in this work
Known gaps in provision	As mapping data is not included in the final report it is not possible to say if this study highlights issues with the Bap modelling, or is a good way of confirming areas of less certainly in the BAP modelling, no overall discussion or conclusion was written in the report.	Patch forming species was a particular issue highlighted as being probabilistic with this technique.	Not considered in this work	Not considered in this work	Not considered in this work
Potential Issues	Location and extent of meadows are generally related to field boundaries, meadows can contain more than one grassland BAP type but this is not recorded in this study Often grassland boundaries are extremely demanding to identify even in the field, due to the gradual nature of ecotones and the prevalence of patch forming species.	Condition can only be objectivity assessed if the methodology is systematically and rigorously adhered to. Otherwise ambiguous recording can lead to a complete lack of scientific vigour.	Change can only be objectivity assessed if the methodology is systematically and rigorously adhered to. Otherwise ambiguous recording can lead to a complete lack of scientific vigour.	Not considered in this work	Not considered in this work
Future potential uses	Not considered in this work	Development of area specific indictor lists could enhance these methods.	Not considered in this work	Not considered in this work	Not considered in this work

Development of the technique	Not considered in this work	These techniques are the standard way of compiling information on site condition, a useful project will be to compare them to features we can monitor remotely and to evaluate how far we can go to dismiss sites that don't meet BAP / Annex 1 settings and concentrate field effort.	With repeat survey using the same methods, change of sites can be worked out given indicator species and condition monitoring features using non-Parametric statistics such as ANOSYM - this is a way of comparing the position in space of all the features of a site between survey intervals to see if there is a significant difference or if all the features roughly occupy the same space.	Not considered in this work	Not considered in this work

6. Saltmarsh work in England

Measure	Location	Extent	Condition	Change	Dynamic environment issues	Ecosystem services
Characteristics of the method & evidence of likely applicability	The saltmarsh mapping work in England and Wales used aerial photography mostly flown between 2006 and 2009 (~1% used 2004 air photography). 3 programs of work covering all regions of England and Wales were coordinated by different departments of the Environment Agency. Regional Coastal Monitoring Programmes (RCMPs), the Marine Monitoring Service (MMS) under their WFD work (MMS-WFD) and the Strategy and Engagement Team in Flood and Coastal Risk Management (FCRM). The SW and SE RCMPs provided both imagery and IHS habitat data, the NW RCMP commissioned aerial photography and mapping of saltmarsh in the 2006-2009 timeframe and the Anglian RCMP provided imagery that was mapped by the other programs.		The definition of saltmarsh used for this project was not sufficient for determining condition of the saltmarsh.	The production of a baseline dataset will allow some determination of change, however as only discrete areas of vegetation were mapped this will not give a complete view of the situation. Part of the project looked at being able to make a national level comparison between the new data with that from the 1989 NCC. This was not considered possible due to the vastly different methodologies, however work is underway to amend the 1989 dataset to make it more comparable.	Not considered in this report	Not considered in this report
Data / information sources used	3 different systems with 3 different imagery, although high resolution (0.1m) aerial photography was used for all 3 methods with NIR where available. IHS habitat classification system was used in the South East and South West RCMPs. **Software** The MMS-WFD and FCRM funded approaches both used Definiens Developer 7.0 software. **Imagery used** *RCMPs* *South East RCMP* - Fugro-BKS 0.1m resolution aerial photography *South West and Anglian* *RCMP* - BLOM 0.1m colour and NIR aerial photography flown at +/- 2hrs from low tide *MMS* - BLOM 0.1m colour and NIR aerial photography flown at +/- 2hrs from low tide *FCRM* - BLOM 0.1m colour and NIR aerial photography flown at +/- 2hrs from low tide		Not considered in this report	Looked at using the 1989 NCC Saltmarsh dataset however this was not a very consistent set of data.	Not considered in this report	Not considered in this report

Indicative accuracy / Fitness-for-purpose	The definition of saltmarsh used for this project was 'discrete marsh or reedbed, subject to tidal inundation from saline waters'. Therefore it does not map vegetation species or areas of patchy pioneer vegetation. An exercise to assess consistency across the mapping methods was undertaken in a section of the Camel estuary. They showed a similarity in extent calculation with at least 95.56% similarity in area and 0.09ha difference in absolute area mapped by the 3 different methods. The area chosen for the test however did not have difficult transition zones and this type of area is suggested for future work.	The definition of saltmarsh used for this project would not be sufficient for determining condition.	1989 data was not considered suitable	Not considered in this report	Not considered in this report
Scale of work	England and Wales	Not considered in this report	Not considered in this report	Not considered in this report	Not considered in this report
Characteristics of the technique - and stage of development of each	*RCMP (SE and SW) method* **Manual API** Air photography was manually mapped using IHS classification. **Ground truthing** completed when there was need to differentiate between species and habitat extents ~1-5% of area mapped *MMS for the WFD method* **Segmentation** Object orientated segmentation approach using Definiens, only mapping areas of discrete vegetation that exceeded 5m^2, internal parts of a saltmarsh that exceeded 150m^2 and creeks wider than 1.5m. **Manual API** The segmented image was used by the photo-interpreter for the creation of the appropriate extent boundaries. The landward boundary of the saltmarsh was determined by eye and using a modelled highest astronomical tide dataset. **Ground truthing** Each WFD area was visited for species diversity to be quantified by walking transects and quadrant sampled every major species. Areas flagged as low confidence were in some cases examined by EA field surveyors. *FCRM method* **Segmentation** Object orientated segmentation approach using Definiens, only mapping areas of discrete vegetation that exceeded 5m^2 and internal parts of a saltmarsh that exceeded 150m^2. Simplification of complex creeks occurred later. **Classification** Semi-automated classification using average pixel value and shape factors. **Manual API QA** The landward boundary was checked visually and using a modelled highest astronomic tide dataset. **Ground truthing** Specifically looking at landward and seaward boundaries of the vegetation of a limited number of validation sites by taking quadrants at points along a transect and recording % cover of saltmarsh species.	Not considered in this report	Not considered in this report	Not considered in this report	Not considered in this report

Known gaps in provision	Does not include pioneer strandline vegetation in the classification. By only mapping areas of discrete vegetation individual species variation within the saltmarsh will not be picked up and likewise the extent of the pioneer species is not included.	Not considered in this report	Not considered in this report	Not considered in this report	Not considered in this report
Potential Issues	Inconsistency across the 3 disparate techniques. Variability in the age of air photos	Not considered in this report	Issues comparing inconsistent datasets, and inherent inconsistency within the dataset between different techniques.	Not considered in this report	Not considered in this report
Future potential uses	Useful as a baseline dataset for extent of discrete patches of saltmarsh vegetation.	Not considered in this report	Can potentially be used as a reference baseline saltmarsh dataset	Not considered in this report	Not considered in this report
Development of the technique	Higher resolution imagery with other spectral bands giving a better spectral signal may allow automated methods be able to pick up areas of non discrete pioneer saltmarsh and determine species variation within the saltmarsh.	Not considered in this report	Not considered in this report	Not considered in this report	Not considered in this report

7. Scotland saltmarsh survey work

Measure	Location	Extent	Condition	Change	Dynamic environment issues	Ecosystem services
Characteristics of the method & evidence of likely applicability	Currently operational 3 year time scale (started 2010) NVC field survey of each site which meets the size criteria. Use of 0.25m air photography for reference to aid mapping. Updating and reviewing the 1980's saltmarsh inventory survey information which is considered very patchy and poorly reported on.		Thorough condition assessments are being collected using Common Standards Monitoring (CSM) for every site visited, therefore will have up to date condition information.	Will provide a robust baseline dataset, with all the surveying complete within a 3 year timescale, therefore any new imagery can be compared against the baseline dataset and change can be detected.	Not considered in this work	Not considered in this work
Data / information sources used	**Base mapping:** 1980s Saltmarsh inventory 0.25m resolution air photography from 2005 onwards **Expert knowledge:** Field visits by trained field ecologists		Field visits using CSM techniques.	As new aerial photography data becomes available the baseline inventory dataset can be checked accordingly.	Not considered in this work	Not considered in this work
Indicative accuracy / Fitness-for-purpose	Unknown, 1st round of reporting is due soon, however staff at SNH are confident that it will provide a robust inventory of all sites above the threshold size.		CSM well established over time to report on a range of condition criteria such as loss/increase in extent, change in species composition.	Unknown as yet	Not considered in this work	Not considered in this work
Scale of work	All known areas of Saltmarsh in Scotland >3ha or >500m in length and some of the smaller patches too. February 2011, end of 1st year of a 3 year program.		As above	Not considered as yet but has potential to be used at the scale of the inventory work i.e. all Scottish saltmarshes.	Not considered in this work	Not considered in this work
Characteristics of the technique - and stage of development of each	**Fieldwork method** NVC - Very well established **Use of air photography in the field** Very well established		**Fieldwork method** CSM - well established	Not considered as yet	Not considered in this work	Not considered in this work
Known gaps in provision	The method is only picking up some of the saltmarsh patches that are below the threshold values. At this stage it is unknown to what extent this will impact the quality of the inventory		unknown at this point	Not considered in this work	Not considered in this work	Not considered in this work

Potential Issues	All field based methods have elements of subjective , however these can be mitigated by rigorous training and QA procedures.		as above	Not considered in this work	Not considered in this work	Not considered in this work
Future potential uses	Can be used as baseline dataset		Building up a suite of habitat data and condition data will allow a view of trends within the habitat to be established	Repeatable method that can be used to build up a view of patterns and condition change within the saltmarsh system.	Not considered in this work	Not considered in this work
Development of the technique	Not considered in this work		Not considered in this work	Change in saltmarsh can be used to determine trends and system health along with planning of coastal defence work	Not considered in this work	Not considered in this work

11. Welsh Phase 1 mapping

Measure	**Location**	**Extent**	**Condition**	**Change**	**Dynamic environment issues**	**Ecosystem services**
Characteristics of the method & evidence of likely applicability	The landscape of Wales was divided into discrete objects of sizes that varied from individual pixels to entire fields. This was done using SPOT-5 high resolution (10m) reflectance data and Land Parcel Information System boundaries. Using the objects as a start-point, a rule-base was then developed and applied; it used data from several optical satellite sensors, derived datasets (e.g., vegetation indices, fractional images) and ancillary information (e.g., topography) to progressively discriminate and map the distribution of 105 sub-habitats across Wales. A second rule-base was then developed to translate the more detailed sub-habitat classification to Phase 1 habitat classes. The rules coupled knowledge of ecology and the information content of these remote sensing data using a combination of thresholds, Boolean operations and fuzzy membership functions. There are 2 outputs: the fuzzy membership values associated with each object (in areas of complex mosaics) and the Phase 1 classification. These are produced for "projects" - areas defined primarily by their biogeographical characteristics but that are subset on the basis of image boundaries.		Could be adapted as a method to assess the condition of habitat or could be incorporated within broader change analysis. The relative condition of a habitat is currently hidden within the broader habitat classification rules. Sub-class condition classifications may require more spectral information (i.e., hyperspectral) and possibly higher spatial resolution imagery.	The approach can be adapted to allow continual monitoring of the extent and condition of habitats and agricultural land. Once the rules have been established, change in extent and distribution of habitats can be determined when new imagery becomes available. Approach would be to produce new map rather than update the existing map.	The method applies equally to dynamic and more stable environments; however, as this is essentially a snap shot, the dynamism of habitats is not captured in the classification. Nevertheless, the use of multi-temporal imagery to generate the classification means that dynamic changes over the period represented by the imagery could be mapped, provided that the spatial extent of the change is appropriate for the imagery. To do this the rule-base would need to be modified to extract the information.	Original Phase 1 was conducted to designate SSSI sites. The EO based classification is an update on this original survey and will the assist in the management of habitats. A draft version of the data for south east Wales was used in the CCW project: 'Modelling Ecosystem Goods and Services and future scenario's for Future Planning' by Environment Systems. A draft version of the Data for the Cambrian Mountains has been used by Bangor University as part of the Cambrian Mountains Initiative to map ecosystem services and land managed options looking at water regulation.
Data / information sources used	**Creating objects:** 1. SPOT-5 High Resolution Geometric (HRG) reflectance data (10 m spatial resolution) 2. Land Parcel Information System (LPIS) boundaries. **Creating sub-habitats:** 1. Time series of spring / summer multispectral imagery spanning up to a three year period: a) SPOT High Resolution Geometric data b) Terra-1 Advanced Spaceborne Thermal Emission and		As above but would need to consider higher spatial resolution imagery and would certainly need to incorporate field spectral analysis.	Acquisition of cloud-free imagery from the sources noted above as and when they come available to build-up an archive of imagery to allow monitoring of change.	As above.	As above

	Reflection Radiometer (ASTER) c) Indian Remote Sensing Satellite (IRS) LISS-3 data 2. Derived datasets (e.g., vegetation indices, fractional images); 3. Ancillary information (digital terrain model, OS MasterMap, LPIS). **Software**: eCognition **Accuracy assessment**: 1. "RGB and NIR aerial photography - 2006 2. Phase 1 habitat map (1990s field based survey) 3. Phase 2 habitat survey data (various dates at specific sites) Expert knowledge: ecology of the environment assessed - essential remote sensing expertise - essential				
Indicative accuracy / Fitness-for-purpose	The mapping in Wales spans diverse landscapes, which contain variation in both the overall structure and species composition of some specific habitat types (due to differences in elevation, geology, soils and maritime influences) as well as differences in the phenological characteristics of habitats (due to regional and local climate influences). The approach allows phase 1 habitats to be mapped within this context of local variation in habitat characteristics. A standard confusion matrix based accuracy assessment has been produced for publication. It was derived from a combination of the original Phase 1 maps, Phase 2 vegetation data and interpretation of aerial photographs. The accuracy assessment process itself is quite complex and described in the paper by Lucas et. al (2010). Accuracy measures have been produced for 2 project areas so far. Several projects have used the draft data and have found it fit for purpose including identification of meadows in Glamorgan, bracken and heather in Torfaen and bog under coniferous woodland in Neath. It is considered highly likely that the approach can deal with other parts of the UK with similarly diverse and variable landscapes. The fact that the approach successfully scales up from individual objects to many detailed habitat sub-classes, suggests that there may be potential to identify specific Annex 1 and BAP habitats - though how comprehensively and how accurately this can be achieved is not known. The technique can draw in and process the specific range of ancillary and specialist datasets needed to map the various Tiers of habitat 2 and 3.	Specific condition mapping was not undertaken. However as the membership to habitats such as *Molinia* and scrub are recorded in the upland and lowland habitats there is the potential to develop some condition assessment criteria	No change analysis conducted to date as this is designed as the baseline. The accuracy of any change map will depend on the habitat specific accuracies of both (or more) census dates. In addition, the precise procedures used to detect change will need to be considered in detail to derive statistically meaningful change.	Is applicable. Most of the areas and conditions noted can be mapped using the rule-based approach discussed in the paper. Vegetation structure is one of the conditions that will require further attention since the best way to retrieve such information is through a radar sensor. This has associated difficulties in terms of spatial resolution and interpretation but may provide valuable additional information to assist in the classification of vegetation structure.	The finer scale of spatial detail given in this mapping has resulted in superior models in both the studies undertaken to date than was achievable using the old Phase 1 mapping. It has therefore been deemed fit for this purpose

