JNCC Report
No: 495 Phase 2

Making Earth Observation Work for UK Biodiversity Conservation

Final Report

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August 2014

ISSN 0963-8091

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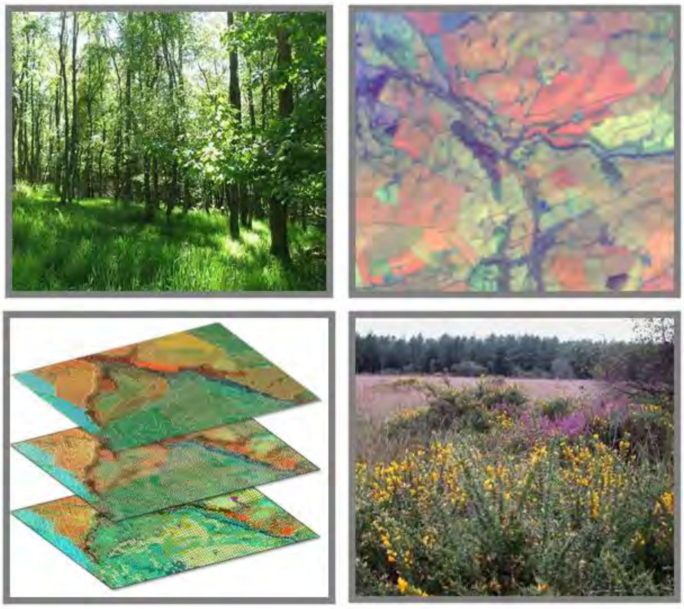

April 2013

A report produced for the JNCC and Defra by

Environment Systems

TEAM

Callen-Lenz Consulting

DEFRA/JNCC project code:	**WC1013**
DEFRA/JNCC contract reference number:	**WC1013**
Report document reference and version:	**EnvSys/MEOW_final_v2**

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When referring to this report please use the following citation:

Medcalf K. A., Parker J.A., Turton, N., and Bell, G. (2013) Making Earth Observation Work for UK Biodiversity Conservation – Phase 2. **JNCC Report 495 Phase 2**, JNCC Peterborough 2014

Acknowledgements

The project team would like to thank Paul Robinson (JNCC) and Helen Pontier (Defra) and the rest of Steering Group for all their input and enthusiasm during the running of the project. Our thanks also go to staff of Natural England, the Wildlife Trust and the RSPB for their help with ground truthing the case study areas.

1 Executive summary

Information on the extent, location and condition of semi-natural habitats is essential to meet UK and country reporting obligations and commitments. These include legislative obligations included in the EC Habitats Directive, as well as domestic commitments to monitor status and condition of priority habitats or provide audits of ecosystem function and service provision.

Recent reviews of the adequacy of biodiversity surveillance to meet the needs of key legislative drivers show that there are still gaps in knowledge about the location and condition of semi-natural habitats of high nature conservation value and in particular where they are located outside the statutory site series. Their scarcity, fragmented nature, occurrence in complex mosaics and often remote location make these habitats particularly difficult and expensive to map and monitor using traditional survey techniques.

The bodies with responsibility for habitat monitoring in the UK are under pressure to meet the demanding requirements for habitat surveillance and need to improve surveillance capacity within existing resource constraints. Earth observation (EO) is identified within all the conservation bodies and Defra as an important development area for monitoring habitats of high conservation value.

This project constitutes Phase 2 of a three-part research project to establish the practical role EO can play in addressing habitat monitoring and surveillance needs in the UK for priority habitats designated under UK Biodiversity Action Plan (BAP) and Annex I habitats.

The objectives of Phase 2 focussed on:

- developing and testing EO techniques for mapping Annex I and priority habitats;
- developing EO measures that inform on habitat condition.

The three phases of the research are:

Phase 1: Review and Scope Potential (completed): reviewed recent activity, reporting the potential of EO techniques for operational biodiversity surveillance of terrestrial and freshwater habitats, and evaluated their potential as a cost effective solution to current surveillance and monitoring needs in the UK (www.jncc.defra.gov.uk/EO).

Phase 2: Pathfinder Projects (focus of this report): comprises a series of projects in a pilot area of Norfolk to demonstrate where and how EO techniques can be used in operational surveillance for biodiversity in the UK for greatest benefit.

Phase 3 is anticipated to include further development of the ecological rule based approach and exploring potential for a national roll out.

Phase 1 (Medcalf *et al,* 2012) demonstrated that EO techniques together with the development of geoinformatics, have the potential to make a significant contribution towards quantifying habitat extent, composition and condition, as part of a suite of surveillance techniques. The "Crick Framework" was developed as a conceptual tool to assess the role of EO in identifying Annex I and BAP priority habitats (which still form the basis of much biodiversity work at country level). It helps users address the questions "Have I got the information I need to use EO in my situation?", "What information/data do I need?" and "What techniques are available?" The Crick Framework groups habitats into one of five

Tiers depending on their data requirements for classification within an EO analysis (e.g. currently unlikely to be classified solely using EO, likely to be classified using EO and ancillary data).

Phase 2 of the research involved a number of tasks:

Review of Crick Framework content: a desk review, supported by targeted consultation and peer review led by two external specialists covering a statement of validity of the current Habitat Tier allocation, any proposed amendments and the addition of information on previous method development that failed to overcome known gaps. The review expanded and updated the Framework in the light of new knowledge and experience.

Implementation and evaluation of a pilot project: a range of case studies in a pilot area to test the Crick Framework and develop and demonstrate a new approach to the use of EO for mapping the extent and condition of habitats that demonstrates significant advances in conceptual thinking and the approach to habitat mapping. Assessment of the effectiveness, practicality and value-for-money of the EO approaches developed.

Communication with users: to identify their needs, share best practice and results.

1.1.1 Findings: Review of Crick Framework

The desk-based review of the Crick Framework confirmed its validity as a tool, with the main work focused on checking the structure and content of the supporting habitat tables and the allocations of habitats to the Tiers of the Framework. A User Manual was produced to provide habitat specialists with examples, explanations and illustrative scenarios of how the framework may be used to support the evaluation of opportunities for mapping habitats using a range of EO and other existing spatial data. The documents produced in this part of the project are available from the project pages on the JNCC website.

1.1.2 Findings: Implementation and evaluation of a pilot project

The implementation and evaluation of a pilot project was the main focus of the research and required further development of an “object-based image analysis” (OBIA) habitat mapping approach. The pilot was conducted in Norfolk; a very different biogeographical environment to Wales, where the OBIA approach has been extensively used. The OBIA approach incorporates ecological contextual knowledge into image classification. It also maps to real world objects, such as field parcels. With knowledge of landscape context applied to image classification, it is possible to create “masks” that successfully delineate areas in which particular habitats are restricted. This allows the user to separately map vegetation assemblages which are spectrally similar but that occur in very different settings (thus avoiding sources of confusion in the image analysis).

The OBIA approach was applied at varying scales, from landscape scale (“broad scale” mapping of a wide range of features, including heavily managed agricultural land and semi-natural vegetation across large areas of the wider countryside) to site-based studies (“finer-scale” more detailed mapping of semi-natural habitats in more localised areas, such as nature reserves, known to contain semi-natural habitat).

There are features of vegetation that previous research suggests EO can detect and that may be useful for assessing habitat condition. The pilot project included a preliminary investigation of some of these and the findings provide an initial analysis of potential condition monitoring tools.

A wide range of satellite and aerial imagery was used. Small objects (e.g., scattered scrub) and linear features needed a suitably fine resolution of imagery to successfully identify them. Ultra-high resolution imagery from flights by an Unmanned Aerial System (UAS) was incorporated to improve the delineation of habitat extent and help identify condition features relevant to Annex I SAC sites in case-study sites. Ordnance Survey MasterMap (OS MM) and digital terrain models brought benefits that were instrumental to the success of the OBIA mapping process and integral to it.

1.1.3 Key messages for senior policy makers

SP1. The EO techniques developed are practical, providing a technique for directly mapping about a third of the Annex I and priority habitats and providing key data sets for targeting identification of all the remaining habitats. They were therefore found to be cost-effective and fit-for-purpose for this task.

SP2. The techniques provide an efficient way of mapping large areas, difficult to reach areas and improve upon the accuracy of habitat mapping individual sites making them a practical and cost-effective solution in these situations.

SP3. The techniques can support and augment current surveillance techniques in a practical way and can add to the suite of tools available.

SP4. The condition measures also compliment and augment existing surveillance techniques rather than replacing them.

SP5. The EO techniques therefore broaden the options available for delivering habitat surveillance by providing enhanced value for money by targeting survey effort.

SP6. The techniques are very adaptable because the developed rule bases and processed imagery and data can be built upon or adapted as necessary to produce additional outputs or products tailored to other policy needs that utilise habitat mapping. This keeps the cost of follow-on work very low in comparison with repeat survey, manual re-interpretation of imagery or other traditional field survey techniques.

SP7. The techniques are considered to be particularly valuable for:

- assisting with filling gaps in knowledge of habitats in the wider countryside;
- generating habitat maps and data to meet a wide range of landscape scale approaches to biodiversity delivery;
- producing management plans for larger sites or discrete areas;
- identifying threats to habitats and ways of mitigating against and monitoring these threats.

SP8. Further knowledge transfer is required to support conservation agencies and others to develop image analysis classification systems that are suited to their particular habitat mapping needs.

1.1.4 Key messages for habitat practitioners

HP1. A range of high priority habitats, distinguished from above by their cover forming species, can be identified at good levels of accuracy (greater than 78%) using the EO techniques developed.

HP2. Where the habitats were not fully identified this was because they are separated from other similar habitats by specific indicator species which are small in size and occur at low frequency or as under-storey vegetation. The EO techniques are, however, useful for generating areas of search for the specific Annex I or priority habitats as the broader habitat is identifiable. The techniques can be used to target follow-up field survey work.

HP3. Simple condition measures have been used to show “productivity of vegetation” and conversely, “bare earth”, “wetness” and “the extent of stands of negative indicator species”; pressures around and within sites illustrated by these measures are not always visible, or easy to assess on the ground.

HP4. The EO techniques are capable of producing high quality site-based habitat maps suitable for use as management products to assist with monitoring, survey and site maintenance. In areas that are difficult to map by field survey, enhanced maps of habitat extent and condition features can be generated.

HP5. The EO techniques are considered transferable to other environments based on work in Norfolk, Wales and more recently, Dorset and the UK Overseas Territories. The successful transfer of the techniques depends on obtaining imagery at suitable spatial and temporal scales for the habitats present in the area of interest. If the habitats are intricate and occur in small patches, then ultra-high resolution imagery will be needed, if they cover broad areas then high resolution imagery will be sufficient. The requirement for temporal frequency depends on the biogeographical, agricultural and habitat system context; in the UK, as a minimum requirement a “leaf-on” and “leaf-off” image is needed.

HP6. The methods are robust and different ways of image analysis can be used for creating objects. Objects can be created through segmentation based on a combination of existing features and the relationship between the spectral reflectance values of groups of pixels in the imagery (as in the OBIA approach) or by using the spectral reflectance values of individual pixels, amalgamated up into existing objects (as in the hybrid approach).

HP7. The EO techniques developed are very adaptable. The data can be reworked, reused and the rule base improved upon, or the data can be interrogated for a different use, such as to map areas using a different classification system or to provide a more detailed assessment of a particular site or area.

HP8. EO expertise is needed to produce the maps but ecological input to the process is essential. For successful mapping EO and ecological expertise, together with GIS and geoinformatics knowledge is needed. These skills are rarely present in just one individual and a team-based approach is recommended. The maps cannot be produced in isolation. Field work, the use of local knowledge and/or existing data are integral to the map production. They allow the ecology to be understood in relation to the imagery and an understanding to be gained of local context, systems and processes, needed in order to develop the rule base. Further validation visits or iterations are then necessary to build on and improve this knowledge as the rule base is further refined.

1.1.5 Findings: Communication with users

Communication and outreach occurred throughout the project. A steering group of key end users from country agencies were involved in all stages of the project. Norfolk Biodiversity Information Services (NBIS) who were project partners and end users of the project outputs were also consulted throughout. A workshop was hosted by them at the inception of the project to inform key stakeholders in Norfolk of the work and to gain a further understanding of the biodiversity priorities and pressures present in the pilot study area. A further workshop on habitat condition monitoring was hosted in Norfolk for habitat practitioners from the wider Steering Group. Work from the project has been presented by JNCC and Environment Systems at conferences and workshops for both National and International audiences.

OBIA techniques require a range of software and hardware together with considerable remote sensing and ecological skills and knowledge. Software packages used for this sort of analysis such as eCognition are not 'tools', meaning suitable results are unlikely to be produced by non-specialists. For effective use of the techniques, both EO expertise and ecological expertise should be drawn upon.

Further knowledge transfer is required to support conservation agencies and others to develop image analysis classification systems that are suited to their particular needs.

1.1.6 Conclusion

Overall, Phase 2 of the research has established the practical role EO can play in addressing habitat monitoring and surveillance needs in the UK for priority habitats designated under UK Biodiversity Action Plan (BAP) and Annex I habitats. The Crick Framework has been further developed in support of this.

The results of accuracy assessment, feedback from local habitat practitioners and the assessment by the research team of how well the techniques worked, all suggest that the EO techniques developed are fit for purpose for supporting the mapping and surveillance of high priority habitats. Work in Norfolk and Wales demonstrates that the techniques are capable of consistent implementation and evidence suggests that the technique is transferable and so can be rolled out to the UK, and beyond. The approaches do not simply duplicate what other habitat surveillance methods provide but compliment them. They can support and augment current surveillance techniques in a practical way, sometimes improving upon the accuracy of habitat mapping and can add to the suite of surveillance tools available, including for condition monitoring.

The knowledge exchange throughout the project was considered to be successful in furthering the case for using EO as part of the surveillance and monitoring tool-kit. The value of EO based habitat mapping and monitoring has numerous added value elements.

1.1.7 Future research

Future research needs identified during the project have been documented. This includes assessment of the suitability and potential role for satellite radar in an OBIA approach and further vegetation structural features that can be described by LiDAR. The development of measures (indices) to assist with the site based assessment of the condition of Annex I habitats is considered to have real potential and specific research questions that need to be addressed for site based condition assessment have been formulated. There would also be further benefit in applying the methods developed to other landscape types and mapping the potential and demonstrated uses of EO to evidence needs for policy development, reporting and evaluation. Data from UAS are considered to have potential for mapping specific tree species.

There is often merit in working with local level initiatives to show how the EO techniques deliver in a "live" context to meet existing data needs (both landscape-scale initiatives and in relation to meeting site-based management needs) and this would seem an obvious next step in the role out of this approach.

2 Glossary of Terms and Acronyms

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
Correspondence matrices	A matrix that displays statistics for assessing image classification accuracy by showing the degree of misclassification among classes.
CIR	Colour Infrared
CSM	Common Standards Monitoring
DMSP	Defence Meteorological Satellite Program, US Department of Defence satellite system
eCognition	Software for developing segmentations and rule-based classifications
DSM	Digital Surface Model – Gives variation of the vegetation structure
DTM	Digital Terrain Model – Gives the variation of the underlying
EC	European Commission
Envisat	Environmental Satellite
EO	Earth Observation
Geoinformatics	Combining and modelling spatial datasets
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 – 30m Satellite imagery available from the USGS (United States Geological Survey)
LiDAR	Light Detection and Ranging – Air borne sensor which gives vertical height data
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 feed forward 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
OBIA	Object based image analysis – process of classification where objects are considered rather than individual pixels

Ortho-rectification	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.
PSA	Public Service Agreement
Radar	An active type of EO imaging sensor
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 that 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
SSSI	Site of Specific Scientific Interest
SWIR	Short Wave Infra-red
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
UK BAP	UK Biodiversity Action Plan
UKSA	UK Space Agency
WFD	Water Framework Directive

3 Introduction

Habitat surveillance and monitoring is needed to meet a range of user needs including policy requirements, land manager and planning considerations and to increase our understanding and appreciation of our natural resources.

Surveillance is crucial to provide us with a broad picture of the extent, location and condition of semi-natural habitats across the UK. This knowledge is necessary to enable us to know enough about specific species and habitats of conservation concern to enable us to provide protection, meet our legislative obligations and ensure that sites are managed appropriately.

There are a number of national and international policies and legislation which require the UK to undertake habitat surveillance activities at a number of spatial scales. Universally they all call for a better evidence base providing consistent and robust information about land cover and habitats. Key drivers are summarised below and are considered in more detail in section 3.4.

- EC Habitats Directive: The UK has a statutory obligation to report every six years on the extent and condition of its semi-natural habitats listed in Annex I of the directive, commonly referred to as Annex I habitats. These are habitats which are considered to be internationally important or scarce across Europe.

- Convention on Biological Diversity (CBD): This was the first global treaty to provide a legal framework for biodiversity conservation. Under it the UK is required to adhere to the Aichi targets and goals which include the provision of Action Plans for target species and habitats.

- Biodiversity 2020: These are national frameworks working towards biodiversity being maintained and enhanced, where further degradation has been halted and where possible, restoration is underway. Therefore habitats can help deliver more resilient and coherent ecological networks, as well as healthy and well-functioning ecosystems.

- National Ecosystems Assessment (NEA) and ecosystems approach: Ecosystem thinking is driving spatial planning policy across the board, trying to achieve multiple benefits from every decision to maximise the use of space and resources. For robust ecosystem analyses and decision making tools consistent land cover and habitats data is required.

- Water Framework Directive (WFD): A European Directive to establish a framework for the protection of rivers, lakes, estuaries, coastal waters and groundwater. It aims to ensure that all aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands meet 'good status' by 2015.

UK country conservation agencies are under pressure to meet the demanding requirements for habitat surveillance within tightly constrained resources. Nationally there remain gaps in knowledge about the location and quality of semi-natural habitats, which because of their scarcity, fragmented nature, occurrence in complex mosaics and often remote location are particularly difficult and expensive to map and monitor using traditional survey techniques.

Following the publication of the new Framework the UK BAP partnership no longer operates but many of the tools and resources originally developed under the UK BAP, including the habitat classification and associated habitat inventories for priority habitats remain in use and form the basis of much biodiversity work at country level. In England they are now Natural Environment and Rural Communities Act (NERC Act S 41) habitats. For ease, these will be referred to as BAP priority habitats throughout this report.

3.1 Background to user needs

This project constitutes Phase 2 of a three part research project to establish the practical role Earth Observation[1] (EO) can play in addressing habitat monitoring and surveillance needs in the UK.

The three phases of the research are:

> **Phase 1**: Review and Scope Potential (completed): reviewed recent activity, reporting the potential of EO techniques for operational biodiversity surveillance of terrestrial and freshwater habitats, and evaluated their potential as a cost effective solution to current surveillance and monitoring needs in the UK.
>
> **Phase 2**: Pathfinder Projects (focus of this report): comprises a series of projects in a pilot area of Norfolk to demonstrate where and how EO techniques can be used in operational surveillance for biodiversity in the UK for greatest benefit.
>
> **Phase 3** is anticipated to include further development of the ecological rule based approach and exploring potential for a national roll out.

Phase 1 of this project (Medcalf *et al,* 2012; www.jncc.defra.gov.uk/EO) reviewed recent activity, reporting the potential of EO techniques and geoinformatics for operational biodiversity surveillance of terrestrial and freshwater habitats, and evaluated their potential as a cost effective solution to current surveillance and monitoring needs in the UK. The review demonstrated that EO techniques together with the development of geoinformatics, have the potential to make a significant contribution towards quantifying habitat extent, composition and condition, as part of a suite of surveillance techniques.