Scale of work	The mapping covers the whole of Wales. The maps operate at a scale of 1:25,000 but are anticipated to contain nearly as many features as OS MasterMap for Wales. Segmented images of the country are produced (3 levels) with habitats classified within each (e.g. super-level - arable; Level 1- woodlands; Sub-level - heaths, bracken). Most habitats mapped at 5m, hedges mapped at a different scale. Outputs are produced for "project" areas (areas defined primarily by their biogeographical characteristics but that are subset on the basis of image boundaries).	Provided that the temporal and spatial resolution of the imagery is comparable with the scale of the habitat being mapped then it should be possible to extract the condition of the habitat. Key here is detecting a condition 'signal' in the imagery. Provided this can be isolated then the method is appropriate for condition mapping.	The method has shown itself to be effective at mapping a wide variety of habitats. Provided that can be duplicated for another census period, then the scale of the work is appropriate to detect change across a wide range of habitats.	The spatial resolution of the work may not be appropriate in all cases e.g., to map species composition. However the techniques could be developed to act in the dynamic environment	Scale of work is good for strategic mapping and modelling projects.
Characteristics of the technique - and stage of development of each	**Pre-processing of satellite data**: well established techniques. Accurate image registration considered vital for good results. **Integration of MasterMap layers:** recent but well-established technique. **Multi-level Image segmentation**: segmentation is established technique but approach used in Wales is novel. **Incorporation of ancillary data**: established technique for some types of data, novel approach in terms of end member fractions. **Object-orientated rule-based classification**: Both single thresholds using Boolean (logical) operations and fuzzy membership is used **Geoinformatic techniques such as fuzzy rules**: recent, novel **Combining object oriented techniques**: novel	The condition of habitats could be extracted in theory by adapting the rule-based classification. Provided that the time-series is appropriate and the imagery is at an appropriate scale, then condition could be extracted; however, this would need to be accompanied by more fieldwork, potentially incorporating ground-based spectral collection.	Not considered in the current work as this is the baseline against which change comparisons will be made. Comparison to 1990's field based phase 1 maps are being investigated using Dempster-Shafer belief functions.	Rule base would need to be modified to classify dynamic changes of interest.	Data is being used in a range of novel modelling applications both by a number of organisations.
Known gaps in provision	Certain Annex 1 habitats are defined by features too small to be picked up by this method / resolution of the data. Those habitats that are unlikely to be identified using EO because they are obscured by canopy or other coverage of features will not be identifiable. Requirement for good quality geological information (up to 8 Annex 1 habitats) - This data not available for Wales at sufficiently detailed scale.	For main species groups that indicate condition - such as *Molinia* or scrub proportion then the technique needs only to be modified. For other condition work detailed field spectra would be needed to guide the rule-based classification.	The method(s) of detecting change between census periods will need to be considered further.	Further information on the spectral signatures associated with changes in dynamic environments may be needed as well as their spatial extent.	This habitat data is sufficient for the modelling needs at present.
Potential Issues	Relies on the quality of the imagery and ancillary datasets. Time needed to tailor rule based approach for different biogeographical areas Requires expert knowledge of RS and ecology for areas of interest. Availability of time series of information for mapping some habitats e.g. meadows, dry grasslands and some coastal habitats	In addition to the points noted above, the spatial resolution of the imagery may limit the extent to which condition may be determined. Higher spatial resolution imagery e.g., aerial imagery including NIR, may help in this respect.	Will need to reassess the rule-base for other census dates to account for sensor properties and acquisition dates. Given cloud cover it may not be possible to get the same temporal coverage as the previous census imagery.	Will need to consider the question of spatial resolution i.e., can all of these issues and conditions be mapped effectively will relatively coarse spatial information?	

Future potential uses	Translation of rules to other biogeographical areas.	Given existing knowledge and understanding of the area classified, condition analysis could be undertaken on this area and transferred to other biogeographical areas.	The same geographical area could be used as a test area given knowledge and understanding gained in the original EO classification. Could also be tested in other biogeographical areas.	Potential not yet assessed.	
Development of the technique	The potential to improve the accuracy of the habitat mapping is inherent to the approach as the rule-base can be refined based on new information. Good potential for incorporation of further imagery and ancillary data Potential to develop technique to look for specific Annex I habitats rather than general context mapping.	Condition analysis would require further development of the decision rules, with a particular focus on the incorporation of more spectral information. An increase in the spectral and spatial information (if that is deemed necessary) would require additional computing resources, which would need to considered in detail.	The question of developing methods to detect change will need to investigated.	Development of techniques should translate well, but finer spatial and temporal resolution needed.	

12. Tweed catchment Phase 1 from aerial photograph

Measure	**Location**	**Extent**	**Condition**	**Change**	**Dynamic environment issues**	**Ecosystem services**
Characteristics of the method & evidence of likely applicability	Tweed catchment covers a large area of land across the border between Scotland and England, extending from the uplands of the Lammermuir Hills in the north, the Southern Uplands in the west and the Cheviots Hills in the south, through the valleys of the Tweed, Teviot and Till, to the town of Berwick in the east. Uses 25cm resolution RGB imagery. This aerial photography was captured over a period of two years at different dates. Image segmentation was used to delineate different habitats from the aerial photographs. Manual attribution and recognising habitats from air photography. This created a baseline is a land cover and habitat map, at Phase 1 level. The final product provides information for spatial planning and sustainable development initiatives. The dataset is updated by local volunteers and managed by the local wildlife trust is responsible for QA and any updates.		Creating the P1 Baseline map allow a spinoff of habitat networks (grassland, heathland, wetland and woodland) to be identified.	The baseline information captured through these processes will allow future assessment of change to take place.	Provides baseline information.	Vegetation carbon storage, water regulation and agriculture.
Data / information sources used	**Imagery used:** The aerial photography was captured over a period of two years at different dates, but most of the area was covered by a flight at the end of September 2007. The southernmost area (17%) was captured in the spring of 2009 and various other smaller parts of the catchment later on in autumn 2009. **Additional data sources:** MasterMap, soil data, river network, forest network.		P1 base map, River network, Flood areas, elevation data and forest network.	NA	NA	NA

	Expert knowledge: ecology of the environment assessed - essential remote sensing expertise - essential				
Indicative accuracy / Fitness-for-purpose	The Phase 1 data had a minimum mapping unit of 0.25Ha. Imagery was captured on two different dates, resulting in very different spectral properties. Base map had a high level of detail, due to manual attribution.	The habitat networks provide and good insight in to the extent of the network provision in the area.	The assessment of change using this method would be only limited by the comparable data availability.	Certain complex habitat mixes were mapped as mosaics, where it was impossible to map small areas of individual habitat separately.	Suitable for regional ecosystems assessment.
Scale of work	Area of the Scottish Borders covering 5570km^2.	Network assessment covered the same 5570km^2.	Could be used to assess change on a similar scaled area.	NA	NA
Characteristics of the technique - and stage of development of each	Image segmentation is a established technique. „Rule" based classification techniques based on the colour and texture of the „objects' were used for large consistent areas. The remaining areas were classified using ecological knowledge.	Network create used spatial proximity and additional datasets.	NA	NA	NA
Known gaps in provision	Habitats below 0.25Ha. Consistent habitat attribution from imagery of differing dates.	None	NA	NA	NA
Potential Issues	Possible consistency issues with manual attribution of habitats.	Networks overextended, therefore not 100% based on sound ecological principles.	Inconsistency across data sets/ data availability.	Scale of map unit.	NA
Future potential uses	Translation of methodology to other biogeographical areas, depending on habitat range.	Method easily transferable to other areas that have similar baseline data.	Method could be used to assess change but dependent on suitability of past or future data sets.	Method could be used to analysis large scale issues.	suitable for large scale ecosystem assessment.
Development of the technique	Potential to use more core data with more sophisticated segmentation software would greatly improve the consistency of future products.	Process can be fully automated.	Purposely tasked data capture including NIR would greatly improve the quality of the output for this purpose.	Purposely tasked data capture including NIR would greatly improve the quality of the output for this purpose.	NA

13. Developing Inventories of Upland BAP and Annex I habitats in Scotland

Measure	**Location**	**Extent**	**Condition**	**Change**	**Dynamic environment issues**	**Ecosystem services**
Characteristics of the method & evidence of likely applicability	Using existing spatial information, the **interim** report discusses the methods used to generate an inventory of Upland BAP and Annex 1 habitats in Scotland. The inventory is based on the correspondence between different data sources/expert knowledge and follows a hierarchical approach including an assessment of the statistical validity of the classification. The interim approach does not provide a worked example to illustrate how the datasets are combined and how the statistical analysis is conducted.		Only Upland BAP and Annex I Habitats will be classified.	There is no consideration of change.	Dynamic environments are not considered separately. According to the work flow, classification is based on correspondence between data sets.	Not mentioned directly but the final product could form an integral data layer of an ES system.

Data / information sources used	Primary data source is the 1988 Land Cover Map of Scotland, which is supplemented by a number of vector data sets including Land Cover Map UK from 2000, Scottish Blanket Bog Inventory, Lowland raised bog inventory, Limestone Pavement inventory, soil map at 1:250,000. NVC surveys where available. Topographic and terrain models.	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Indicative accuracy / Fitness-for-purpose	The interim report does not provide an accuracy assessment. The work is in development and further statistical information is needed before it is possible to comment on the effectiveness of the method.	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Scale of work	Scotland-wide. Worth noting here is that the datasets used in the construction of the inventory have been produced at different scales.	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Characteristics of the technique - and stage of development of each	Development of upland habitat inventories using a geoinformatic approach. Where good land cover data was available this was used where this was not a combination of knowledge based and statistical based rules allowed for 'likely' habitat occurrence to be determined where possible and gaps to be flagged.	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Known gaps in provision	Some habitats are already better well known across Scotland with fairly robust inventories already available (such as Raised Bog). Modelling of some habitats has been limited by the amount or resolution of data available such as geology.	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Potential Issues	Some of the data sets are in excess of 20 years old and have been generated at different scales. Combining these will cause a variety of issues.	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Future potential uses	The inventory will be of use as a starting point to meet the requirements of the EU Habitats Directive, and be very useful in targeting resources for filling gaps in habitat knowledge provision.	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Development of the technique	Technique is credible but needs statistical validation, which will follow in due course.	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work

14. Scotland Inventory of Upland BAP and Annex I habitats

Measure	Location	Extent	Condition	Change	Dynamic environment issues	Ecosystem services
Characteristics of the method & evidence of likely applicability	A three pronged approach to the classification of upland vegetation for the purpose of producing a baseline of Upland BAP and Annex 1 habitats in Scotland's is discussed in the **interim** report. Given the interim nature of the report, several key aspects of the study have yet to be completed including an accuracy assessments and a comparison of the three methods. The 1st method follows traditional digitising and classification of aerial photography, whilst the 2nd involves the digitizing of satellite imagery and the 3rd is a hybrid of the other two but includes object based classification. Little detail is provided in the interim report on the 2nd method and there is no information with respect to the 3rd approach.		Not specifically considered in this work	Not considered in this work	Not considered in this work	Not considered in this work

Data / information sources used	Aerial photography with NIR band and satellite images (although the exact imagery is not specified) Also drawing from local ecological knowledge and pre-existing habitat survey (mainly NVC survey)	Not specifically considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Indicative accuracy / Fitness-for-purpose	This aspect of the work has not yet been reported on, and the 1st stage of field validation of the work will take place next year.	Not specifically considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Scale of work	Trial of methods in 2 upland pilot areas in Scotland, one on the East coast, and one on the west coast.	Not specifically considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Characteristics of the technique - and stage of development of each	**Heads-up digitising and classification** The digitising and classification of the aerial photography and subsequent classification follows traditional methods. Each habitat of interest was characterised by its visible features. Training sets were also provided to the digitisers as examples of how the habitat presented in each pilot area. The use of space borne imagery for classification is potentially novel but little information is provided on this. It is understood that an object-orientated rule-based approach is being used.	Not specifically considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Known gaps in provision	Work is on-going therefore difficult to assess.	Not specifically considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Potential Issues	Need to review after the report is completed. Difficulty in characterising mosaics with heads up digitising. There have been issues transferring the rules between the 2 pilot areas due to ecological variation within species in different biogeographical areas.	Not specifically considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Future potential uses	A baseline of Upland BAP and Annex 1 Habitats for the ecological community in Scotland will be produced.	Not specifically considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Development of the technique	Need to review after the report is completed.	Not specifically considered in this work	Not considered in this work	Not considered in this work	Not considered in this work

16. LCM 2007

Measure	Location	Extent	Condition	Change	Dynamic environment issues	Ecosystem services
Characteristics of the method & evidence of likely applicability	LCM 2007 is a strategic data set with a minim mapping unit of 0.5ha.It incorporates field boundary data and will cover broad habitat groups. It does not cover small or specialist habitats nor does it identify liner features in systemic way.	The data set has a minimum mapping unit of 0.5ha and as such will only give a broad view of the extent of the main habitat groups.	LCM 2007 does not measure condition of habitat.	There are opportunities to assess change, but there have been significant technical developments between surveys and it will be important to initially decide if it is possible to accurately measure change that does not simply measure a difference in techniques.	The data set is not at a sufficient scale to consider issues of relevance to the dynamic environment	The data set has been used in models for ecosystem services. It strategic coverage means that it can usefully provide some good information for whole country projects, but lacks detail for regional or county projects.
Data / information sources used	LCM is a combination of Earth Observation data, digital cartography and other ancillary information (such as	Field boundaries are incorporated to give contextual detail, the other	Not considered in this work	It would be important to decide whether any change detection could (and should) be done with the	Not considered in this work	Various data sets will have been used together with Landover map 2000 to map ecosystem

	generalised Ordnance Survey MasterMap polygons).	boundaries are derived form remote sensing data.		classified map, or at the imagery level, or at an indicator (e.g. NDVI) level.		scenarios, LCM 2007 has not been released for a sufficiently large area yet to enable modelling work.
Indicative accuracy / Fitness-for-purpose	Accuracy was well described for LCM 2000 and it is anticipated that it will be the same for LCM 2007. It is a generalised data product and therefore is very fit or purpose in terms of modelling at a UK level strategic policy issues, it is less robust where a finer spatial scale is needed. However it is more spatially accurate than the CORINE mapping, to which it is the UK contribution to the European project.	Accuracy was well described for LCM 2000 and it is anticipated that it will be the same for LCM 2007.	Not considered in this work	Change detection between LCM 2000 and 2007 could be useful (if shown to be valid) at a national, possibly regional scale.	Not considered in this work	Has been shown fit for purpose for strategic UK scale studies, problems have been noted in the level of detail for regional/county level studies.
Scale of work	The whole of the UK is covered.	Broad land cover types are covered for the whole of the area.	Not considered in this work	Because the whole of the country is covered it may be possible (if a robust method of modelling was identified) to map change in a strategic way.	Not considered in this work	The whole of the UK is covered.
Characteristics of the technique - and stage of development of each	The big technical leap forward for the 2007 map is the generalisation of Ordnance Survey MasterMap and the subsequent integration into the processing chain.	For broad land cover types the work will provide a good strategic picture, more detail will be needed for Annex I intricate habitats.	Landcover map 2007 still in development	The use of objects gained from OS MasterMap to guide the classification is an important development in the latest phase of the report.	Not considered in this work	Landcover map 2007 still in development
Known gaps in provision	It covers broad land cover types only not Annex I or Bap habitats.	It covers broad land cover types only not Annex I or Bap habitats.	Not considered in this work	The classification changes will be challenging when looking at change detection.	Not considered in this work	Landcover map 2007 still in development
Potential Issues	Scale and minimum mapping unit mean that smaller and more intricate habitats are often missed.	Landcover map 2007 still in development	Not considered in this work	The classification changes will be challenging when looking at change detection.	Not considered in this work	Landcover map 2007 still in development
Future potential uses or	Landcover map 2007 still in development	Landcover map 2007 still in development	Not considered in this work	Landcover map 2007 still in development	Not considered in this work	Landcover map 2007 still in development the more detail the classification covers the more power it will have in terms of modelling.
Development of the technique	Landcover map 2007 still in development	Landcover map 2007 still in development	Not considered in this work	Geoinformatic approaches may provide a key to looking at strategic land cover changing using the past version of Landcover map	Not considered in this work	Strategic all country data sets are extremely useful for modelling issue that affect the whole country at a broad scale, with incorporation of more data sets and techniques the data set will become more useful for other tasks.

17. Geomatics Group (2011) Dartmoor National Park Authority Remote Sensing Project

Measure	Location	Extent	Condition	Change	Dynamic environment issues	Ecosystem services
Characteristics of the method & evidence of likely applicability	The project set out to address specific questions on extent and condition of set moorland and woodland habitats in the Dartmoor National Park: Extent of Section 3 moor and heath (LG1) Extent of broadleaved woodland (LG5 and targets 1A and 1B in Moorland AP of Dartmoor BAP) Characterising Scrub - divided into discrete height bands Blanket Bog - good quality, areas with good Sphagnum cover and areas of bare peat Erosion and Gullying Archaeology Field boundary mapping - mapping of hedges Unimproved/semi-improved fields - greenness SSSI condition assessment The method involved special flights of LiDAR and CASI across the study area to collect very high resolution and high spectral resolution data. The analyses was compiled using a range of techniques, depending on the habitat in question. This ranged from skilled manual interpretation and on screen digitisation with a range of reference images to help identification of features to be analysed, to semi-automatic methods including segmentation and classification. The report does not however state what software and automatic techniques were used. The imagery used proved sufficient for separation and identification of features of interest in terms of Annex I and Priority habitats Also interesting use of LiDAR to check condition of features.		This report has put a lot of thought into how condition may be assessed using techniques such as monitoring the extent of scrub and Molinia on the bogs, the amount of gullying on the bogs and erosion features. All of these proved very possible with this high quality, high resolution airborne data. Project was set up to look at condition of gully features in the bog using LiDAR. In addition the amount of Molina as an indicator of drying of the bog was assessed using a brightness threshold within the NDVI. Hydrological analysis was carried out to evaluate consequence of damage using LiDAR and DTM which were in filled to create a flow model , the flow map was then interacted with the gully map to highlight area of most risk. Condition of semi-improved fields in terms of productivity was looked at - but with just a single data ways from the time of field survey was not found to give a good correlation	This study was specifically set up to provide a rigorous baseline and methods against which change could be assessed. The approach can be adapted to allow continual monitoring of the extent and condition of habitats and agricultural land. Once the rules have been established, change in extent and distribution of habitats can be determined when new imagery becomes available. Approach would be to produce new map rather than update the existing map	Very high quality airborne data is clearly very well suited to monitoring features with sub meter accuracy for change detection of dynamic environments The changes in erosion features both on the deep peat and other peat and the quality of bog vegetation found in this survey will allow the sort of data collected in this study to be readily modelled and analysed to give key information about the rate of change of these systems, this is not likely to be as high as the very dynamic environments and will require a re-flight of the CASI and LiDAR at every monitoring period, but is a very accurate and repeatable method	This data has already been modelled together with flow data to give some idea of water movement across the bog and landscape, the data is at such a level of detail that it could easily be used to model ecosystem goods and services. The project provided what appears (without any formal testing) good quality data - as such it will be easily incorporated into ecosystem modelling tasks.
Data / information sources used	**Imagery** Specially flown CASI and LiDAR with simultaneous flight in May 2009 OS MasterMap used as base and could be used for determination of linear features **Software used** Erdas Imagine and ESRI ArcGIS		Both LiDAR and CASI was necessary for condition assessment	The requirement for change analysis is a good baseline, the data here was compared in an interesting way with previous surveys to look at where bog vegetation had increased and decreased - this was a visual rather than analytical assessment but show the power of comparing surveys for monitoring.	As above CASI and LiDAR used	additional data would be necessary to model ecosystem goods and services.

Indicative accuracy / Fitness-for-purpose	Indicative comparative maps and photos show a good correlation with air photography and what would be expected. Accuracy is dependent on this method on the skill of the digitiser / interpreter and the quality and range of reference photographs. The data clearly provides sufficient detail for manual separation of bog, woods, hedges and scrub, but not at present for semi-improved grassland. (this probably needs a time series and knowledge of the agricultural processes).	In order to assess the accuracy of the condition assessment a follow on piece of work would need to be completed comparing the results of the Molinia ingress and gulling with known condition of features at the moment and drying out of the bogs etc. Full account will need to be made for the contextual difference in each site and plants such as Molinia and it would need to be fully worked out.	LiDAR and CASI are both suitable for the scale of features being mapped in upland bogs.	LiDAR and CASI are both suitable for the scale of features being mapped in upland bogs.	LiDAR and CASI are both suitable for the scale of features being mapped in upland bogs.
Scale of work	This was a pilot project to test methods and the suitably of the area. A comparatively small region of upland (~18% of Dartmoor) was covered by the techniques could be rolled out over a wider area. Flying times are limited by the practicalities of air borne flying, but techniques show promises in terms of upland habitats.				
Characteristics of the technique - and stage of development of each	Visual interpretation of imagery is well established. Use of reference photographs has proved in other sites to lead consistency. Algorithms used are standard NDVI and LiDAR first return and DTM, but both well established techniques are performing well in this instance. Moorland and heathland extent: This was recorded using on screen digitising using different band combinations from the CASI sensor and a well defined set of reference pictures Extent of blanket bog : Visual interpretation based on a set of reference pictures Extent of broadleaved woodland: this was done using a LiDAR height model and CASI data to visually interpreted coniferous woodland, Hedgerow extent: was compiled using LiDAR and centre lines to give width in an automated way. Scrub features were assessed in height bands based on the LiDAR data and then classified using an NDVI. Extent of archaeological features: Surveyed using LiDAR and artificial illumination analysis to allow multiple sun angles to visually highlight areas of potential archaeological interest	Use Of LiDAR to identify gullies and use of gully modelling are innovative techniques	Use of boundary difference to record change is well established, but this is a good implementation of the technique	No specific techniques for dealing with dynamic environments were presented in the report	Use of flow models in this situation was novel and could be applied to other ecosystem goods and services.
Known gaps in provision	Using a single date capture did not provide sufficient detail for semi-improved grasslands. Sphagnum was able to be mapped within the Blanket Bog where it was visible from above although in other areas	This project set out to address specific habitat types and issues and, these are well addressed, how they compare to CSM field results needs to be field tested.			

Potential Issues	Relies on the quality of the photographic interpreters	Using certain proxy for measurement of condition - these need to be field tested across a range of conditions before they become suitable for wider use. Different vegetation types have different condition factors which may be better determined by imagery from different seasonal time-frames.	Change detection will rely on repeat flights providing repeat imagery. Different vegetation types are better determined by different seasonal capture or time series which adds to the cost.		
Future potential uses	Adding a rule base to this excellent level of data could provide useful automation which would make coverage's of larger areas more economically feasible	The condition assessment using LiDAR will be an extremely efficient way of monitoring the condition of the gullies of the bog.	With new imagery the process is repeatable to give change information on extent and distribution of habitats.		
development of the technique	The use of LiDAR for Scrub and bog condition modelling is an interesting features of this research - development of a modelling scenario which equates to the condition monitoring CSM would be extremely useful way forward.			LiDAR and CASI have potential to be used to monitor dynamic environments, although costly - they are high accuracy and achievable. May be an option to cost the befits of these approaches against the current monitoring regimes. Or maybe to assess the current regimes against existing data captured for monitoring	Things like modelling carbon flux under Molinia and relating this to spectral changes provide a good way forward with the use of remote sensing.

18. Remote sensing of Dune habitats at Kenfig NNR

Measure	Location	Extent	Condition	Change	Dynamic environment issues	Ecosystem services
Characteristics of the method & evidence of likely applicability	The primary reason for the study was to look at he extent of Annex I habitats 2190 - Humid dune slack in terms of the embryo dune slake and the successionally-young dune slack. 30 Different habitat related to the sand dunes were of interest, however the most interest was in the Annex I habitats The method used was a standard supervised classification of CASI and ATM flight data from 1997 and LiDAR from 1999. Each of the flight lines was analysed separately. Training and testing data was collected on homogeneous stands during field seasons. Several iterations of the supervised classification were run until a satisfactory result that was fit for purpose was gained. Because a supervised method was used, only spectral differences were considered, and no ancillary data or modelling was carried out.		The project was to look at extent of young dune features, however, these contain open sand and as such the method id identify that the system was in poor condition because there was a general lack of open sand.	Change was compared to field mapped data, but no specific change analysis was set up or intended form this study.	Sand dune systems can be very active and dynamic, but his aspect was not considered as part of this study, predominately due to cost of repeat collection of airborne data.	Ecosystem services were not considered as part of this study.

Data / information sources used	Field survey data from the dune system collected using a GPS was used for training and testing CASI and ATM imagery was used LiDAR imagery was available for some more offshore areas but was not built into the classification.	No specific condition data was collected in this survey	Change was not analysis although the detail of data collected together with current registration and analysis could be very valuable tool for looking at difference	Not considered in this study.	Ecosystem services were not considered as part of this study.
Indicative accuracy / Fitness-for-purpose	A formal accuracy statement was not included in the report, However the survey was judged fit for purpose in its representation of the Embryo dune slack by comparison with field experience from the sites. The young dune grassland habitat was also convincingly distributed in relation to expected location for field experience. Supervised classifications suffer from a number of issues that were apparent in this study: Vegetation types with similar spectral properties cannot be separated as ancillary information, such as topography, is not incorporated within the classification system GPS collection of field reference data needs to be very close in time and space to the remote sensing data acquisition date for a good match to be generated Timing of remote sensing data needs to be appropriate as many dune vegetation species are very seasonally variable Habitats need to be separable and to have clearly defined ecotones. Misclassification results from areas where no training data has been given and therefore the closest class is assigned, it is not possible to find these out other than by error analysis.	Condition was not specifically considered as part of this project,	Not considered in this study.	Not considered in this study.	Ecosystem services were not considered as part of this study.
Scale of work	The study was carried out at Kenfig dunes in South East Wales which is a 600ha Nature Reserve.	N/A	Not considered in this study.	Not considered in this study.	Ecosystem services were not considered as part of this study.
Characteristics of the technique - and stage of development of each	**Supervised classification** This is a standard entry level remote sensing technique, which simply considers spectral difference. It allows very discretely visible classes to be separated with success but is less robust at dealing with ecotones, or data that needs a geoinformatic modelling component.	Because of the limitations in supervised classification in particular on the way that all the image is assigned a class regardless of how near it is , condition assessments may be hard to produce using this technique.	Not considered in this study.	Not considered in this study.	Ecosystem services were not considered as part of this study.
Known gaps in provision	This technique successfully separated out he embryo dune grasslands, however it did not manage to separate out the semi-natural grasslands successfully. The subsequent work in Wales has suggested a times series and the incorporation of other information factors may be a way to solve this problem.	Condition not specifically covered in this study	Not considered in this study.	Not considered in this study.	Ecosystem services were not considered as part of this study.
Potential Issues	Location of each patch is only accurately identified in supervised classification if there is good spectral separation in the layer being considered. This is less robust than separation using object creation,	No condition work was carried out, the potential issues with the technique are outlined above.	Not considered in this study.	Not considered in this study.	Ecosystem services were not considered as part of this study.

	unless one supposes that hyper spectral imagery may give sufficient information to separate out any vegetation types.				
Future potential uses	This project showed that the data and technique was suitable to identify some of the younger dune habitat types.	The scale and quality of the data would lend itself to more sophisticated analysis if collected today.	Not considered in this study.	Not considered in this study.	Coastal processes can have a profound effect on the surrounding land and it would be extremely useful to have an active means of monitoring them
Development of the technique	Use of high resolution data with some of the more robust remote sensing analysis techniques has great potential to identify coastal environments.	Sand- dunes are a highly mobile environment and with this level and precision of data and new analysis techniques there is a good possibility to look at features indicative of quality using remote sensing techniques.	Coastal processes can have a profound effect on the surrounding land and it would be extremely useful to have an active means of monitoring them	Coastal processes can have a profound effect on the surrounding land and it would be extremely useful to have an active means of monitoring them	Coastal processes can have a profound effect on the surrounding land and it would be extremely useful to have an active means of monitoring them