The “Crick Framework” was developed within Phase 1 as a tool to assess the role of EO in identifying Annex I and (the former) UK Biodiversity Action Plan (BAP) priority habitats, which still form the basis of much biodiversity work at country level. It helps users address the questions “Have I got the information I need to use EO in my situation?”, “What information/data do I need?” and “What techniques are available?”

The key findings of the Phase 1 research are included below and have fed into this stage of the project, Phase 2.

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[1] Earth Observation (EO) is also commonly referred to as Remote Sensing (RS). RS is the process of obtaining information about a range of phenomena through analysis of data from a device which is not in contact with those phenomena. RS includes imaging systems such as cameras, but may include other geophysical systems and sensors such as magnetics and radar returns. EO is the ‘Earth facing’ component of RS. For this EO is taken to mean data from satellite and airborne systems which allow mapping and monitoring of the surface of the Earth.

Key findings of the Phase 1 research

An assessment of a range of policy / legislative drivers and the information needs outstanding from existing surveillance and monitoring activities were reported in Phase 1 of this research (Medcalf, 2012), focusing in particular on those policy drivers associated with Annex I and BAP priority habitats. Gaps in provision were identified.

- The report concluded that the most urgent need is to complete the habitat inventories of high priority habitats as these underpin a wide range of on-going and planned activities.
- In addition to this there is a need for information on condition, function and change of semi-natural habitats, in particular of Annex I and BAP priority habitats, considered within their landscape context.

A range of initiatives were evaluated, funded by UK government, government agencies and others. The project established that there are significant opportunities to contribute to the knowledge on, location and changes to important, less common and more intricate habitats, including many Annex I and BAP priority habitats, particularly outside the protected sites network. Areas were identified which lack suitable habitat inventory information required for national monitoring and EU reporting which are unlikely to be addressed efficiently using current techniques. Phase 1 established the techniques available, the context in which they had been used, as well as their suitability for wider application and roll-out. The project also considered the potential for using satellite and airborne radar, hyper-spectral sensors and unmanned aerial systems (UAS) to deliver a flexible and timely source of high resolution EO-derived information, many of which have been addressed in this phase of the project.

The Phase 1 research concluded that there is no single approach to deliver information on the full range of higher priority habitats. The habitats vary in their appearance from above and therefore vary in how they appear in EO data and require varying spatial, temporal and spectral resolution for monitoring and reporting. 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 targeting field survey for habitats that will continue to require field identification.

There is a wide variation in the use, awareness and capacity of organisations in relation to EO techniques which are currently available and under development. Therefore to facilitate large scale uptake, this variation in adoption of techniques must be addressed. Knowledge and data sharing across organisations will underpin the successful establishment and continuing application led development of EO techniques for habitat monitoring. Actively promoting awareness of developments within the research community will help further understanding of the processes involved within habitat discrimination using EO and geoinformatics as well as allowing the incorporation of new technologies and techniques into established systems.

On-going projects of particular relevance

The Phase 1 research provides a useful reference source describing a range of recent EO initiatives for biodiversity surveillance funded by UK government, government agencies and other members of the Forum for Earth Observation Applications. Some of these are considered in Table 3:1.

Table 3:1: Current and on-going projects since Phase 1

Project	Description
BIO_SOS	This project is developing algorithms for analysing high resolution EO imagery (SIAM) and multi-scale EO data down to Very High Resolution data (EODHaM) to produce Land Cover maps to the Land Cover Classification System and General Habitat Category systems (developed under EBONE). It is also looking at biodiversity indicators and their trends. These are intended for use within Natura 2000 sites across Europe. (Lucas *et al*. 2011a)
MS-MONINA	MS.MONINA supports European, national and local authorities in monitoring the state of European nature sites of community interest – not only at the benefit of EU national authorities, but also addressing local authorities that manage these sites, and EU authorities overseeing the overall development of the NATURA 2000 programme. (Lang, 2012)
LWEC	The LWEC Partnership contains 22 public sector organisations that fund, carry out and use environmental research and observations. They include the UK research councils, government departments with environmental responsibilities, devolved administrations and government agencies. Projects funded under LWEC cover a broad range of applied research projects relating to the adaptation of land cover and biodiversity to climate change. (LWEC, 2012)
Anguilla	This project has used earth observation to produce a habitat map of Anguilla and its offshore cays looking at selected plant community groups with particular functional elements. This habitat mapping has used field studies undertaken by the Government of Anguilla and earth observation classification that can be subsequently used to show how the vegetation contributes to both biodiversity and other ecosystem services. (Medcalf and Cameron, 2013)
Environment Agency and Natural England	The intention of this work has been to apply data collected from sensors mounted in aircraft, to create operationally useful products such as coastal and wetland habitat mapping. (Petchey *et al*. 2011)
Dorset	Network and habitat data created for Dorset County Council and the AONB under a project partly funded by CORDIALE and the South West Protected Landscapes and with input from the Wild Purbeck Nature Improvement Area. Habitat data was created by combining existing habitat surveys (where they were present) and remote sensing image analysis to determine broad habitats for the classification of habitat networks and for identifying sites which contain opportunities for habitat recreation. (Medcalf and Ties, 2012).
Gwylio habitat inventory map for Wales	A Wales-wide inventory of Phase 1 Habitat types. OBIA fuzzy membership has been used to indicate spatial variation and ecotones. Some features with hard boundaries have been mapped as Boolean classes. (Lucas *et al.* 2011b) Further to the image analysis, geoinformatics analyses have occurred to integrate the high priority scarce habitats identified by the original Phase 1 with the updated Phase 1 habitat map and record the original classification for comparison and identifying change.

3.2 Aims and Objectives

The objectives of Phase 2 are focussed on:

- developing and testing EO techniques for mapping Annex I and BAP priority habitats;
- trialling EO measures that inform on habitat condition.

Phase 2 aims to address specific known gaps in knowledge about the use of EO-based techniques for the surveillance of these habitats, accelerate the introduction of EO methods for mapping both the extent and condition of these habitats and identify user needs and share best practice. As well as developing and testing these techniques through the Norfolk pilot, there is a specific focus on ensuring knowledge exchange, enabling habitat practitioners to understand EO imagery, products and techniques. These will be addressed by:

Review of Crick Framework content: a desk review, supported by limited consultation and peer review led by two external specialists covering a statement of validity of the current Habitat Tier allocation, any proposed amendments and the addition of information on previous method development that failed to overcome known gaps. The review expanded and updated the Framework in the light of any new knowledge and experience.

Implementation and evaluation of a pilot project: a range of case studies in a pilot area to test the Crick Framework and develop and demonstrate a new approach to the use of EO for mapping the extent and condition of habitats that demonstrates significant advances in conceptual thinking and the approach to habitat mapping. Assessment of the effectiveness, practicality and value-for-money of the EO approaches developed.

Communication with users: to identify their needs, share best practice and results.

3.3 Continuing gaps in knowledge

There have been limited applied research projects which assess the potential of some image types, such as radar, which have a potential role in providing additional information about habitats. Radar has already been used to measure forest parameters in the rain forest, for assessing tree stock in large scale logging operations and more recently for measuring biomass in forest ecosystem function modelling (Antonarakis *et al*, 2011). Radar could help measure habitat structure and other biophysical properties relevant to habitat condition.

3.4 Policy and legislative drivers

The main policy driver for this research was to meet EU Habitats Directive reporting requirements, as well as other policies. Since the Phase 1 report was published international and domestic biodiversity policies have evolved and there have been further contributions to the UK biodiversity surveillance strategy. These developments are of particular relevance to Annex I and BAP priority habitats and are described in this section.

3.4.1 Convention on Biodiversity (CBD)

The Convention on Biological Diversity (CBD) was adopted at the Earth Summit in Rio de Janeiro, Brazil in June 1992, and entered into force in December 1993. It was the first global treaty to provide a legal framework for biodiversity conservation. It established three goals:

- the conservation of biological diversity,
- the sustainable use of its components,
- the fair and equitable sharing of the benefits arising from the use of genetic resources.

The CBD lists a number of 'Aichi' goals and targets for habitat surveillance which are shown in Box 3:1.

Box 3:1. CBD Strategic Plan 'Aichi' goals and targets generating a requirement for habitat surveillance

Goal A: Address underlying causes of biodiversity loss by mainstreaming biodiversity across government and society
Target 5: By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.
Goal B: Reduce the direct pressures on biodiversity and promote sustainable use
Target 8: By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity. Target 9: By 2020, invasive alien species and pathways are identified and prioritised, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.
Goal C: Improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity
Target 11: By 2020, at least 17% of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascapes.
Goal D: Enhance the benefits to all from biodiversity and ecosystem services
Target 14: By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and wellbeing, are restored and safeguarded. Target 15: By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.
Goal E: Enhance implementation through participatory planning, knowledge management and capacity building
Target 19: By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred and applied.

Box 3:2

In delivering the Aichi goals, national strategies and action plans are required to conserve, protect and enhance biological diversity. Action is also required on ecosystems and a range of cross-cutting issues which have been established to take forward the provisions of the Convention.

Within Europe, the Pan-European Biological and Landscape Diversity Strategy was developed in 1994 to introduce a coordinating and unifying framework for strengthening and building on existing initiatives which support the implementation of the CBD. In 1998 the European Community Biodiversity Strategy was adopted, defining a precise framework for action, by setting out four major themes and specifying sectoral and horizontal objectives to be achieved.

In 2001, this was followed by the production of Biodiversity Action Plans for fisheries, agriculture, economic cooperation and development, and conservation of natural resources. These Action Plans define concrete actions and measures to meet the objectives defined in the strategy, and specify targets.

3.4.2 UK Post-2010 Biodiversity Framework

The UK Biodiversity Action Plan (UK BAP) was the UK Government's response to the Convention on Biological Diversity (CBD) between 1992 and 2012. Action plans for the most threatened species and habitats (BAP priority species and habitats) were set out to aid recovery and regular national reports showed how the UK BAP was contributing to the UK's progress towards the significant reduction of biodiversity loss called for by the CBD.