19. English Nature, the development of remote sensing techniques for marine SAC monitoring, 2003

Measure	**Location**	**Extent**	**Condition**	**Change**	**Dynamic environment issues**	**Ecosystem services**
Characteristics of the method & evidence of likely applicability	Saline lagoons, inter-tidal mudflats, vegetated coastal shingle, saltmarsh and sand dunes habitats were targeted to asses the ability of remote sensing to determine them within candidate SACs.		Not considered in this work	For most habitats data from 2 different years was used allowing a simple change analysis looking at class area was attempted with varying success.	Some evaluation of change in habitat morphology was considered as part of the change assessment which would give indication of dynamic trends within the system. For some of the habitats imagery was captured at low tide to minimise the tidal effect when considering change.	Not considered in this work
Data / information sources used	CASI, LiDAR, high resolution DEM, aerial photography, expert knowledge.		Not considered in this work	As above	LiDAR time series for shingle morphology evaluation	Not considered in this work

Indicative accuracy / Fitness-for-purpose	**Saltmarsh -** there were issues with the classification as the 2 different years were captured at different times of year which confused the classification specifically for pioneer species. **Sand dune -** The final classifications for both the 2001 and 2002 imagery resulted in very similar class accuracy values. Most of the classes for both years have User"s accuracy values of greater than 80% (with the exception of the Dune slack class) indicating a good final classification. **Saline lagoons -** Generally there was good agreement between the areas determined by CASI and digital photography, especially in 2002. There are greater differences in the estimated lagoon areas from each of the two sensors from the 2000 data than the 2002 data, due to the difference in image capture date, therefore changes in tide, rainfall or evaporation. **Mudflats -** there were issues with the quality of the ground control data so no accuracy assessment was undertaken. **Vegetated shingle -** The Rye classifications indicate that multispectral remote sensing has the potential to discriminate between some of the general habitat types present on vegetated shingle. However, it has difficulty in discriminating between some species, particularly those that cover small proportions of the shingle.	Not considered in this work	**Saltmarsh** - meaningful land cover change analysis was not possible due to the large differences in the classifications, possibly from the different time of year capture of the imagery. **Sand dune** - A simple change analysis using class areas appears to be possible, but care needs to be taken to ensure that differences seen are the result of genuine change rather than artefacts of errors within the data layers used. **Vegetated shingle** - change in volume of shingle, range and profiles were attained using a series of LiDAR data and high resolution DEMs where available to pick up significant change in morphology.	Not specifically considered in this work	Not considered in this work
Scale of work	Testing of the methods were undertaken at a range of candidate SAC sites around the English coast.	Not considered in this work	As above	Not specifically considered in this work	Not considered in this work
Characteristics of the technique - and stage of development of each	At the time this project was completed most of these techniques were fairly novel and not very well established, although more work had been done looking at saltmarsh mapping. **Saltmarsh** - method was tested at 1 specific site, Tollesbury. It ended up using a combination of the CASI multispectral data and a 1m DEM from the LiDAR, to allow stratification based on tidal inundation and presence of creeks. A MLP neural network classifier was used with 500 ground control points. There were a large difference in the classifications between the September 2000 and June 2001 data, due to different points through the growing season. **Sand dune** - a 3 stage approach was used. A MLP neural network classifier was used with CASI and LiDAR slope classification to establish vegetation types. This was manually QA'd in an expert system classification to remove errors predominantly from shadow. Dune slacks were then distinguished by using the LiDAR slope data to isolate areas of low slope <3° and <2° these were combined with a MMU of 60 pixels into a dune slack layer. **Saline lagoons** - an unsupervised classification was undertaken on both CASI data and air photography for 2000 and 2002 data. LiDAR was used to help differentiate between areas of shallow water, mud and algal blooms. **Mudflats -** unsupervised classification using ISODATA algorithm using	Not considered in this work	For most habitats a simple change analysis using class area was attempted with varying success (see fitness-for-purpose column). The success seems to be most affected by the quality and capture date of the imagery used.	Not specifically considered in this work	Not considered in this work

	CASI, LiDAR and aerial photography captured in September 2002. **Vegetated shingle** - CASI data from 2000 and 2002 was used with a MLP neural network classifier, the classification was compared with Rye ground survey data from 2000.				
Known gaps in provision	Each habitat classification was only tested at one location therefore no determination of geographic transferability was included.	Not considered in this work	Due to differences in the imagery, from different tidal states, and differences in the time of year the information was collected not all habitats were successfully evaluated for change.	Not specifically considered in this work	Not considered in this work
Potential Issues	The resolution of the CASI multispectral data is too coarse to be used for determination of a number of vegetated shingle species. Unsupervised classifications have limitations in classification, however some of these issues have been mitigated by the use of geoinformatic techniques.	Not considered in this work	Where there is variation in the imagery temporal, or quality including artefacts change determination has to be very carefully considered for meaningful variation to be established.	not specifically considered in this work	Not considered in this work
Future potential uses	This work compared the ML classifier with the MLP neural network classifier and in every case it was found that the more sophisticated MLP classifier was more suitable. Evolution of habitat classifiers lead to a potentially better result and improvement of techniques. Being open to these advances in knowledge allow a better result to be obtained.	Not considered in this work	This work had some good ideas in the use of LiDAR for morphological variation	Not specifically considered in this work	Not considered in this work
Development of the technique	With more robust training data extent could have been better determined for all the habitats. This is a good example of using multi spectral data with LiDAR and other ancillary data to get a remotely sensed result.	Not considered in this work	With more robust and repeatable methods change can be reliably determined. Using higher resolution data the finer vegetation types may also be determined.	Not specifically considered in this work	Not considered in this work

20. Remote sensing of bog surfaces JNCC

Measure	Location	Extent	Condition	Change	Dynamic environment issues	Ecosystem services
Characteristics of the method & evidence of likely applicability	The bog area was manually masked out of the image. The classification was then achieved by using a variety of data across the sites. the Ikonos satellite sensor data, with 4m resolution in multispectral mode; Airborne Thematic Mapper (ATM data captured by NERC; aerial imagery RGB. Both unsupervised and supervised classification (maximum likelihood) techniques were used to identify different bog features. LiDAR was also used in a supporting role, but it was mainly interpreted by eye.		The combination of automated and visual classification enabled classes from 'Lowland Raised bog inventory' to be defined spatially.	Not considered within this study.	Study demonstrates methods that reveal spatial distribution of the bog land cover classes, which could be applied to other sites. The classification results were not used for ecological assessment.	Includes information on water retention and carbon storage, however this project does not consider ecosystem services directly.

Data / information sources used	**Imagery:** Ikonos satellite sensor data using the three visible bands, and the NIR for delineation of the outer boundary (Wedholme Flow), ATM data flown by NERC (Cors Caron), and aerial imagery (Ballynahone Bog). Some LiDAR data was used, however extent was limited. **Known software:** ENVI. Classification classes based on either habitat type or the Lowland Raised Bog Inventory (LRBI) (Lindsay and Immirzi, 1996). **Expert knowledge:** ecology of the environment assessed - desirable remote sensing expertise - essential	Field work carried out prior to study. 20 3x3m quadrates were mapped according to landcover classes.	Not considered in the work	Not considered in the work	Not considered in the work
Indicative accuracy / Fitness-for-purpose	The technique is simple to repeat and with sufficient satellite data and a dedicated field visit the method is easily repeatable for other sites across the UK. Study demonstrated the that feature extents were clearly defined using various image manipulation techniques. Subtle boundaries were also picked up in relatively undisturbed areas.	With the addition of visual interpretation, condition could be assess using the Lowland Raised bog inventory classes.	The assessment of change using this method would be only limited by the comparable data availability.	Could be used for limited habitat structure assessment, but only with addition manual quantification.	Sites visited were suitable for ecosystems work, however this technique is unlikely to be used to assess large scale areas (regional) due to consistent data availability
Scale of work	Three locations within the UK. Wedholme Flow in Cumbria, Cors Caron (Tregaron Bog) in mid-Wales and Ballynahone Bog in Northern Ireland. Size of sites ranged from 243 to 816ha.	Not considered in this work	Not considered in this work	Could be repeated on similar sized areas	Could be repeated on similar sized areas
Characteristics of the technique - and stage of development of each	Pre-processing of satellite data: well established techniques. Accurate image registration considered necessary for good results. Supervised classification (maximum likelihood): segmentation is established technique.	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Known gaps in provision	Inconsistent data used across the three study sites. At the time of the study, data availability, in particular LiDAR, was a restriction to the study.	Not considered in this work	Not considered in this work	Not considered in this work	Not considered in this work
Potential Issues	Relies on the quality of the imagery and ancillary datasets. In the case of Wedholme flow, the Iknos imagery, Sept and Oct scenes were used, which might have placed limits on there classification. An airborne MS data October image was used was for classification of Corrs Caron, which may limit the potential of the classification.	Inconsistency across data sets	Inconsistency across data sets	Inconsistency across data sets	Inconsistency across data sets
Future potential uses	There may be issues of translation of the methodology to other biogeographical areas, depending on data availability.	Established method which can produce consistent but limited classification results, limited by ecological expertise.	Established method which can produce consistent but limited classification results, limited by time series available.	Established method which can produce consistent but limited classification results, limited by ecological expertise.	Spatial extent too limited for large scale ecosystem assessment.
Development of the technique	There is potential to improve the use of LiDAR data with an improved methodology such as advanced classification methods thus limiting the need for manual interpretation of elevation data, and allowing these data to add value to the classification.	Purposely tasked data capture in high resolution multiband imagery would greatly improve the quality of the output for this purpose.	Purposely tasked data capture in high resolution multiband imagery would greatly improve the quality of the output for this purpose.	Purposely tasked data capture in high resolution multiband imagery would greatly improve the quality of the output for this purpose.	By using more current, widely available (more expensive) datasets with consistent coverage (commercial data).

21. Scottish Government Peat Erosion pilot

Measure	Location	Extent	Condition	Change	Dynamic environment issues	Ecosystem services
Characteristics of the method & evidence of likely applicability	EO project incorporating several different data sources from airborne and spaceborne sensors as well as thematic information from ancillary vector and raster data sets. The study reports on mapping landcover in a relatively remote area of Scotland through the application of object based segmentation of imagery and their classification using a rule-based scheme. Underpinning the project is a desire to map peat for the modelling of this carbon sink. The accuracy assessment indicates that the approach is applicable in this context.		The extent of the peat in the study area is assessed and forms the basis of the classification. The issue of mapping heterogeneous or transition landcovers is discussed in the report.	Although essentially a one-off classification, the report does consider change by comparing the outputs to stereo-pair photography dating from the mid-90s. Manual assessment of this kind is valuable for certain key sites but for wider monitoring may not be particularly effective. Now that a baseline has been established through the study, change can be monitored by using comparable imagery for future census dates.	The peatlands are dynamic and the erosion and gullying dynamic features. The methods used have been shown to be applicable.	As a set of methods, this report produces a product that could be integrated with ES. In this context the product delineates the spatial extent of exposed peat, intact peat, vegetated bog surfaces, which enable the modelling of this carbon store.
Data / information sources used	ASTER, IRS P6 and SPOT5 satellite imagery in combination with aerial photography. Thematic information from vector and raster data sources: MasterMap, NVC, soils, DEM from NextMap etc.		As above.	As above. Could utilize time-series CIR imagery from unmanned aerial vehicles for classification purposes and high resolution DEMs from the same source. These would enable detailed monitoring of change, particularly gully depth following storm events.	As above. Could utilize time-series CIR imagery from unmanned aerial vehicles for classification purposes and high resolution DEMs from the same source. These would enable detailed monitoring of dynamic processes such as gullying.	As above
Indicative accuracy / Fitness-for-purpose	Landcover is mapped to an overall accuracy of 75% with significantly higher accuracies for more homogeneous components. An accuracy assessment is also used, with classes of a similar ecological make up accepted as being of a plausible fail, and included as correct.		Fit-for-purpose but could be refined.	Although not the main thrust of this study, change detection could evolve from this work.	Method is suitable but could be further refined through the generation of high spatial resolution DEMs.	Not discussed in this context.
Scale of work	Monadhliath Mountains in Scotland (319 sq km)		For landcover condition mapping the resolution of the imagery is appropriate. Likewise the higher resolution RGB aerial photography is good for mapping the scale is appropriate for mapping gullies and bare peat.	The scale of change has to be comparable to the spatial resolution of the imagery used. In this respect, small scale (sub 5m) changes will not be detected if SPOT5 imagery is solely utilised.	High resolution airborne imagery could greatly assist the monitoring of this dynamic area.	Not discussed in this context.
Characteristics of the technique - and stage of development of each	Pre-processing of aerial photography, ASTER, IRS and SPOT5 imagery: well established techniques. Accurate image registration considered vital for good results. Integration of thematic information from vector and raster data sources: MasterMap, NVC, soils, DEM from NextMap etc. Various classification schemes assessed (pixel based e.g., Maximum Likelihood, K means) but multi-level image segmentation with a rule-based classification was		As above.	Manual comparison in relation to stereo-pairs discussed. Needs to progress to a comparison of automated classifications for different census periods.	DEM generation methods would need to be employed if temporal stereo-pair imagery could be acquired in the future. Segmentation and rule-base classification are well defined but may need to be refined to account for future image acquisitions.	Not discussed in this context.

	used. Although still novel, such an approach is quickly gaining recognition. Object-orientated rule-based classification: Both single thresholds using Boolean (logical) operations and fuzzy membership is used Geoinformatic techniques such as fuzzy rules: recent.				
Known gaps in provision	Accuracy of DEM limits the extent to which it is possible to accurately map the depth of gullies, particularly if gully depth change is being monitored in any future study employing the same methods.	High resolution DEMs capable of assessing gully depth. Increased spectral capabilities through using hyperspectral technologies should allow for an assessment of peat composition.	Change detection methods are not discussed. These would need to be developed.	Classification of heterogeneous landcovers and severity of gullying.	Not discussed in this context.
Potential Issues	Question of classifying transition cover types as there are no hard lines between types. Field data collection accuracy issues regarding to the GPS instruments used.	Potential confusion between transition landcovers having a negative impact on classification accuracies.	Acquisition of imagery with little or no cloud cover.	Regular or appropriately timed acquisition of higher resolution imagery (most probably airborne).	Not discussed in this context.
Future potential uses	Combination of airborne and spaceborne imagery provides an opportunity for consistent, objective mapping, from a selection of sensors over a range of mapping scales.	Map changes to gully systems after storm event through the generation of detailed DEMs from stereo-pair images captured from unmanned aerial vehicles.	Provided appropriate imagery is acquired, the methods described in the report could be used for mapping changes in landcover, landcover condition and extent of gullying.	Combination of airborne and spaceborne imagery provides an opportunity for consistent, objective mapping, from a selection of sensors over a range of mapping scales	Could be integrated within ES.
Development of the technique	Additional data sources could be used to refine the classification as well as other imaging platforms to allow monitoring of change. In terms of data, radar to extract structural information; hyperspectral to differentiate species and condition. In terms of platforms, unmanned aerial vehicles are suggested for more routing monitoring of such sites to enable the acquisition of time-series high spatial resolution imagery.	Further refinement of the decision rules and field work may lead to an improvement in the classification accuracies. Incorporation of CIR aerial photography may make a significant improvement to classification accuracies.	Not discussed in the report.	Would need to incorporate higher resolution DEMs to the rule base.	Not discussed in this context.

22. The application of remote sensing to identify and measure changes in the area of moorland which has been burned as part of a management system NE

Measure	Location	Extent	Condition	Change	Dynamic environment issues	Ecosystem services
Characteristics of the method & evidence of likely applicability	The location and extent of *Calluna* dominated vegetation was established using segmentation from Ikonos imagery and the NE Upland heath and blanket bog habitat datasets. This formed an early part of the process to stratify the imagery to limit the spectral differences and target the burn classification.		Work originally undertaken as auditors highlighted the large amount of time staff were required to spend on moorland burning without a specific monitoring program in place. Object orientated approach to identify areas managed by burning in upland moorland. The Ikonos imagery was segmented at progressively coarser segment sizes until *Calluna* dominated areas were separated. This was used to create a mask to exclude any vegetation that was not *Calluna* dominated. A secondary mask was created to include areas of bog and heath habitat that were not included in the *Calluna* mask, for visual inspection by NE during each monitoring round as bracken and 'scraggy' vegetation patches can also be affected by burning. Segmentation was completed on the clipped out area comprising *Calluna* dominated vegetation, starting at 45 and increasing in segment size until the polygons were equal to the smallest visible burns. Training data for the burn classification was provided by API. It was determined in phase 1 of the project that there was a high level of concordance between API and ground cover recorded in the field. The classification system originally used was that developed by Yallop et al. 2006, specifically for interpretation of burns from API. It divides the *Calluna* vegetation into 4 classes, Class 1 (new burn with no visible *Calluna* re-growth); Class 2 (older recovering burn with partial canopy of *Calluna* visible); Class 3 (old burn, complete dense canopy of *Calluna* visible); Class 4 (no burn visible, recognisable as older and degenerate *Calluna*); Class 4 incorporates all *Calluna* in the English uplands as all of it has been burned at some point during its history.	The report suggests with the ability of the technique to be transferred to a larger area that it is suitable for use as a national monitoring scheme. After a baseline is created, repeat burn classification would allow monitoring of the frequency of heather burning.	Not considered in this work	Not considered in this work
Data / information sources used	**Imagery:** Quickbird, Ikonos and SPOT imagery was all trialled in the first phase of the project with Ikonos being used for phase 2 due to its spatial resolution and coverage of the study area. It was found that imagery with a resolution of less than 4m was required to achieve the required accuracies. **Other data:** NDVI, NE Upland heath and blanket bog habitat datasets **Software:** Definians Developer for the production of the *Calluna* mask and burn areas, ESRI software was suggested as the platform for the GIS management tool			Complete VHR area coverage (<4m resolution) is required for repeat analysis and therefore change.	Not considered in this work	Not considered in this work
Indicative accuracy / Fitness-for-purpose	The location and extent of the *Calluna* was a side product and used for masking out other vegetation types which were not likely to be burned as part of management practices, therefore accuracies were not specifically considered, however visual inspection incorporated all *Calluna* dominated vegetation into the mask, therefore making it fit-for-purpose. NE staff very happy with result.		The accuracy of classification of burns that are <3 years old (Class 1 new burns) across the North Yorkshire Moors National Park met the initially stated required accuracy of >90%. Modifications to the mask which were specific to the region were required which required local knowledge, such as the inclusion of scraggy vegetation and bracken which occurs within areas of bog and heath which may also be burned during management.	For a monitoring system, regular repeat imagery would be necessary which would be very expensive but this is potentially still cheaper than current surveillance methods.	Not considered in this work	Not considered in this work
Scale of work	In Phase 1 of the project, the development of techniques was tested in 3 trial areas of England, the main trial area was a 50km^2 area in the Cheviots, with an 50km^2 area in the Yorkshire Dales and a 25km^2 area in the Peak District were used to test the method in different geographic locations. These areas were chosen as the imagery available for them had less than 20% cloud cover, and they exhibited a high intensity/ density of burn management. Phase 2 rolled out the method over the majority of the *Calluna* dominated moorland in the North Yorkshire Moors National Park.			Not considered in this work	Not considered in this work	Not considered in this work

Characteristics of the technique - and stage of development of each	**Pre-processing of satellite data** well established techniques. Accurate image registration considered vital for good results. Including ortho-correction and radiometirc correction **Image segmentation** well established technique creating parcels of land on their spectral differences, used in a multi stage segmentation approach firstly to create the mask, then to define areas which had been burned **Classification** Using training data - well established system of automated classification **Proposed monitoring system** Set up in ESRI with a heather burn management tool that allows different datasets to be displayed. 3 tier grid system of 'burn intensity' (10km/1km/100m depending on scale interested in) and the burn map clipped to various criteria, such as proximity to dwellings, woodland or water courses.		does not go into detail about how it intends change to be monitored just that this system would allow new burns to be detected therefore changes in the management and changes in the vegetation stages to be addressed.	not considered in this work	not considered in this work
Known gaps in provision	One of the scenes in the North Yorkshire Moors National Park was badly affected by snowfall therefore that area was not included in phase 2 of the project. Also the VHR data needed for the classification is not available for the whole of the NYM for the same year, and there are gaps in the provision of the imagery for rolling it out nationally which would need commissioning.	This method was only able to determine the 'new burns' those with less than 3 years growth at image capture, with a high degree of accuracy. Older stages of re-growth of vegetation were not easily differentiated, therefore were all just classified as background *Calluna.*	Repeat processing would need to be undertaken with new imagery in order to determine change	not considered in this work	not considered in this work
Potential Issues	Funding for roll out of system and capture of repeat imagery.	Differences in scale, accuracies and definitions of spatial datasets which have been used in conjunction to create models for the GIS monitoring system. Program needs rolling funding for repeat imagery and processing to make it a successful monitoring program.	not considered in this work	not considered in this work	not considered in this work
Future potential uses	Targeting restoration effort for bog habitat	Additionally proposed management GIS tools have been devised by the project, looking at sensitive areas, areas where particular care should be taken and areas where it is unlawful to burn. This can be used for managing burning and habitat regeneration, allowing more sensitive areas to be allowed to recover for longer, or not to be burned at all. Imagery for the whole of the North York Moors was collected in 2009 ADS40 to take the project forwards however this has not been capitalised upon yet. Has potential for being used for targeting blanket bog restoration. Also work in Leeds looking at colour of water in the uplands and invertebrates, finding higher Carbon in areas with more burning and consequently fewer invertebrates.	not considered in this work	not considered in this work	not considered in this work
Development of the technique	This project developed the technique to a point at which it would be possible to roll it out wider, although parameters within the method may have to be tweaked for different locations.	This project developed the technique to a point at which it would be possible to roll it out wider, although parameters within the method may have to be tweaked for different locations.		not considered in this work	not considered in this work

23. Random Forest characterization of upland vegetation and management burning from aerial imagery

Measure	Location	Extent	Condition	Change	Dynamic environment issues	Ecosystem services
Characteristics of the method & evidence of likely applicability	Location and extent of upland land-cover classes was established from colour and infrared aerial photography using training points on the ground and from API and the Random Forest ensemble machine learning algorithm. Seven upland land-covers were first classified, and then subsets of these land-covers classified further; *Calluna vulgaris* areas were differentiated into growth phases, including recently burnt sites. Applicable in upland areas which are difficult to map on the ground; allows rapid classification of heather growth phase which is highly labour intensive on the ground or using API.		Four growth phases (including 'newly burnt') of heather were classified, and then areas misclassified as 'newly burnt' heather were reclassified using reflectance values and landscape context parameters (*e.g.*% edge pixels). Facilitates analyses of extent of heather management in region	Report suggests that the technique could be applied to enforce prescriptions of agri-environment schemes and monitor the effects of environmental change. Burning may be currently deployed on sensitive steep slopes, for example; this practice is not recommended and monitoring of its occurrence could facilitate appropriate policing of the practice.	Not explored in this paper	Not explored in this paper
Data / information sources used	**Imagery:** true colour RGB and false colour infrared aerial photography at 25cm resolution (Infoterra Ltd.), all orthorectified to 1m accuracy. **Other data:** Stratified sampling of dominant vegetation stands at 1540 points across the Peak District. Points geo-located using hand-held GPS **Software:** ESRI ArcMap 9.2 to calculate reflectance statistics and create mask; R package used to classify the imagery using 'random Forest'			Not explored in this paper	Not explored in this paper	Not explored in this paper
Indicative accuracy / Fitness-for-purpose	Cross-validated and unbiased 'out of bag' accuracy estimate for the broad vegetation classes was 94.3%; accuracy of subsequent classification of 'heather' class 95.3%. Reclassification of misclassified 'newly burnt heather' achieved 83.1% accuracy. Overall accuracy estimated to be 90-95%; collection of further training data from mixed land-cover areas could improve this. Reliable classification of upland land cover and heather growth phases rendered this highly fit for purpose.			Not explored in this paper	Not explored in this paper	Not explored in this paper
Scale of work	Classification gave a 5-m pixel map of land cover for 514km^2 of unenclosed moorland in the Peak District National Park			Not explored in this paper	Not explored in this paper	Not explored in this paper
Characteristics of the technique - and stage of development of each	**Process imagery**: Calculate reflectance ratios and aggregate to 5m pixels. Well established techniques. **Classification:** Broad land-cover classes x7; heather subsequently classified into 4 growth phases. Misclassified newly burnt heather reclassified, post-processing. Comparatively recent application of Random Forest classification technique			Not explored in this paper	Not explored in this paper	Not explored in this paper
Known gaps in provision	Aerial photography widely available. Some further geo-located training points may have improved the classification accuracy.			Not explored in this paper	Not explored in this paper	Not explored in this paper
Potential Issues	Availability of suitable training points to base classification on could become an issue if rolled out to larger areas			Availability of suitable training points and especially of aerial photography from a similar point in the growing season in subsequent years is likely to determine potential success of change analysis	Not explored in this paper	Not explored in this paper
Future potential uses	Targeting of conservation and restoration of upland land-cover types		This paper conducted further analyses to establish the incidence of occurrence of managed burning, and particularly advocates use of the technique to monitor burning practices, particularly in areas identified as sensitive. Use in planning conservation and restoration measures, enforcing agri-environment scheme prescriptions and monitoring effects of environmental change		Not explored in this paper	Not explored in this paper

Development of the technique	Technique demonstrated as effective and accurate; should be easy to apply to other areas, contingent on availability of appropriate aerial photography (generally widely available) and geo-located training points	Repetition of analyses could enable analyses of change; this was not explicitly considered in this paper	Not explored in this paper	Not explored in this paper

24. Integrated Assessment of Countryside Survey data to investigate Ecosystem Services in Great Britain

Measure	**Location**	**Extent**	**Condition**	**Change**	**Dynamic environment issues**	**Ecosystem services**
Characteristics of the method & evidence of likely applicability	Reports on data collected in the Countryside Surveys, alongside other relevant datasets, to provide integrated assessments of a range of indicators of ecosystem services at the national scale.		The Countryside Survey does capture condition and the availability of a time-series spanning near thirty years allows condition change to be mapped over time. However, snapshots every decade will not provide information on the rate of change between these census dates.	Change between data of different Countryside Survey census dates incorporated.	The relative coarseness of the grid may make the input data ineffective at capturing more complex local changes in dynamic environments.	Integral component of the report
Data / information sources used	Countryside survey includes measures of soil, water, vegetation and landscape. 38 biophysical variables measured in CS were identified as potential indicators of ecosystem service provision relating to different aspects of landscapes and ecosystems: 11 for headwaters, 3 for ponds, 8 for soils, 10 for wild species diversity and 6 for cultural aspects of landscapes. Focuses on Broad Habitat types with a representative sample of the major land classes at a national scale		As above	Data / information sources used	Not considered in this report	As above For the macroinvertebrate communities - each CS square for each survey was summarised as biotic indices - Average Score per Taxon (ASPT) and Biological Monitoring Working Party (BMWP). E.g. 'Appropriate Diversity' - measured by the species richness and cover of Common Standards Monitoring (CSM) Indicator species in Countryside Survey vegetation plots. Species selected included were those referable to Biodiversity Action Plan Priority Habitats within Common Broad Habitats in Britain.
Indicative accuracy / Fitness-for-purpose	Both spatial and temporal analyses seem fit-for-purpose.		For relatively long term condition mapping this is good but the sampling unit may be too coarse to capture more subtle condition changes.	Ideally suited to UK-wide change mapping on a decadal level.	Not considered in this report	Appropriate.