As a result of devolution, as well as new country-level and international drivers, much of the work previously carried out by the UK BAP is now focused at a country-level rather than at UK-level, and the UK BAP has recently been succeeded by the 'UK Post-2010 Biodiversity Framework' (JNCC and Defra, 2012). This Framework, published by JNCC and Defra on behalf of the Four Countries' Biodiversity Group, covers the period from 2011 to 2020 and sets out a framework of priorities for UK-level work for the CBD.

The Framework is designed to identify the activities needed to galvanise and complement country strategies, in pursuit of the CBD Strategic Plan 'Aichi' targets. Countries do not necessarily need to develop a national target for each and every global target, but reflect their own national priorities, targets and key actions in their Country Biodiversity Strategies with reference to this flexible international framework.

UK-scale co-ordination and action on such a wide range of biodiversity related matters requires contributions from many sources, including Defra, JNCC, devolved administrations, other government departments and country conservation bodies. Common solutions require that any EO based approaches are transferable.

The UK BAP priority habitats cover a wide range of semi-natural habitat types. Many are familiar wildlife habitats including hedgerows, meadows, heathlands, woodlands, sand dunes, wetlands and flower-rich field margins and are the main habitats that form the core areas, stepping stones and many of the connections of ecological networks (Lawton, 2010).

3.4.3 Biodiversity 2020

The importance of biodiversity has been identified by the UK National Ecosystem Assessment (NEA) and was reported to be often undervalued. In the most recent analysis, it reported that over 40% of priority habitats and 30% of priority species were in decline. The mission for Biodiversity 2020, for the next decade, therefore is:

> *"to halt overall biodiversity loss, support healthy well-functioning ecosystems and establish coherent ecological networks, with more and better places for nature for the benefit of wildlife and people."*

The outcomes require action in four areas:

- A more integrated large-scale approach to conservation on land and at sea
- Putting people at the heart of biodiversity policy
- Reducing environmental pressures
- Improving our knowledge

The country strategies for biodiversity and the environment in each of the four countries of the UK deliver UK commitments under the Convention on Biological Diversity and the EU

Biodiversity Strategy, they are underpinned by the 'UK Post-2010 Biodiversity Framework', published in July 2012.

Objectives of the country strategies include:

- Halt the loss of biodiversity and continue to reverse previous losses through targeted actions for species and habitats.
- Increase awareness, understanding and enjoyment of biodiversity, and engage more people in conservation and enhancement.
- Restore and enhance biodiversity in urban, rural and marine environments through better planning, design and practice.
- ·Develop an effective management framework that ensures biodiversity is taken into account in wider decision making.
- ·Ensure knowledge on biodiversity is available to all policy makers and practitioners.

This project will help to inform these country strategies for biodiversity. For example in England, the project will contribute to meeting objectives in Biodiversity 2020 . It will contribute to the Biodiversity 2020 policy outcome of maintaining and enhancing biodiversity, developing coherent ecological networks and healthy functioning ecosystems. Biodiversity 2020 sets out a number of policy outcomes, including: 90% of Priority Habitats in favourable or recovering condition, at least 50% of Sites of Special Scientific Interest (SSSIs) in favourable condition and 95% in favourable or recovering condition, no net loss of Priority Habitat, restoring degraded ecosystems, reducing environmental pressures and piloting offsetting, all of which require reliable habitat extent and condition mapping.

3.4.4 Water Framework Directive (WFD)

Rivers, lakes and coastal waters are vital natural resources: they provide drinking water, crucial habitats for many different types of wildlife, and are an important resource for industry and recreation. A significant proportion of them are environmentally damaged or under threat. The EC Water Framework Directive expands the scope of water protection to all waters and sets out clear objectives that must be achieved by specified dates.

The purpose of the Directive is to establish a framework for the protection of inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters and groundwater. It will ensure that all aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands meet 'good status' by 2015.

The Directive requires Member States to establish river basin districts and for each of these a river basin management plan. There are four distinct elements to the river basin planning cycle: characterisation and assessment of impacts on river basin districts; environmental monitoring; the setting of environmental objectives; and the design and implementation of the programme of measures needed to achieve them.

3.4.5 Habitats Directive

The Habitats Directive identifies 77 terrestrial, freshwater and intertidal habitats (listed in Annex I of the Directive) in the UK. The most threatened and endangered of these are given priority status under the Directive (there are 23 “priority habitats” in UK terrestrial, freshwater and intertidal environments). Article 11 of the Directive explicitly requires Member States to implement surveillance of the conservation status of Annex I habitats and Article 17 requires reporting of their conservation status every six years. The provisions of the Directive require Member States to introduce a range of measures, including to maintain or restore European protected habitats and species listed in the Annexes to a “favourable conservation status”.

JNCC and country conservation agencies are legally responsible for assessing surveillance requirements. The reporting format set out by the Commission requires information on four different parameters, how they are to be been assessed in the UK has been set out by the JNCC (JNCC, 2007). The status of the habitat is assessed in relation to each of these criteria and these are combined to give an overall conservation status for each habitat.

Range	the outer limits of the overall area in which a habitat is found
Extent	an estimate of the surface area covered by the habitat
Structure and function	the main pressures currently acting on the habitat, information on the habitat condition and the status of typical species associated with the habitat
Future prospects	the potential future threats to the habitat, and an analysis of the possible future habitat condition

JNCC, in collaboration with country conservation agency partners (2012) has recently set out their surveillance approach for the Habitats Directive. Important principles are shown in Box 3:3 and will help determine the circumstances in which EO is suitable for habitat surveillance:

Box 3:3. Important principles for assessing surveillance requirements for Annex I habitats in the UK

Risk: Habitats at high risk of a significant negative impact will generally require a high frequency of sampling. Assessment of risk can build on the six- yearly assessment of Future Prospects and should take into account the best available information and information on pressures.

Ecology and Management: Naturally very dynamic habitats will need a greater frequency of surveillance to get a clearer understanding of their status. Habitats that depend on annual management or management prone to significant variation in type or intensity also need higher frequency surveillance as they are vulnerable to decline/deterioration if management regimes change.

Sensitivity to change: Frequency of surveillance of different parameters (e.g. range/extent, condition) should be appropriate to their sensitivity to change. For example, range is often less sensitive to change than condition.

Existing knowledge: The level of existing knowledge of the habitat/species itself and/or of pressures affecting it should be taken into account. Habitats lacking basic inventory information have a high requirement for surveillance to solve this information gap because we cannot usually assess if it is under threat until we know where it is.

Quality of existing evidence: The confidence we have in the overall conservation assessment should influence surveillance required. Habitats for which assessments are based on poor evidence are generally at a higher need of surveillance in the next period.

‘**Priority’ status Habitats**: Some habitats are assigned ‘Priority’ status in the Habitats Directive, or the UK has special responsibility for a resource due to it having a high proportion of the European resource. If several habitats were judged in need of frequent surveillance due to the principles above but resources were limited, it may be best to meet the requirements of these habitats first. These habitats will not necessary be at greater risk of poor conservation status than a non-priority habitat, but implications of a decline in status would be of greater concern.

Assess need in context: Surveillance should be balanced against other activities that can help achieve FCS. Reviews of pressures can be particularly useful in helping to understand causes of decline. This is needed to inform action that can be taken to reduce negative impacts, for example, reducing the pressure, or altering site management. There is little value in continuing to survey a habitat that we know is at unfavourable conservation status if no action is taken to improve known pressures. Resources would be better spent in conservation action.

Take a broader view and seek efficiencies: Habitats Directive surveillance requirements should be integrated with the requirements of other drivers (e.g. PSA targets) and local site management plans. This may increase the level of surveillance needed. For example, surveillance should be carried out where needed to provide useful feedback for site management, even if the habitat is at FCS and not in need of frequent surveillance at a UK scale. However, efficiencies can be achieved by using the same surveillance for multiple purposes.

What is known already about the conservation status of Annex I habitats?

The first report on Article 17 (JNCC, 2000) provided an analysis of implementation of the Habitats Directive between 1994 and 2000, focusing on work to select SACs. Assessment of Annex I habitats established that a significant proportion (57%) of terrestrial habitats are recovering, reflecting the considerable efforts put in by the conservation sector over the last 20 years. Few are favourable, in the main due to deficiencies in structure and function - restoration of habitats is a long-term process. There are more freshwater habitats in favourable condition, although many are still deteriorating; improvements in geochemical quality of many rivers and lakes does not necessarily equate to improvements in biological quality (JNCC, 2007).

The overall conservation status of habitats takes account of all four parameters, and is produced using the Commission's evaluation matrix. The overall assessment (including for marine habitats), is the worst of the reported parameter assessments with few habitats at favourable conservation status, although about half are improving and there is recognition in the reporting that more effort is needed to change their status.

Future requirements for surveillance of Annex I habitats

The next reporting round for Annex I habitats is in 2013 and will focus on conservation status.

For terrestrial habitats extent and condition are currently measured using field based techniques, or air photo interpretation often using the National Vegetation Classification (NVC) which is subsequently translated into Annex I habitats and are relatively costly to do. The required frequency of condition assessment is ideally determined by local threat and management needs. At a national level the overall picture of extent and condition will change slowly, and hence a complete picture is required less frequently.

For restricted habitats, the majority of information has come from Common Standards Monitoring undertaken by the country agencies for Special Areas of Conservation (SACs). However, most widespread Annex I habitats are not well covered by current surveillance and represent a major gap. The major gaps in knowledge are for habitats outside of SACs and these form nearly two-thirds (64%) of terrestrial / freshwater Annex I habitats (Table 3:2).