Scale of work	Countryside survey is mapped on a 1km grid and covers both terrestrial and freshwater ecosystems. Analysis takes place at different scales UK and then at national level.	UK-wide grid	UK-wide grid. Service relationships change according to the scale at which they are observed. They also vary by habitat according to biotic and abiotic processes. The coarseness of the grid may not capture these dynamic and complex relationships which are influenced by the variation in ecosystem properties and habitats and the variation in policies and land management.	Not considered in this report	UK-wide grid
Characteristics of the technique - and stage of development of each	In most cases the report documents quantitative methods of comparing different Countryside Survey variables. Correlative relationships between ecosystem service indicators across Britain are discussed. Multivariate analysis at low and high spatial resolutions undertaken.	Correlation and multivariate analyses of ecosystem services. By creating an ordination space of ecosystem service indicator values within the survey plots across UK ecosystems, it is possible to infer the major ecological gradients that appear to constrain biodiversity and its relationships with ecosystem services at the large scale.	Well developed.	Not considered in this report	Well developed e.g., for soil carbon a flow diagram is presented indicating how data integrates for the benefit of ecosystem services.
Known gaps in provision	The countryside survey does not provide representative coverage of coastal and urban habitats. Gaps in data - limited soil and water sampling in 1km squares and from timings of surveys. Rationale behind the specific surveys at the time of their initiation and the temporal structure of the surveys.	Temporal data is only available for a selection of ecosystem services.	In terms of soil carbon, there are limitations in A) sampling - limited to top 15cm, therefore changes in lower horizons cannot be quantified. B) No measure of erosion loss - surface erosion losses will effectively result in sampling of lower soil horizons in later surveys C) Variable depth sampling in peat soils - organic horizon in peat soil is at least 40cm deep and therefore a loss or gain is not likely to be reflected in a 0-15cm fixed depth sample.	Not considered in this report	Seems well covered. The survey demonstrates ways to quantify and measure Ecosystem Services but does not attempt to value the ecosystem services it reports on.
Potential Issues	There are Indications that there may be many associations specific to individual habitats or to subsets of the data which cancel out and/or fail to achieve significance at the broad GB scale reported in the CS survey.	There is a risk that ecological responses over time cannot be easily coupled with datasets [e.g. agri-environment] that track positive management impacts [therefore] large scale attribution results from the survey will be biased towards expressing the effects of negative drivers	Not considered in this report	Not considered in this report	Lack of detailed land management data i.e. finely-resolved data on the history of management impacts linked to agri-environment scheme prescriptions. Difficult to quantify the effects of habitat maintenance and restoration efforts. Lacking relevant social data at the 1km square level.

Future potential uses	Mapping and/or Modelling Ecosystem Services. Although this is restricted by data availability	Not considered in this report	Not considered in this report	Not considered in this report	Values of ecosystem service indicators can be predicted in terms of the proportion of Broad Habitats present in a 1km square. This offers the prospect of a model-based mapping of a range of ecosystem service indicators across all 1km squares in the UK
Development of the technique	Further attribution of change at a range of spatial and temporal scales, data on explanatory variables are required at a sufficiently high resolution.	Not considered in this report	Not considered in this report	Not considered in this report	There is a need to close the gap between the differing aims and perceptions of researchers and policymakers with regard to ecosystem service research including assessment initiatives. Further work is needed to provide assessments of equivalent detail for other ecosystem services and their indicators.

Phenology And Vegetation Earth Observation Service (PHAVEOS)

Measure	**Location**	**Extent**	**Condition**	**Change**	**Dynamic environment issues**	**Ecosystem services**
Characteristics of the method & evidence of likely applicability	Utilises the MERIS (Medium Resolution Imaging Spectrometer (MERIS) on-board ENVISAT launched in 2002 to enable the monitoring of vegetation change at a 300m resolution ever 2-3 days across the UK and Ireland. A four level approach, Level 1, data is geometrically, radiometrically and atmospherically corrected. Level 2, Biophysical parameters and indices are derived using biophysical algorithms and the data resampled and composited to a 250m spatial grid. Level 3 output products are then created including composite vegetation maps. Additional modelling steps are applied creating a time series of Level 4 biophysical maps which retain daily temporal resolution, but with full spatial coverage.		Leaf Area Index, fraction of Absorbed Photosynthetically Active Radiation and the MERIS Terrestrial Chlorophyll Index.	Temporal resolution of 2-3 days with a time series of ~10y, thus allowing possible change detection over a limited period.	Temporal change in carbon storage or productivity on a large scale.	Carbon storage
Data / information sources used	Level 1b MERIS 15 band 300m resolution imagery which is geometrically, radiometrically and atmospherically corrected through the use of various MERIS processing tools such as Accuracy MERIS Othro-Rectified Geo-location Operational Software (AMORGOS) and the BASIC Envisat AATSR and MERIS toolkit (BEAM).	UK and Ireland wide with extents constrained by the area of data acquisition, snow and cloud cover on the day.	Only a data product in this paper	Only a data product in this paper	Only a data product in this paper	Only a data product in this paper

Indicative accuracy / Fitness-for-purpose	On a UK wide scale, data appears useful, however it is likely that on a smaller site basis a larger error may be introduced.	Scene covers a large area, however could be degraded by cloud cover.	Would be good for assessing productivity of particular large scale habitats or landcover units. Maybe more suitable for Corinne landcover mapping at present. More detailed mapping maybe possible in future developments.	Could be applied to a sub-decade change study.	Resolution to course for detailed habitat assessment.	Applicable for large scale(up to national) studies.
Scale of work	UK and Ireland wide over a 250 m grid if data is available	UK wide	Only a data product in this paper	Only a data product in this paper	Only a data product in this paper	Only a data product in this paper
Characteristics of the technique - and stage of development of each	Standard pre-processing techniques used on the Level 1b imagery using specialist software designed for the purpose. Data resampled and various standardised indices such as the MERIS Terrestrial Chlorophyll Index (MTCI) used.	NA	NA	NA	NA	NA
Known gaps in provision	Some areas are subject to high levels of cloud or snow cover.	NA	Only suitable of large habitat areas	Limit temporal extent therefore only allowing studies on a sub-decade level.	Only suitable of large habitat areas	None known
Potential Issues	Knowledge gaps in methodology.	Availability of data.	Resolution of data could limit any habitat condition study using these data.	Temporal availability of data could limit any ecological change study using these data.	Resolution of data could limit any dynamic environment issues studies using these data.	New methodology.
Future potential uses	G Mosaic - Project looking at forest degradation in the Democratic Republic of Congo. CFAS - Coastal monitoring looking at sediment deposition in intertidal areas such as the Wash. Monitoring the state of all woodland in the UK, rather than the current 20 sites through forest research. Monitoring of indicators of drought areas within the worlds arid areas, and insurance claim verification across areas such as farming.	Could be applied to any area covered by MERIS, only limited by computer processing power.	Quantify vegetation productivity but on a large scale (250m grid squares). Wide-scale quantification of leaf are index	Could be used to measure phenological variables	NA	Wide-scale quantification of changes or carbon flux over time.
Development of the technique	Requirement for characterisation of vegetation parameters in relation to noise issues within the data. Also requirement for ground truthing of datasets. Plan also to expand the product range through the inclusion of a second fAPAR (fraction of Absorbed Photosynthetically Active Radiation) parameter.		Linking MERIS chlorophyll Index to condition of large scale habitats	Possible time-series extension using addition data sources. Plan to utilise Sentinel 2 data with a 20m resolution to allow for a far more detailed assessment of change to be made. Temporal resolution will be lower though due to the longer revisit time.	Use higher resolution Sentinel 2 data could make this more applicable and enable the feedback into national ecosystem assessment and climate change.	Linking MERIS chlorophyll Index to biomass and carbon storage.

Support to Defra EO Strategy Development on Land Observations - 'hub' and 'spoke' project

Measure	Location	Extent	Condition	Change	Dynamic environment issues	Ecosystem services
Characteristics of the method & evidence of likely applicability	This project tests the potential of a 'collect once, use many' philosophy, whereby airborne and spaceborne imagery are integrated for use in as many applications as possible through the basic classifications of generic classes and their dissemination via the web. The main driver for the work is to make EO derived products available to decision makers across a wide range of policy issues. The term 'hub' is used to convey the data repository, with 'spokes' delivering online products to users. The processed imagery aims to provide a baseline for woodlands, land parcels and land cover, which can then be used for detecting woodland change, landcover change, flood management, responses to animal disease outbreaks etc.		Mentioned in part in the example focussing on land cover classification to identify deductible features. This is based on a landcover classification product.	Considers change with respect to woodlands based on recent and archive aerial imagery.	Tends to take a broad brush approach to provide generic products. Data set could be used for dynamic environments but data would need to be processed appropriately.	Strong linkage here. EO products stemming from the hub could assist in a range of policy areas including agri-environment, flood management, CAP etc.
Data / information sources used	Airborne and spaceborne imagery. These include: current (ADS40) and archive aerial imagery; medium resolution satellite imagery via GMES, DMC imagery for seasonal imagery and other ad hoc imagery. In addition, ancillary vector data for the test sites was used.		Multi-temporal imagery based on aerial imagery and land parcel vector data.	Aerial photography /DMC but could involve data from most air or spaceborne sensor.	Not specifically considered in this work	As above
Indicative accuracy / Fitness-for-purpose	No specific accuracy assessment, however the work was presented at two hands-on workshops, and there was positive feedback from users.		No accuracy assessment provided.	Should be ok, but does not provide an accuracy assessment.	Not specifically considered in this work	unknown as yet.
Scale of work	5 test areas in England (Cambridgeshire, North East Norfolk, Peak District, Devon, Hampshire), covering a cross-section of habitats and topography. Typical size of each area: 50 by 50 km.		At test site level.	At test site level but could be expanded depending on the availability of imagery. Need to investigate woodland classes further. Need more information on classification methods and classes.	Not specifically considered in this work	Test site.
Characteristics of the technique - and stage of development of each	Classified imagery provided at hub level. Classification methods are insufficiently described to comment.		Classification methods unclear.	Classification methods unclear. Change detection is manual. Could be automated.	Not specifically considered in this work	Not specifically considered in this work
Known gaps in provision	Trialled in a few pilot areas. The potential for provision is essentially limitless.		Methods insufficiently described to comment.	Classification methods (info not provided) and automatic change detection.	Not specifically considered in this work	Not specifically considered in this work
Potential Issues	There may be issues in scaling up the system, with management of large datasets		Appropriate time series imagery. Availability of CIR imagery archive.		Not specifically considered in this work	Not specifically considered in this work

Future potential uses	Significant although technique requires more work to determine its reliability.	Significant if technique is deemed reliable.	Significant if technique is deemed reliable.	Not specifically considered in this work	Making sure that users of the products understand the strengths and weaknesses of the data provided.
Development of the technique	It is suggested in the report that the system would benefit from up-dated 'hub' software to allow the integration of raster datasets. Development and testing of the 'spoke' components would allow for better functionality.	Automatic change detection would be better. Needs accuracy assessment.	Automatic change detection would be better. Needs accuracy assessment.	Not specifically considered in this work	Not specifically considered in this work

Section 5 - Briefing papers

5.1 - Geoinformatics paper

Briefing Paper 1

Geoinformatics

Translating Earth observation techniques into cost-effective support for higher priority evidence needs for habitats in the UK

Katie Medcalf

Environment Systems

December 2010

Contents

1. What is geoinformatics and how is it applied

Geoinformatics is the technology relating to the construction and character of spatial information, its capture, processing, classification and evaluation as well as the infrastructure to optimally store and disseminate this information.

This document describes the role of geoinformatics in Earth Observation (EO) techniques for the purpose of constructing habitat inventories and monitoring. It provides a short introductory background for those who are not fully familiar with the concepts.

2. Background - geoinformatics and environmental data

Informatics in its broadest sense has evolved over millennia but large storage devices and high-speed computing have revolutionised the ability to organize and conduct queries on an ever expanding heterogeneous pool of data. An integrated approach based on geoinformatics is considered increasingly important in the drive to address diverse socio-economic challenges brought about by environmental pressures. Responses to such challenges require integrated and innovative solutions for analysing, modelling, managing, and archiving extensive data sets (Sinha *et. al.,* 2010).

The reality of implementing geoinformatics is complexFils *et. al*., 2009 and Butenuth *et. al.,* 2007), depending on the breadth and nature of the datasets under consideration. Nevertheless, the transformation of geoinformatics from a concept into practical reality has already been demonstrated in a variety of disciplines e.g., geology (Sikora *et. al.*, 2006), urban planning (Jang and Sui, 2010), water and energy resources (Gupta *et. al.,* 2010 and Ramachandra, 2010). Geoinformatic approaches are regularly utilised in EO research. The diagram below shows how the concepts of geoinformatics are related.

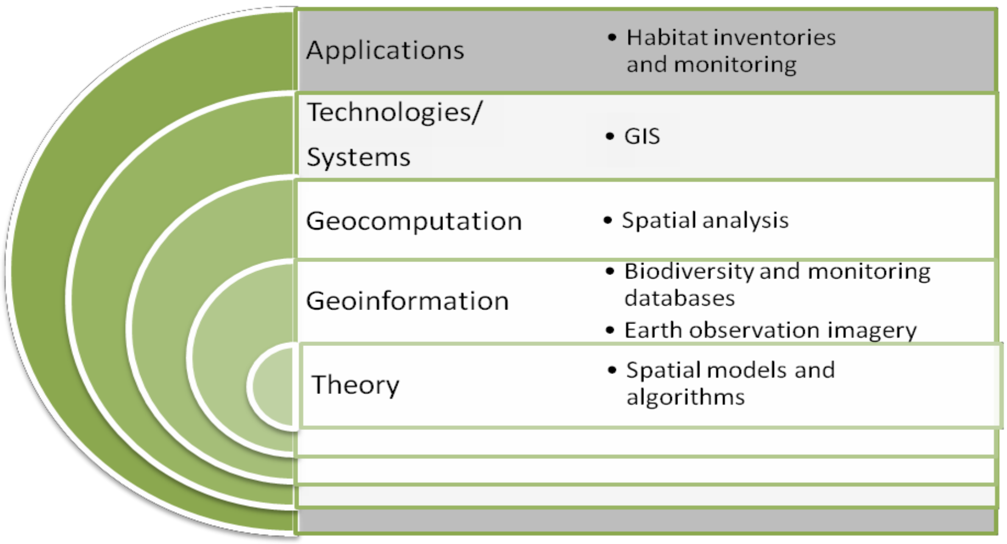

Figure 1: A simplified concept diagram demonstrating the components of a likely geoinformatics system for habitat services (Diagram modified from Geoinformatics Lab, School of Information Science, University of Pittsburgh http://gis.sis.pitt.edu/).

3. Key concepts in geoinformatics

Ontology is one of the key concepts in geoinformatics. Ontology is used to describe the pieces of information that make up the data set, its underling descriptive systems and the relationships between items in the same data set and how they relate to other items in other databases. Computer technology has developed this for web searching functions, using specific words or phrases to draw out disparate pieces of information for example articles, web pages and pictures.