Earth observation is identified as an important development area for habitat monitoring for Annex I Habitats within all the conservation bodies and Defra (JNCC, 2012), with the expectation that: "*large improvements in knowledge are likely to result from this work (e.g., better range and extent figures), but its limitations should be recognised (e.g,. in its ability to show change in condition)".*

Table 3:2: Summary of current and preferred surveillance approaches for terrestrial and freshwater Annex I habitats (derived from JNCC, 2012 and JNCC 2009)

Category	Habitat	Current	Preferred Approach	Suggested lead
Over 80% habitat within SAC network	25 habitats (approx.) (and an additional 8 marine habitats)	Site condition monitoring using field based techniques. Marine habitats in inshore SACs are also covered by this site condition monitoring.	Combination of EO and field based techniques, streamlining of field protocols, better collaboration to integrate sampling with other needs e.g., forest stock/condition, coastal/flood defence, Water Framework Directive	NE NIEA, SNH, CCW (NRW after Apr 2013)
Habitats with much of their extent outside SACs Typically widespread	44 habitats (approx.)	Occasional habitat specific surveys, 5 woodland habitats through the National Forest Inventory, 3 habitats are covered by Countryside survey, but surveillance of habitats outside SACs is a major gap	Combination of EO techniques, sample-based field survey including using volunteers (re-design of Countryside survey and other schemes), improving habitat recording for Stewardship monitoring, and integration with other needs (e.g. forest stock/condition).	CCW, NE, NIEA, SNH collaboration with other agencies at country level, Defra/JNCC/CEH determining future role of UK sample based schemes, land cover mapping

3.4.6 Characteristics of these habitat classification systems

It is important to understand that the nature and variability of habitats encompassed by these habitat classification systems influences our ability to carry out surveillance. The relationship between Annex I habitats and habitats listed under the UK Biodiversity Action Plan (UK BAP) is not straightforward due to classification differences.

Annex I habitats are tightly defined and therefore are not expected to differ much across the UK. However, BAP priority habitats by their nature, are likely to encompass wide bio-geographical variations in the way they appear on the ground and therefore when assessed by EO. This variation has been acknowledged in the Crick Framework.

3.5 Summary of key earth observation concepts

A summary of key earth observation concepts were included in the Phase 1 report and within the Crick Framework User Manual which can be downloaded from the project pages on the JNCC website http://jncc.defra.gov.uk/page-5563.

Earth observation is the use of data, from satellite and airborne systems, for mapping and monitoring the Earth. It provides an accurate and repeatable methodology for ecological mapping particularly where vegetation is hard to survey or study areas are remote.

The most common types of earth observation used for habitat mapping include aerial photography, and satellite-based optical sensors. Over the past 50 years there have been progressive improvements in the spatial, temporal and spectral resolution of these sensors, making them a valuable resource across a range of mapping scales for a variety of mapping requirements. Imagery at different working scales and timings can provide information from species level right through to the wider area perspective, as well as tracking cause, effect and change which are not directly possible with field methods.

Optical remote sensing techniques have been used for many years with manual interpretation of RBG (red, green, blue or true colour) aerial photography. Satellite imagery advances these techniques by recording information at different wavelengths to those visible to the naked eye. These include the Near Infrared (NIR) bands and the Shortwave Infrared Bands (SWIR). These bands are particularly useful for land cover mapping as they have a close relationship to vegetation.

Figure 3:1 shows the reflectance curve for vegetation. The horizontal axis shows the electromagnetic spectrum with the Blue Green Red visible part of the spectrum and then the longer wavelengths into the NIR and SWIR.

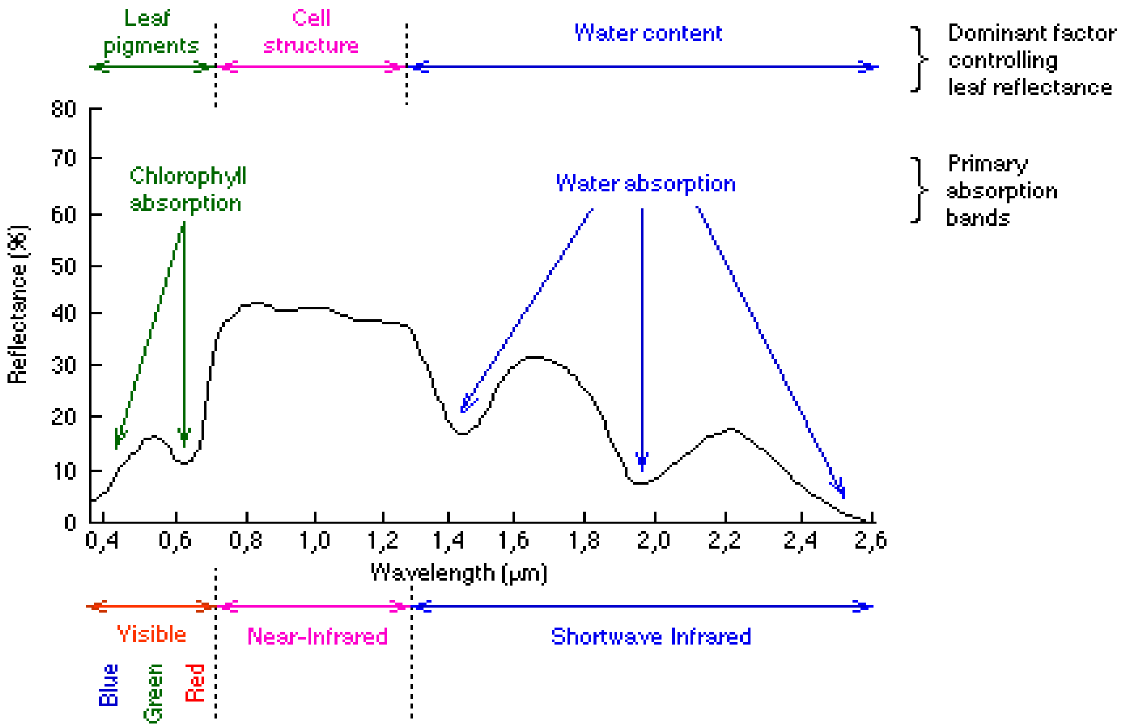

Figure 3:1: The spectral reflectance curve for vegetation

Green light is reflected from the top surface of the leaf, red and blue light are absorbed by the leaf and are used in photosynthesis, NIR light passes through the top surface of the leaf but is generally reflected from the lower surface, shown in Figure 3:2. The near infrared signal is particularly useful for recording vegetation types as its strength is related to the leaf structure. Therefore the more open and productive the leaf, the higher the NIR signal. Species such as agricultural grasses have a much stronger signal in the NIR band than scrub species for example, even though the RGB signal could be very similar.

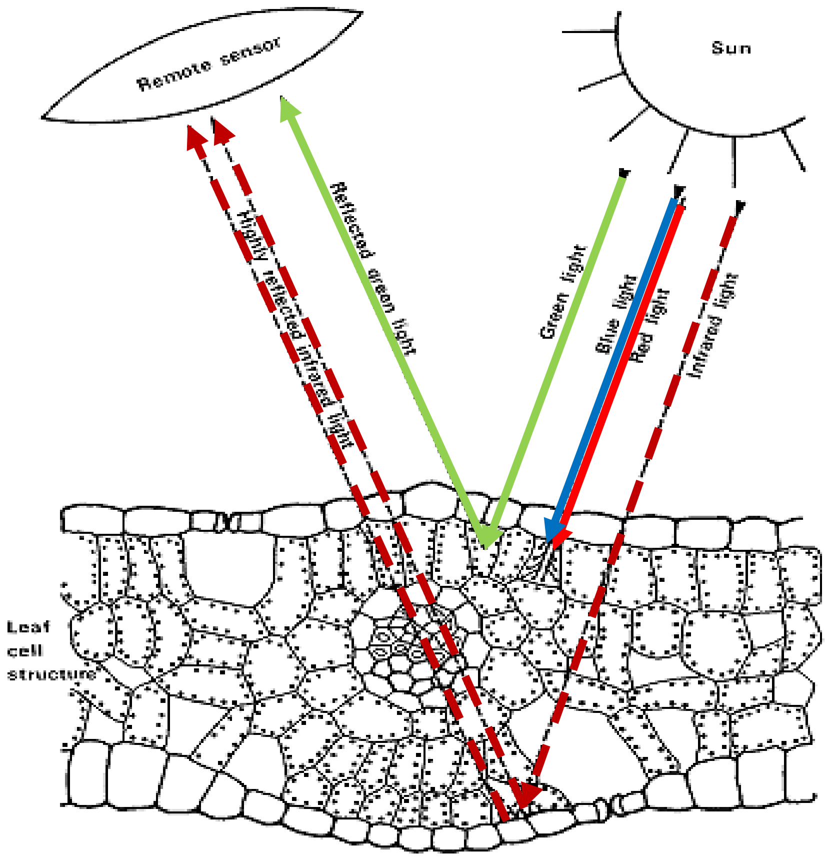

Figure 3:2: The profile of a leaf and how light is reflected and absorbed

Within the SWIR bands the signal is influenced by the water content of the vegetation and the soil and therefore can be useful for separating wet habitats such as mangrove from those with similar species but on a drier soil type such as limestone scrub.

Earth observation images are gathered from above and therefore are best at identifying plant communities which have a distinctive appearance from above, either as an even cover of one or a range of canopy forming species. It struggles to find communities that are distinguished by the presence of small sized plants which occur in low frequency hidden by the over-storey canopy. The classification provided by remote sensing will therefore not completely equate to that which a botanist may record on the ground. However, as earth observation can quantify other biophysical features of the vegetation such as productivity, it enables mapping of ecological functions which have a range of effects in terms of the ecosystem services that an area provides.

In order to show the maximum differences in the vegetation, the imagery can be coloured up viewing the NIR band as red, SWIR as green and green band as blue. Since plants reflect greatest in the NIR portion of the electromagnetic spectrum areas of productive vegetation appear as red. Green is the next colour that the human eye is sensitive to and thus is linked with the next most significant reflectance with regards to the vegetation curve, the SWIR portion of the spectrum. Finally, the green band is displayed as blue.