Descriptive work on habitat identification and evaluation has resulted in agreed descriptions for the main inventories (Figure 2) and monitoring methodologies, many of which are available for the same area of land. Ontological descriptions of each piece of data that make up the inventories and ontological descriptions of how the classes from each inventory relate to each other, forms the mechanism for understanding linkages and overlaps.

- Phase 1 Habitat
- NVC Annex I
- BAP Broad Habitats
- BAP Priority Habitats
- Common Standards monitoring
- HLS monitoring - England
- Tir Gofal Monitoring (adapted from Common standards) – Wales only
- Tir Cynnal Habitat Monitoring– Wales only
- RDS monitoring – Scotland

Figure 2: A list of main habitat inventories.

Ordering in a systematic way the issues relating to the inventories and the pieces of information they contain, comes under the general concept of geoinformatic ontology. The diagram below (Figure 3) shows the main components within ontology:

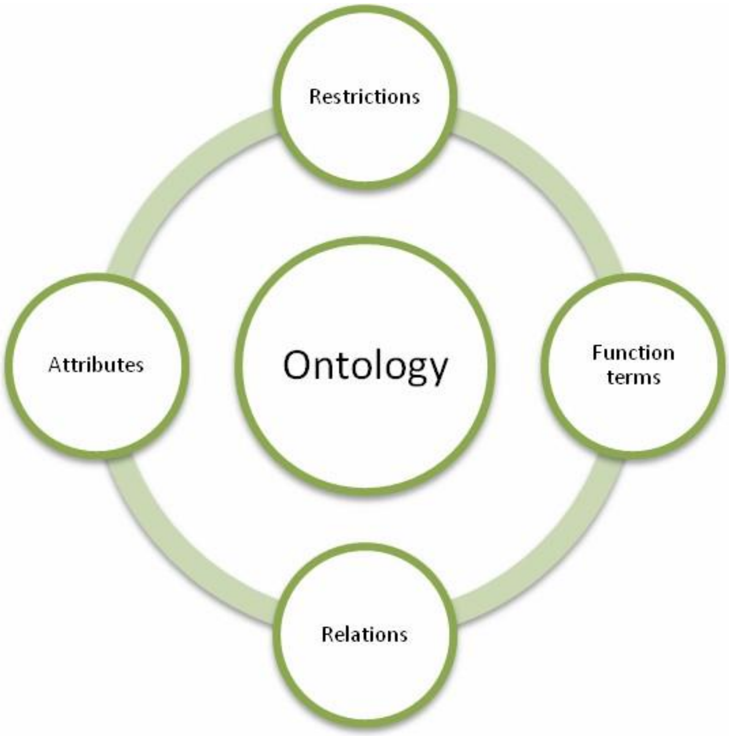

Figure 3: Common components of ontology.

4. Fuzzy logic

Fuzzy logic is a way of describing pieces of information, for example 'classes of a habitat inventory', in relation to how closely they relate to the 'standard' or 'ideal' 'set' of objects relating to this class. An example of this may be a dry acid grassland with common bent and heath bedstraw may be a completely in the centre of the set described as B1.1 upland unimproved acid grassland, in Phase 1 terms. Where this also has a little white clover it may move towards the edge of this set into the overlap with semi-improved acid grassland. The ecological boundary between the two vegetation types is not a hard, but a soft boundary, therefore fuzzy logic is an ideal mechanism for describing this in a mathematically robust way. Fuzzy sets are a development of this mathematical concept since membership of a particular set is treated in a more flexible manner. The term *fuzzy does not mean* a lack of knowledge about the object but rather the capability of algorithms to weigh and combine factors as a gradation rather than as crisp, absolute elements. The diagram below illustrates this concept.

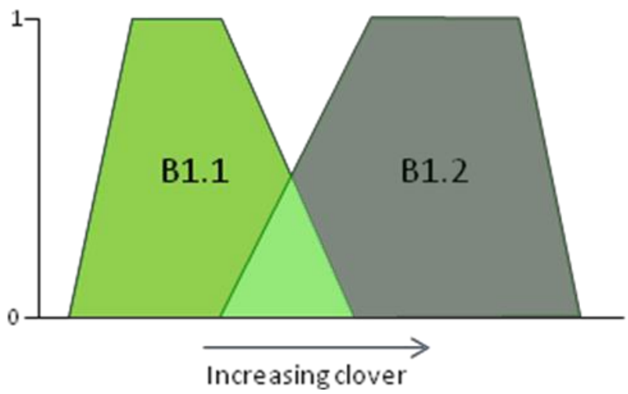

Figure 4: Diagram illustrating the relationship between two fuzzy sets of vegetation communities.

Within field based studies areas of habitat are delineated by precise lines on a map and these are recorded as one (or sometimes a mosaic) of habitats. However, many areas of habitat do not have distinct boundaries and grade from one habitat to another over 10s or even 100s of meters. For example wet heath on a steep slope will grade into blanket bog as the slope lessens; in many areas the habitat will have elements of both communities. Furthermore there may be small areas within the wet heath of rock outcrops or other habitats which although distinct are included in the heath area for mapping purposes. These features are described as mosaics within many mapping systems. Whilst some effort has been made to describe the occurrence of these mixed vegetation types within defined boundaries, there have been limited attempts to allocate confidence limits to the ecotones and mosaics in a statistically structured way. Remote sensing views the habitats from above, edge effects and mosaics are much more readily apparent and geoinformatics has been well utilised to classify boundaries and mosaics in terms of membership and certainty. These very useful geoinformatics techniques could also be applied to field mapping exercises. They would also greatly assist in the situation where two habitats classification systems need to be combined.

Here situations where one class contains aspects of another can be expressed in terms of certainty or membership.

The application of fuzzy logic within an ecological context is well established (Lucas *et. al.,* 2007). The Welsh Habitat mapping exercise undertaken by Environment Systems on behalf of CCW implements fuzzy logic e.g., to differentiate upland and lowland vegetation complexes. In this context it is know that vegetation with certain attributes detected by remote sensing characterise the group of objects that comprise part of the fuzzy set of 'acid grasslands', and using the ability of the computer system it is possible to map membership to that set in terms of how near each of the area of land is to the 'ideal'.

5. Dempster-Shafer belief functions

One of the most powerful tools to be emerging from geoinformatics science is the ability to join datasets with known mathematically rigorous degrees of certainty. In this way it is possible to join knowledge from EO and field surveys to give the most robust description of the map. The integration of different habitat databases is potentially powerful technique but a challenge. In this respect Dempster-Shafer belief theory has been useful in providing the mathematical rigour for this technique. Within Dempster-Shafer belief theory two concepts are particularly useful, these are plausibility and support. An example of how these two theories operate in habitat mapping could be when looking to transfer some information from an NVC field survey to a Phase 1 strategic map. A many to many relationship exists between ‘classes’ i.e., data elements in the two distinct data sets.

As an example consider B1.1, dry unimproved acid grassland, which may contain NVC types U4 (Sheep fescue – common bent grassland), U5 (Mat-grass – Heath Bedstraw grassland), U6 (Heath Rush – Sheep's fescue grassland); however in some circumstances (on deep peat) U6 could be considered also part of E1.8 (dry modified bog). With only this single piece of evidence all that can be construed from joining the two datasets is that U4 and U5 maps to B1.1 but with U6 there is only a certain chance that B1.1 is an adequate Phase 1 interpretation of U6. It is plausible that U6 could be part of B1.1 but not certain. The more we know about the meaning of the datasets the more we can ‘quantify’ our certainty of this chance.

Dempster-Shafer concepts therefore allow the user to represent uncertainty because they allow description of the interval between support and plausibility and therefore enable the development of confidence bands (Tangestani, 2009).This technique has the advantage of being capable of handling virtually all types of data and is a means of quantifying subjective judgements[i]. Additionally it is a transparent process permitting many configurations and iterations such that the end user specialists can be intimately linked to the process itself, which in itself is a powerful attraction for employing such an approach.

6. Where geoinformatics is being used for habitat inventory and mapping

In this project we will identify where these techniques are being implemented and describe the possibilities inherent in this science in terms of habitat surveillance and monitoring. Geoinformatic processes are in-built to many GIS systems but it is rare that the formality of their use to be described and documented. The project will look both at the soft science and the statistical evaluation which have been applied to EO, habitat inventories and modelling data as well as monitoring systems.

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5.2 - Accuracy paper

Briefing Paper 2

Accuracy Assessment

Translating Earth observation techniques into cost-effective support for higher priority evidence needs for habitats in the UK

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January 2011

Contents

1. Accuracy and vegetation mapping

Field based Habitat Mapping

Most habitat maps attempt to turn the complex vegetation patterns found in the field into a generalised, simplified map showing areas of set habitat types. These maps will have a minimum mapping unit, below which changes in vegetation are ignored or incorporated into other classes. The purpose of the map is usually to establish and then track the change in extent of the particular habitats under consideration. When commenting on or assessing the accuracy of such a field map the question under discussion can be summarised as:

> *"Is this representation of the habitats one that most ecological experts can agree is a sensible representation given its purpose, also are the boundaries drawn in such a way that changes in the habitat can be picked up?"*

Errors in habitat maps produced by field mapping typically arise where a particular plant has been overlooked or wrongly classified by the ecologist, or where an indicator of condition may have been assigned to a class that other ecologists do not equate with that environment (Cherrill and McClean, 1999; Tyre et al., 2003). For example an area could be assigned to acid rather than neutral grassland due to the misclassification of *Agrostis curtisii*. In addition, ecotones between one habitat and the next can be very wide, making it difficult to decide where to draw the boundary between habitat types. Because field survey is labour intensive and gaining access to land can be problematic, areas are often not accessed directly but assessed from a distance exacerbating these mapping problems and increasing the chance of error. Often field maps will have extensive notes supporting the decisions made, describing reasons for the habitat classification and positioning of habitat boundaries but these are very rarely incorporated into the final map and this knowledge is lost. Ecologists therefore have an expectation that habitat maps are likely to contain errors associated with (Cherrill and McClean, 1995):

- The position of boundaries on large ecotones;
- Habitat misclassification arising from missing one or more specific plants indicative of one condition or another;
- Areas not actually visited but mapped from phenotypic appearance from a distance;
- Translation of the field notes when mapping boundaries to the final map product.

In such cases it is very rare for the broad habitats type to be wrongly classified; even an inexperienced ecologist will be able to tell a coniferous woodland from grassland, or a bog from ruderal vegetation (Hearn et al., 2011). If such a gross misclassification was observed at one point on the map, the whole of the map would be questioned. However, if there was disagreement about where the wet heath turned into a wet modified bog, most people would be happy to accept a sensible interpretation, as these can be hard, even for experienced ecologist to separate with certainty as they rely on other determining features such as peat depth. If a map of an area was expected to be 'modified bog' and came out as 'wet heath', the rest of the map would probably be accepted as this is a reasonable choice to make.

Ecologists are used to judging accuracy by a quick assessment of whether the broad habitat groups are correct and that specific areas of known interest to themselves are present. They may well be slightly taken aback by a map produced by remote sensing, as the types of errors that appear on the map can be very different in nature.

The sources of error in remote sensing maps are due to the quality of the imagery and its processing as well as the accuracy of the classification. The more time spent identifying and classifying out a particular habitat and the more distinct the attribute the habitat has, and the more targeted the zone of mapping the better the map that can be produced by remote sensing. However if the imagery is poor or the geometric correction is not precise then the best classification system in the world will return a poor map. This is the equivalent of an experienced ecologist mapping NVC communities with a GPS with an accuracy of only 20m (Dauwalter and Rahel, 2010) .

A habitat map derived from remote sensing, which in many respects represents habitats well, may have an area of acid grassland on a steep north facing slope under shadow misclassified as coniferous woodland. The remote sensing specialist would know this error is due to the lack of information in the imagery under the shadow and would not dismiss the rest of the map due to this inaccuracy. However, a field ecologist would think 'if remote sensing can't identify a conifer tree then the rest of the map will be very suspect'.

These perspectives need to be borne in mind as future approaches are developed, because they influence what the two user communities consider to be a 'fit-for-purpose' product (Fuller et al., 2005).

2. Why and how accuracy is described in remotely sensed data

Very rarely are attempts made to statistically describe or quantify the accuracy of a habitat map derived by ecologists from field mapping. Instead the ecologist responsible for the QA of the work or who commissioned the work, or the expert in that particular habitat review the map, often using aerial photography as a checking mechanism, together with their knowledge of the area and either 'believe' or 'reject' the output as 'fit for purpose'.

By contrast, assessing the accuracy of maps derived from remote sensing has traditionally taken a very different approach. Three approaches in use in remote sensing are described in this briefing note:

- Confusion matrix
- Fuzzy logic
- Dempster-Shafer (DS) belief theory

Confusion Matrix

In the development of remote sensing techniques, a standard method of accuracy assessment has developed over time. This is called user / producer accuracy. In this technique regions of the image with similar reflective characteristics, are classified as belonging to a single habitat type using a binary probabilistic model, that is, the class is deemed correct or incorrect. The data used to assess whether the classification gives the desired output is collected either from field work or using other means and split into two groups in a random way. The first group of points is used to 'train' the image analysis, giving the computer regions with a spectral characteristic to be designated as each class under consideration. The rest of the data is reserved until the end of the classification process and is called 'testing data'. This data is then compared to the classification in order to evaluate how many of the areas were correctly attributed. This data is displayed in a confusion matrix table.

A confusion matrix is shown in Figure 1. This matrix shows how much of each class is identified correctly and how much has been missed (errors of omission), or overestimated (errors of commission). When a simple supervised classification (that is the computer using just spectral information from the imagery to find similar regions) is under consideration this gives useful information about which classes can be separated out spectrally and which are being confused. Therefore it shows the parts of the processes which needed amending. It has become the standard way for remote sensing research to publish results about the effectiveness of classifications and has become a necessary part of any research paper.

		Field Data (Testing Samples)				
RS Classification		Forest	Regrowth	Non-Forest	Total	User
	Forest	101	5	1	107	**94.4 %**
	Regrowth	14	10	2	26	**38.5 %**
	Non-Forest	2	4	12	18	**66.7 %**
	Total	117	19	15	151	
	Producer	**86.3 %**	**52.6 %**	**80 %**		**81.5 %**

(101/117) x 100

(10/19) x 100

(12/15) x 100

Overall Accuracy
(101+10+12)/151 x 100

(101/107) x 100

(10/26) x 100

(12/15) x 100

Figure 1 - Confusion matrix

Multiple descriptive measures can be derived from these error matrices; including overall accuracies, user and producer accuracies and the kappa coefficient.