Satellites and their sensors vary in terms of spatial, spectral and temporal resolutions. The satellite data used in this project is listed in Table 4:4. The image extent is the area covered by a single image and can range from a few kilometres to hundreds of kilometres. Higher spatial resolution typically means a smaller image extent. However, wider area coverage can be achieved by combining several scenes into a mosaic, taking any timing differences into account. Spectral wavebands refer to the number of colours or discrete spectral samples that are recorded for each image pixel. Satellite imagery affords the opportunity to map surface features over a variety of geographical and temporal footprints using different parts of the electromagnetic spectrum.

Typically the presence of more spectral wavebands increases the ability of the imagery to discriminate between landcover types as there is more data and therefore more discriminating power in the image. Temporal resolution is related to the repeat frequency with which a system can acquire images of the same location. Although this may be fixed for an acquisition system, environmental factors such as cloud cover have an overriding impact on the availability of usable images. Within this study we have concentrated on the use of optical sensors. However, there are other sensors becoming available including microwave, or synthetic aperture RADAR, systems. These systems are being actively researched in their role for vegetation mapping and will become increasingly useful for understanding vegetation and cover types.

4 Project approach

In order to meet the aims and objectives as stated in section 3.2, the project was split into 3 tasks:

1. Review of Crick Framework content. Reporting on a desk review, supported by limited consultation and peer review by two external specialists, Dr Geoff Smith and Dr Alexis Comber covering a statement of validity of the current Habitat Tier allocation, any proposed amendments and the addition of information on previous method development that failed to overcome known gaps. The review focused on the content of the Framework and expanded and updated this in the light of any new knowledge and experience.
2. Implementation of a pilot project. Assessing potential of a new approach using EO for mapping the extent and condition of habitats (the "Norfolk Pilot"). The pilot area provides a suitable test of the Crick Framework and demonstrated significant advances in conceptual thinking, the approach to habitat mapping, the possibility for sustainability and the consistency with which it can be rolled out to the UK. This project reports on accuracy, effectiveness, practicality and value-for-money of the EO approach to habitat extent and condition mapping. Consideration of field-based attributes of habitat condition, that evidence suggests should be detectable from EO and which are of value in surveillance and monitoring to assess which can be discriminated using EO and how well. These are then incorporated into the Crick Framework.
3. Communication with users to identify their needs, share best practice and communicate results.

4.1 Headline questions for the pilot project to address

Based on the objectives and project specification a set of key questions for the project to address were identified. These provided a focus for evaluating findings and bringing together and reporting findings in a way that has clear relevance to policy and applications development. These are addressed in section 7.

Headline questions
• How well did landscape-scale mapping perform? • How well did site-based mapping perform? • What do we know about the accuracy and cost of producing the mapped information arising from the pilot? • How transferable are the results of the pilot and what considerations need to be taken into account to ensure success? • There are features of vegetation that evidence suggests EO can detect and that may be useful for the assessment of condition - could these features be mapped in the pilot area? If so, how well? • Are these types of condition measure likely to be useful for habitat surveillance? • What is the evidence for the potential of the techniques for monitoring, forecasting and hindcasting? • What benefits arose from increasing the resolution, spectral range and seasonal spread of imagery used and what difference did it make? • What benefits arose from the use of a range of other spatial data and what difference did it make? • What were the main issues encountered? • How was the Crick Framework used in the planning, delivery and assessment of potential within the pilot project and how useful was it as a tool to support these activities?

4.2 Rationale for the earth observation approach adopted

The research required development of a new technique that had to fulfil a number of requirements;

- demonstrate significant advances in conceptual thinking and advance approaches to habitat mapping,
- be capable of consistent implementation so the technique, and principles that are developed,
- can be rolled out to the UK, and beyond,
- offer the possibility for sustainability as a cost-effective and repeatable method,
- not overlap with or duplicate other work being carried out elsewhere.

In response to these requirements, it was decided to build on existing work, trialling methods of EO-based habitat analysis in new environments and using new techniques to assess stock of particular habitats or condition. The work will concentrate on those habitats classified in the Crick framework as 'professional belief' (i.e., adjudged by experts as being correctly classified but without supporting evidence from published papers and reports). The trialling would be accompanied by a critical assessment of effectiveness and practicality of the methods and a value for money assessment.

The work uses an object orientated rule-based habitat mapping approach similar to the one used for the production of the habitat map of Wales (Lucas *et al.* 2011) which uses earth observation technology and a thorough understanding of the landscape ecology of the region. A simple conceptual process summarising the logic and way this EO approach works is provided in Box 4:1.

Box 4:1: Summary of earth observation concepts used in an object orientated rule-based approach

EO and Vegetation Identification: Summary of an object-orientated rule based approach

- The surface of the Earth reflects the suns radiation back into the atmosphere. Earth observation satellites can detect this reflected radiation and store it as data.
- The visible portion of the electromagnetic spectrum, RGB, is a narrow portion of the light reflected by surfaces. Satellites can record reflectance values for other parts of the spectrum, such as Near Infra-red (NIR) and Shortwave Infra-red (SWIR) which interact with plants and surfaces giving additional information.
- For vegetated surfaces, the satellite data value represents a combination of the signal from the surface of the different plant species forming a vegetation stand, as well as any shadows and can include the ground or ground covering vegetation.
- The level of detail that satellites can record is based on their spatial resolution; SPOT imagery contains one piece of information for each 10x10m area on the ground, recorded as a pixel.
- Object based analysis groups pixels into those with similar spectral values; then the whole object is analysed.
- As the data values for these objects represent a combination of what is present within the object, it is necessary to understand the appearance of the dominant vegetation type and any effects on this of the sub-dominant vegetation type, shade and soil present, for a meaningful classification.
- Ecologists work in a similar way during a vegetation survey by fieldwork or manual aerial photographic interpretation; they consider what is there, find assemblages of plants and group them into an area, then describe the vegetation within the area.
- However, ecologists also use their understanding of landscape ecology to help identify the vegetation type present and assess condition or identify site pressures

(e.g., an ecologist would not expect to find a wetland on a well-drained hilltop).

- A rule-base can be developed to incorporate this ecological contextual knowledge into the classification to separate vegetation assemblages with a similar look but occurring in very different settings.
- Combining knowledge of landscape ecology, plant communities and vegetation reflectance within a “rule-base”, the likely presence of habitats within an area can be mapped.

4.3 Rationale for piloting the techniques in Norfolk

The rationale for choosing Norfolk as a test area is summarised in Table 4:1.

Table 4:1: Norfolk’s applicability as a pilot area features

Requirement	Why is Norfolk well suited as a test area?
A sufficiently diverse environment to allow testing and application of the Crick Framework	There are a wide range of relevant habitats (many are Annex I habitats) allocated to component parts of both Tier 2 and 3 of the Crick Framework, occurring in mosaics with other habitats and improved land. (Appendix 1 lists priority habitats and Annex I habitats known to occur in Norfolk). These habitats occur in diverse landscapes, from coastal areas, through to wetlands and dry areas. Norfolk contains a wide range of BAP priority habitats and Annex I habitats which in many cases differ phenotypically from those found in the west where the techniques have initially been established. Although BAP priority habitats occur across the UK, different regions have different descriptions of what forms a good example of the habitat. It is therefore essential to understand how the habitats appear in the landscape that is being assessed.
Minimise overlap or duplication of other work being carried out elsewhere	There has been little habitat analysis rule-base work carried out in the East of England covering lowland habitats or in drier and warmer parts of the UK. Most of the large scale detailed habitat mapping to date has been undertaken in Wales, with some further smaller studies in Scotland and Ireland. These have focussed on habitats which are mostly upland in nature. The semi-natural habitats in the lowland of the West and North form larger patches than in the heavily agriculturally managed South East. The West and North are wetter and colder than the east of the country with a clear separation of the landscape into upland and lowland units with slope, aspect and altitude important for all habitats types, valleys being influenced strongly by the surrounding mountains. Many of the Annex I and priority habitats which occur in Norfolk are not found in the western parts of the UK at all and it will also be a useful test to see if these can be identified.

Requirement	Why is Norfolk well suited as a test area?
Differing ecological drivers	If the concepts developed in Wales are to be used to identify habitats across the country it is necessary to understand how they apply in the east of the country where the major ecological drivers, the scale of the habitat features and the influence of water are very different. Norfolk was chosen as the study site as it is a relatively flat landscape. The habitats are mainly aquifer fed, rather than influenced by surface water and the influence of saline water affects a large proportion of habitat. Norfolk provides a wide and representative range of semi-natural habitat types. However, because of the importance of the agricultural element of land use in the east of England these habitats are, in the main, limited in extent and in some landscapes they are isolated from other areas of semi-natural habitat.
Make best use of any existing available datasets and local knowledge	Norfolk County Council provided in-kind support and advice to the project as they are keen to utilise EO to strengthen the resources of their Biodiversity Information Service (NBIS). There are many sites protected by a range of designations, including SSSIs and SACs, meaning that there is likely to be some information on habitats present and their condition to support assessment of the findings.

This combination of small-scale variability and the isolated nature of some of the habitats provides a clear challenge for EO analysis as there is a need to both:

- identify the presence of possible habitats in a very managed landscape and then,
- classify them appropriately.

In image classification it is hard to take into account the variability of habitats with a small representation as it may be an exceptional habitat type. The project therefore looked at both identifying likely habitats within the overall landscape context and then how these can be separated into Annex I and priority habitats.

Work in such a pilot area, in the east of England with different landscape habitat drivers and different habitat focus from work undertaken before, identifies transferability concepts and will ultimately be of benefit to all partner organisations and has implications and benefits that are applicable across a wider range of habitat types across the UK.

4.4 Grouping of habitats and habitat characteristics

4.4.1 Grouping of habitats

For this reporting the semi-natural habitats have been split into two high-level groupings and a number of subgroups based on their ecological and earth observation characteristics, with dominance referring to the feature that defines the habitat when viewed from above:

Habitats dominated by woody vegetation
- Environments dominated by tree canopy cover
- Environments dominated by shrub canopy cover

Habitats dominated by non-woody vegetation
- Dry environments dominated by graminoid species
- Environments dominated by a saline and brackish water influence
- Environments dominated by a fresh water influence

The two high level groupings (split by whether the habitats are dominated by woody or non woody vegetation when viewed from above) appear very differently in EO imagery, and therefore this is one of the first divisions that occurs during the landscape splitting process (see section 4.8). At the next level down, the habitats are grouped into those with distinct land form patterns and distribution, arising largely from the interaction of the soil and water regimes. This split requires contextual and spectral information to start to avoid confusion with other habitats in the rule-base.