The overall accuracy is computed by dividing the total number of correctly classified areas (e.g. in the example above, 101 forests) by the total number of reference areas for that class (107 forests) Note: in Figure 1 these are shown on the diagonals (and highlighted red). Off-diagonals are misclassified pixels/objects. The accuracy figures do not reveal if error was evenly distributed across the map. Neither is there any acceptance of plausible errors (for example classifying an area of wet heath instead of blanket bog) In order to deal with this authors have started introducing the concept of 'plausible' classes (Jarman *et al.,* 2009; Vanden Borre *et al*. 2010).

The producer accuracy tells us about errors of omission (e.g. 16 forest sites omitted from the forest class in error and mapped instead as regrowth (14) and non-forest (2)).The user accuracy corresponds to errors of commission (e.g. 6 forest sites included in the forest class in error when they should have been mapped as regrowth (5) and non-forest (1)).

$$k = \frac{\text{observed accuracy - chance agreement}}{1 - \text{chance agreement}}$$

Figure 2 – Kappa Coefficient

The kappa coefficient (*k*), reflects the difference between actual agreement and the agreement expected by chance. A high kappa value indicates that the results are likely to be a 'real' feature, rather than occurring randomly. A value of above of 0.70 is generally taken as giving a result more likely than by chance alone.

This is a sensible way to approach land cover where just spectral data is being used and a binary approach is appropriate, for example hard surface urban areas are either urban or not. However, from the perspective of an ecologist, the nature of the misclassification determines whether or not the habitat map is fit for purpose. If 50% of the map has been classified as wet heath and the expected class was modified bog, then the map may still be fit for purpose; however, if 50% of modified bog was classified as coniferous woodland it would not be. The overall accuracy, producer and user accuracies alone are too simplistic as measures.

Though the nature of the errors shown in the matrix is of value when dealing with spectral classifications there is an issue with assessing accuracy based using field collected point data. Much of the complexity of describing classes based on single point data on the map arises from the fact that vegetation communities rarely occur in discreet well ordered blocks. The more natural the community under investigation the more likely it is to contain small areas of other habitats, ecotones where it grades to another habitat and areas where there is an untypical phenotypic expression due the presence of a particular species. All these issues are easy to dismiss in the field where one is looking at the description of a larger area or object at a time. In the binary probabilistic model favoured by the remote sensing scientist, only point data is considered. Figure 3; below showing eroding bog vegetation, shows some of the issues this generates when dealing with a map of defined points.

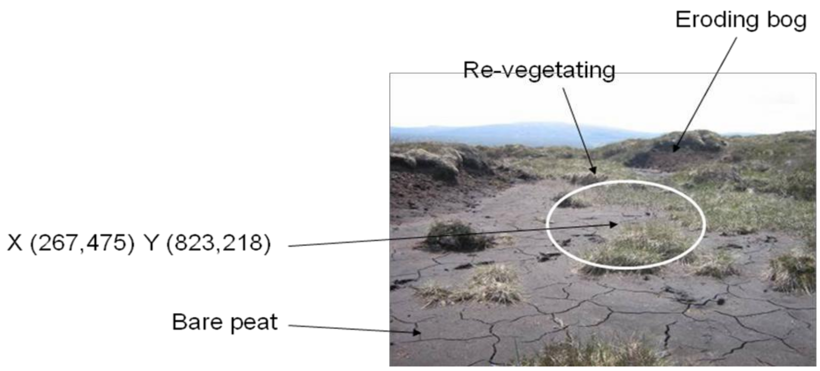

Figure 3 – Issues with using point data for accuracy assessment.

Suppose the point on the classified map fell at the end of the arrow with the x,y co-ordinate. This is in fact on a tuft of *Eriophorum vaginatum* in the midst of an area of bare peat on the edge of an eroding bog. If ground truth data for comparison was collected with a GPS with one metre accuracy (a very common setting) then anywhere in the white circle could have been selected as the point. This contains bare peat and re-vegetating peat. So if an object had been classified as one of these it only has a 50% chance of being right in the probabilistic model. In fact in terms of field mapping either would have been accepted as a description of this particular area, the important point with a field map may have been the delineation of the main area of bare peat. Thus, for the ecologist, going with simple statistical analysis not only is a misleading statistic produced, but the 'fit for purpose' question is completely ignored in favour of a much less relevant mathematical description. In addition, in the past maps derived from remote sensing have been presented to the user as a 'final map' and end product. The map will have been subject to a final accuracy assessment, but typically the mapping errors this assessment detects remain in the map, a practice which has led field ecologists to distrust such maps.

Ecotones, mosaics and fuzzy logic

In order to deal with issues of 'fit for purpose' plausible classes, ecotones and mosaics of vegetation, there is the potential to make use of fuzzy logic and geoinformatic techniques (the subject of Briefing Paper 1). Using remote sensing techniques and a rule based, fuzzy mapping approach it is possible to report on how well each object matches to the 'membership' of a particular class. The closer the match, the more likely the habitat is to occur.

The fuzzy logic approach uses a different conceptual model to classify objects than that which is undertaken by using traditional hard classification approaches such as the maximum likelihood estimator, or by neural network schemes (Baum *et al.,* 1997). The theory of fuzzy logic is based upon approximate reasoning, whereby 'fuzzy sets' display strength of membership for all potential classes, with the degree of membership to any particular class provided by a membership function (Figure 3). The stronger membership values will denote the potential for a particular class to be present in that sample and therefore be present within the final hard classification (Baum *et al.,* 1997).

The use of fuzzy membership functions has introduced some flexibility into the classification of vegetation types and potential for associating several memberships with a given mapped object (Lucas *et al*., 2007). The main strength of the fuzzy logic method is that it enables more than one class to be chosen dependent upon the strength of the membership (between 1 and 0) for the samples of that chosen class (Tovinkere *et al.,* 1993; Baum *et al.,* 1995). Therefore, instead of having explicitly defined classes that symbolize a combination of land-cover types, only a core set of single layered classes will be required.

This is illustrated in Figure 4, where the membership to *Vaccinium* (Bilberry) has been mapped on a hill side, where blue represents a higher membership to the class *Vaccinium* and light yellow represents a lower membership. Areas that have not been classified have no membership to *Vaccinium* at all.

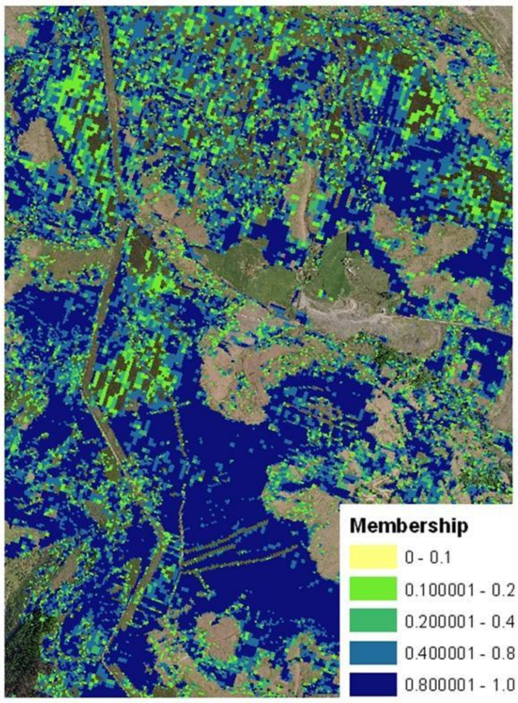

Figure 4 - showing membership to *Vaccinium Myrtillus* using a rule based system and fuzzy logic.

The advantage of this approach is that an additional layer can be provided with the mapping showing the certainty of classification. An area with only a low membership will therefore be more prone to error than an area of high membership. These figures can be used in several ways. The first is in the improvement of the rule base to produce an updated and better map, the second is to guide QA effort and to actually check those areas with low membership in order to amend the output map if appropriate. The layer will also be a good indication to users of the distribution of errors across the map. It may also point out areas where it will be necessary to field visit to check out the actual species assemblage.

Specifically, the concepts of fuzzy sets have been employed for defining the spatial and attribute characteristics of geographic objects (Burrough 1989), soil classes (Burough *et al.,* 1992), thermal interpolation (Dragicevic and Marceau 2000), and enhancing the classification of remote sensing images (Wang 1990; Bradtberg 2002).

Dempster-Shafer (DS) theory of evidence

Another method for solving the problem of misclassification in complex landscapes is the concept of Dempster-Shafer (DS) theory of evidence. This approach allows for the integration of different pieces of information through formal reasoning in a well-documented manner. The approach itself is a generalisation of the Bayesian theory of subjective probability which allows for the combination of different independent lines of evidence derived from different sources to establish degrees of belief for different hypothesises (Mertikas and Zervakis 2001).

Within a remote sensing context, the DS classification procedure involves the combination of different probability images from the evidence derived from both multispectral data and expert knowledge-based lines of evidence (Figure 4). Following the combination of all evidence within the DS algorithm, results are obtained in the form of layers that define the degree of probability or belief of each pixel belonging to each of the hypotheses or classification categories. A habitat map can then be created by assigning each pixel to the category that was most probable after the spectral and ancillary data is combined. A layer containing the classification uncertainty is also produced.

The main advantage of employing a DS approach is that the potential conflicts between classes within the classification process are resolved through problematic reasoning meaning that logical inconsistencies are avoided. Also the formalised use of probability to express uncertainty associated with the information used in the classification procedure is available to help describe and reflect the dynamic nature of the landscape under consideration.

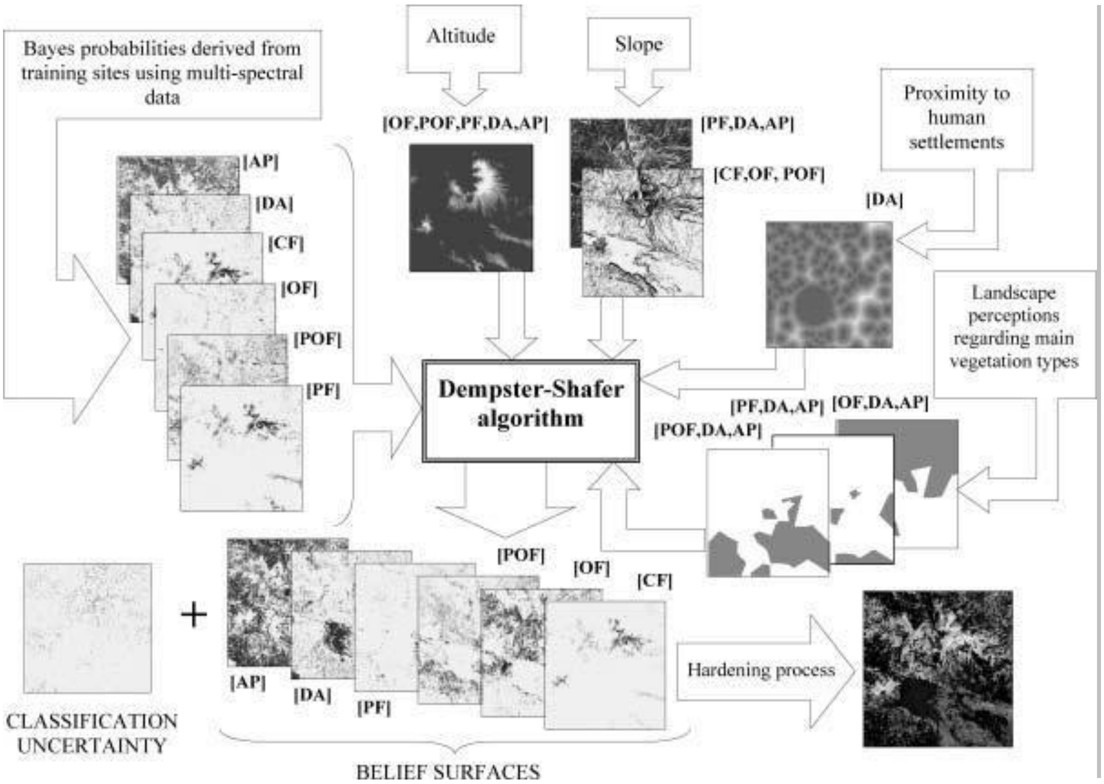

Figure 5 - Dempster - Shafer classification approach combining different evidence reams (Cayuela et al., 2006)

Error types in habitat maps produced using remotely sensed data

Unlike the two stages of field mapping (gathering data in the field and then digitising it) remote sensing data has many stages of processing. Any of these can be responsible for the generation of mapping errors. In studies of landcover change based on a temporal sequence of remotely sensed imagery (Roy 2000), mis-registration errors can act to significantly limit the value of remote sensing for monitoring land cover dynamics. This has been borne out by the experience of mapping habitats in Wales, where without image registration at the subpixel level (i.e. more accurate than the scale of an individual pixel), the resulting map of habitats is poor. This is because many small objects (i.e. distinct areas on the ground) cannot be identified correctly and the ‘spectral signal’ from these becomes mixed and confused with neighbouring objects.

A rule based system is only going to identify communities specifically looked for, so if a community occurs as a distinct object in the image data but no rules have been developed it will not be identified. If the thresholds of the rules are wrong, then only half the community may be picked up. If shadow or clouds lead to a lack of spectral signal, then a misclassification will result. Some of these issues are easier to trace and rectify than others. For example using a cloud mask is a quick and easy way to check the classification on areas affected by cloud cover to ensure that the map is correct. Many habitat classes need a time series to identify them well, the quality of each image is important, a poor image taken at a less than ideal time can have a big effect on the overall success of mapping habitat for the area covered by that particular image.

Therefore within a national mapping context, sub areas of mapping (called "projects" in the Welsh Habitat Inventory mapping) have their own accuracy issues and therefore need their own quality statement. These issues mean that a small well targeted area is likely to be more accurately mapped than a very large area.

The erroneous allocations made by a classification are typically not randomly distributed over a region (Congalton, 1988). Often there is a distinct pattern to the spatial distribution of error arising from the sensor's properties and/or the ground conditions, with for example, errors spatially corrected at the boundaries of classes (Foody, 2002). One example of this from the Wales mapping is the confusion generated by areas where there is a red soil type and the soil is visible through the vegetation cover. Unless this is specifically accommodated in the rule-base these areas end up misclassified. The hard nature of standard thematic mapping may therefore be considered inappropriate to model continuous variations in land cover properties. Unfortunately, standard confusion matrixes are unable to provide information on the spatial distribution of error.

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