For each of these main habitat groupings, further divisions of the land cover are needed to get down to the habitat level (e.g., so that the range of component habitats in environments dominated by dwarf-shrub canopy cover can be identified).

4.5 Selection of study areas

Study areas within Norfolk were chosen in discussion with NBIS staff. It was important to focus the pilot project in areas which contain a good range of the semi-natural habitats. It was also important to take into account the footprint of satellite imagery routinely acquired in the area (e.g., SPOT).

Although areas within Norfolk will have similar habitat types to the rest of the UK, for example native woodlands, it is important to recognise that the way the habitat appears will vary between areas and likewise the EO reflectance will vary. This is not just a function of the dominance of characteristic species in the canopy but is also influenced by climate, ground flora and even in some instances soil reflectance. These regional habitat and ecological driver differences need to be understood when describing the landscape.

4.5.1 Using landscape ecology for the study area selection

In order to understand how habitats are seen in the remotely sensed imagery it is necessary to understand the land use and characteristic features of the landscape which can alter the appearance of the vegetation types. Norfolk is a mainly in agricultural use and is dominated by intensive agriculture. Through discussion with Norfolk Biodiversity Information Service (NBIS) staff as well as other interested parties in the area, it was identified that there are four parts of the county that together contain a good range of the semi-natural vegetation present in the county. These four areas are described by four of the eleven National Character Areas (NCAs) found in Norfolk (Figure 4:1).

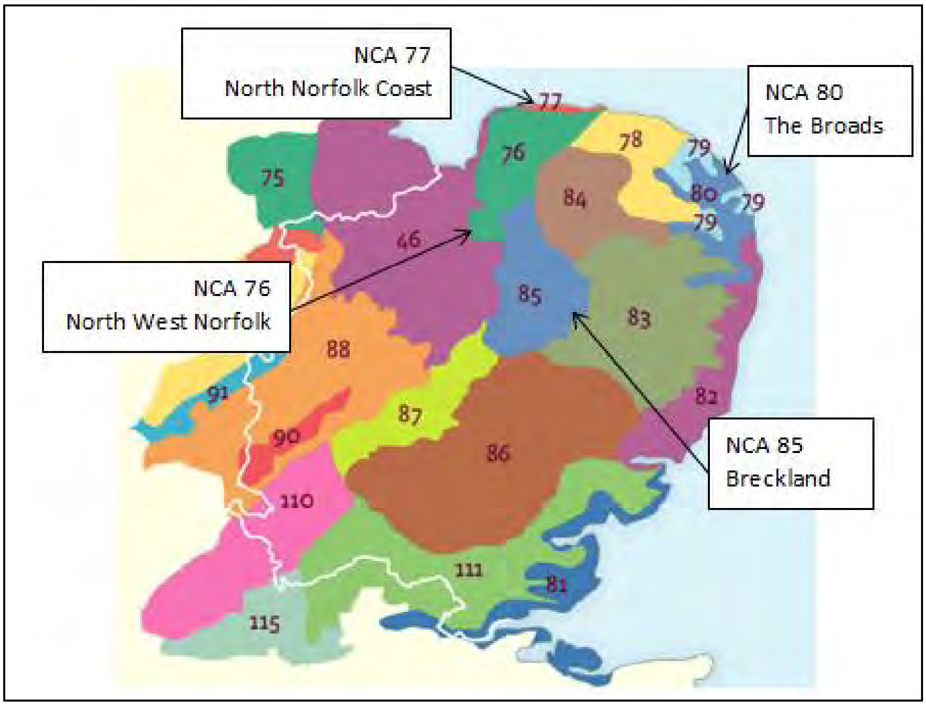

Figure 4:1: National character areas present in Norfolk

These NCAs differ considerably in character and the types of semi-natural habitat they contain; these are described in Boxes 4:2 to4:5.

Box 4:2: The landscape of North West Norfolk

North West Norfolk

Description: This is a large-scale arable and grassland landscape on expansive rolling terrain, with frequent long views over remnant heath and large belts of mixed woodland. Large estates give a unified and well-managed quality to the landscape, enhanced by the rectilinear network of late enclosure, contrasting with the open heath of the north/south Lower Greensand ridge on the western edge. There are comparatively few roads which are often straight and tend to have wide verges, especially in the northern part of the area and uniform hawthorn hedges set well back and well-maintained. There are few hedgerow trees or copses.

Ecological drivers: Physically this landscape is unified and distinctive, consisting mainly of the shallow dip slope of a low Chalk escarpment sloping west to east in the north-western corner of Norfolk. This forms a plateau of brown rendzina soils with a few shallow river valleys running into the Wash, which have little impact on the medium-scale rolling upland. The scarp soils are variable, with outcrops of brown sands and sandy gley soils contrasting with the alluvial soils of the river valleys.

Semi-natural habitats typical of the area:

- Small blocks of existing native woodland.
- Field margins, hedges and dykes help with connectivity and provide refugia for wildlife in this intensively arable landscape.
- Isolated hollows of heath and acid valley mire remain as significant habitat features, such as Dersingham Bog and Royden Common.

Main Source: Natural England character area descriptions – legacy documents (76)

Box 4:3: The landscape of North Norfolk Coast

North Norfolk Coastal Environment

Description: The North Norfolk Coast is an area of enormous variety, from the mud flats and saltmarshes around Blakeney to the shingle banks of Salthouse or the extensive sandy beach and dunes near Holkham. The area occupies a narrow strip of land from the northeastern edge of the Wash, where it abuts the Lower Greensand scarp that marks the edge of North West Norfolk and along the northern coast of Norfolk as far east as Weybourne. Along this coast it is distinguished from North West Norfolk by the change from an extremely low-lying marine character to that of higher arable land. This change occurs quite close to the coast and is marked along much of its length by the coast road and its settlements, which act as a dividing line.

Ecological drivers: Erosion and deposition are extensive features of this coast. The strata that once formed cliffs are nearly all of soft or loosely-aggregated glacial sands, gravels and clays and are now confined to the outer limits of this area. Long-shore currents and wave action have deposited this eroded material further west along the coast, creating shingle spits when river mouths are encountered, as at Blakeney Point and Scolt Head. These shingle spits have provided the protection from wave action necessary for dune complexes and has allowed the development of mudflats, which grade into saltmarsh. This is a highly dynamic environment dependent on sediment mobility along the coast. The coast of Norfolk is extremely important in habitat terms supporting a wide range of plant, birds and invertebrate species.

Semi-natural habitats typical of the area:

- Mudflats and sandflats
- Saltmarsh
- Sand dune complexes
- Saline lagoons
- Shingle

Main Source: Natural England character area descriptions – legacy documents (77)

Box 4:4: The landscape of The Broads

The Broads

Description: The Broads form a network of wetland that is unique in Europe, in terms of both ecology and landscape, forming one of the few remaining large areas of lowland floodplain grassland in Britain. The 'Broads' themselves are shallow lakes, often fringed by fen and reedbeds with associated areas of carr woodland. This is a low-lying area on the eastern edge of East Anglia, between Norwich and the North Sea coast. Its boundary follows the edge of the floodplain of the rivers Yare, Bure and Waveney and their tributaries as well as the flat river-valley land and some lower valley slopes to the west. It is largely bounded by fertile arable plateau to the north, with which area there is an intimate interaction, and by the eastern edge of the Central North Norfolk area of fertile arable and woodland.

The character of the Broads is very mixed, consisting predominantly of a contrast between large, open, grazing marshes and low-lying wetland which is made up of an intricate mix of Broads (flooded former peat diggings), waterways, reed swamp, fen and carr woodland. In the upper reaches of the river valleys, deciduous woodland, copses and hedgerows give an pastoral character which is more akin to the small valleys incised into the East Anglian glacial till. In contrast, the open valleys nearer the coast, which form the other dominant characteristic of the Broads, are still flat but extensive, with little woodland; river embankments are a strong landscape element. This is a more homogeneous landscape, with a mix of arable and grazing and a rectilinear framework of dykes.

Ecological drivers: The main ecological driver for the Broads is the soil / water interactions which have developed over time. In Roman times sea levels were around 5m higher than at present, and the area now known as the Norfolk Broads was a river estuary. Over time this estuary silted up and eventually closed the river mouth, allowing large areas of peat to develop. The peat was later dug out by man for use as fuel, creating the Broads as we know them today. Reeds are still cut and used for thatching in some areas.

Semi-natural habitats typical of the area:

- Grazing marsh,
- Woodland (including wet woodland),
- Fen,
- Reedbeds

Main Source: Natural England character area descriptions – legacy documents (80)

Box 4:5: The landscape of Breckland

Breckland

Description: Breckland contains one of the most extensive areas of lowland heathland in Britain. This is one of Europe's rarest habitats; it has suffered great losses last century and many of the remaining heaths have become fragmented. Breckland has numerous meres (five of which are BAP quality) that are aquifer-fed and so are independent of precipitation. Breckland is composed of a mixture of acidic and calcareous areas sometimes in intricate mosaics. Breckland heath management was based on low frequency disturbance, with a 15 year ploughing cycle. Arable margins have been created around some heaths, consisting of 5-10m maize strips; these are used as cover for recreational shooting. Arable margins can support important invertebrate species. Some Breckland heaths have been degraded due to imposition of management regimes more suited to Calluna heath species and improvement from overgrazing. Bracken and unmanaged gorse can be a problem. The heathland of Breckland comprises a mixture of dry dwarf shrub heath dominated by heather, lichen heath and both acidic and calcareous heath grassland and occasionally scrub. These different communities often occur in close proximity and form complex mosaics.

The landscape is mostly of late enclosure, set out in large fields bounded by neat thorn hedges or pine shelter-belts, interspersed with the conifer plantations which lead into the vast depths of Thetford Forest, the largest area of lowland wood in England, and some areas of open heath. To the north, Breckland runs into the 'Good Sands' of North West Norfolk, with its carefully managed, well-cultivated arable character while, to the north-east, the transition is to Central Norfolk, with its undulating topography and mix of arable and woodland and to the west the Fens, which differs considerably in character from Breckland. In each case, there is a transitional zone where discrete landscape areas mingle.

Ecological drivers: A combination of climate and geology has produced a low, gently undulating plateau which is very different from the areas that surround it, despite their similar topography. Breckland can be very cold as well as dry meaning frost can be experienced at any time of year and the area bears some similarities to Steppe. The coastal influence extends all the way to Breckland so coastal species can be found, including inland dunes.

Semi-natural habitats typical of the area:

- Acid and calcareous heathlands,
- Semi-natural grasslands
- Arable habitats, including field margins and hedgerows,
- Meres

Main Source: Natural England character area descriptions – legacy documents (85)

The national importance of the semi-natural habitats within these four NCAs for nature conservation is recognised by various statutory designations including several National Nature Reserves, Special Protection Areas, Ramsar sites and many Sites of Special Scientific Interest.

Natural England have produced data on the extent of priority habitats in these National Character areas (Natural England, 2011a, 2011b, 2011c and 2012); 14 of the 35 priority habitats known to be present in Norfolk are found within these four NCAs. There are large SACs that fall within or straddle these NCAs, together they are known to contain 35 Annex I habitats (Appendix I).

In relation to the habitat groupings identified in section 4.4, all are represented in these four areas (Table 4:2). This illustrates how diverse these landscapes are and demonstrates how important it is in a regional context to separate out characteristic areas in order to adapt the general rules to specific habitat conditions.

Table 4:2: Habitats and case studies

High level habitat grouping	Sub class	NCAs where these habitats groups are typically found			
		North Norfolk Coast	North West Norfolk	Breckland	Broads
Habitats dominated by non-woody vegetation	Dry environments dominated by graminoid species		X	X	X
	Environments dominated by a saline and brackish water influence	X			X
	Environments dominated by a freshwater influence		X	X	X
Habitats dominated by woody vegetation	Environments dominated by tree canopy cover		X		X
	Environments dominated by shrub canopy cover		X	X	

4.5.2 Pressures on the natural environment in Norfolk

Norfolk as a whole is a heavily managed environment and the habitats face multiple pressures. Current pressures range from wholly anthropogenic, including development pressures, tourism and intensive arable management, to an anthropogenic response to natural processes such as coastal erosion and flood defence work in response to flood plain development and sea level rise.

Current development pressures include road improvement works, such as the widening of the A11 to form a dual carriageway and housing expansion planned to the northeast of Norwich, including 30,000 extra houses and associated infrastructure. Norfolk already has high demand on ground water supplies due to population and irrigation; this pressure is likely to continue to increase in light of housing expansion. Norfolk receives a large number of seasonal visitors (approx. 7-8 million each summer), which tend to be concentrated in three regions: the north coast, Thetford forest, and the Broads. The arable landscape affects the semi-natural land around it in a number of ways not only in the demand for land but also through water cycle interruptions and nitrogen enrichment downwind of pig farms.

The mobile nature of the Norfolk coast and the important habitats it supports relies on the unimpeded movement along the coast of sediment for habitat development. The change in erosion and deposition that ensues when this is interrupted creates numerous pressures on existing infrastructure. Sea level rise is also putting pressure on the low lying environment which is driven by water processes, with the saline inundation of freshwater systems.

4.5.3 A dual scale approach

Mapping work investigates using the object-orientated rule-base (see section 4.2) at two quite differing scales, mapping at both:

- **landscape scale**: with a focus on mapping the broad range of features in the landscape including heavily managed and semi-natural vegetation;
- **site-based scale**: detailed mapping of areas containing specific Annex I and priority habitats within case study areas.

These two approaches require differing inputs in terms of imagery and ancillary data but both share a "rule-based" approach to image classification.

4.5.4 Landscape-scale study area

Two landscape scale study areas (shown in Figure 4:2) were chosen to pilot the mapping of a broad range of land cover types, including both semi-natural habitats and agricultural land. These two study areas cover a range of environments as described by the four NCAs and contain a variety of priority habitats. The Norfolk Broads are located in the East Norfolk landscape scale study area and the three other NCAs (Breckland, North Norfolk Coast and North West Norfolk) are in the West Norfolk study area.

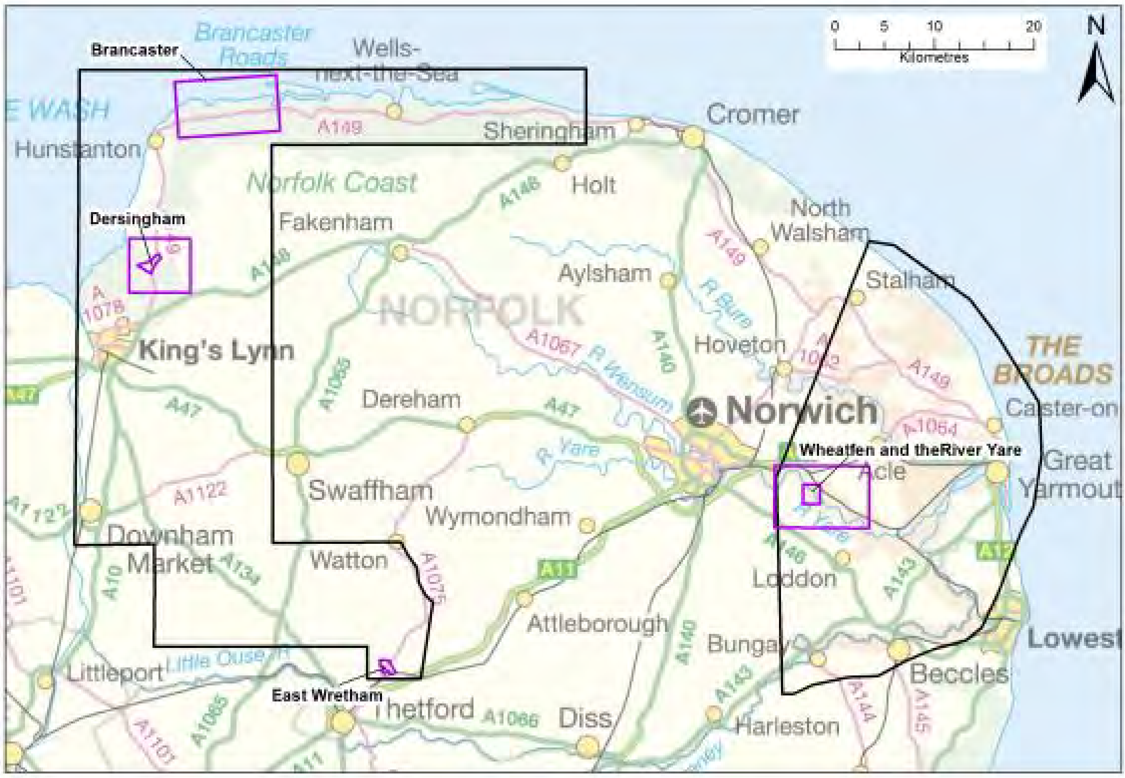

Figure 4:2: The study areas in Norfolk

4.5.5 Site-based study areas

Within the Norfolk study area specific case study sites were chosen in consultation with JNCC, NBIS staff and other locally interested parties for piloting "finer-scale" more detailed mapping of semi-natural habitats. These sites are all designated as SSSIs or SACs and have been selected as they are known to provide a good range and high proportion of

Annex I and priority habitats (Table 4:3). The full range of Annex I and priority habitats present in Norfolk is provided in Appendix 1: Priority and Annex 1 habitats present in Norfolk.

These sites have been studied in more detail both in the mapping habitat extent using a variety of satellite imagery types and for identifying condition monitoring features using additional ancillary data and UAS flights. The case studies are discussed in more detail in the results section (Sections 6.3 and 6.4) and further analysis of these sites for condition is presented in Section 6.5.

Table 4:3: Case study areas and the habitats they contain

Site-based	**Landscape scale study area (and NCA)**	**Designations which the case study site forms part of**	**Habitats dominated by woody vegetation**		**Habitats dominated by non-woody vegetation**		
			Environments dominated by tree canopy cover	Environments dominated by shrub canopy cover	Dry environments dominated by graminoid species	Environments dominated by a fresh water influence	Environments dominated by a saline and brackish water influence
Coastal case study near Brancaster	West Norfolk (North Norfolk Coast NCA)	North Norfolk Coast **SSSI** North Norfolk Coast **SAC** The Wash and North Norfolk Coast **SAC** North Norfolk Coast **SPA** North Norfolk Coast **Ramsar site** Holme Dunes **NNR**					x
Dersingham Bog	West Norfolk (North West Norfolk NCA)	Dersingham Bog **SSSI** Royden Common and Dersingham Bog **SAC** Dersingham Bog **Ramsar site** Dersingham Bog **NNR**	x	x		x	
East Wretham Heath	West Norfolk (Breckland NCA)	East Wretham Heath **SSSI** Breckland **SAC** Breckland **SPA**	x		x		
Rockland and Surlingham Broads	East Norfolk (The Broads NCA)	Yare Broads and Marshes **SSSI** The Broads **SAC** Broadland **SPA** Broadland **Ramsar site** Mid Yare **NNR**	x			x	

4.6 Image acquisition

4.6.1 Considerations

In the same way that is important to appreciate the landscape ecology, it is also important to understand and take into account land use practices, the length of the growing season and timing of seasonal changes in the growth of vegetation in Norfolk.

Past work on an object-orientated rule-based approach has taken place in western and northern parts of the UK. Spring starts much earlier in Norfolk and summer ends later. So the well-established principles used to date needed to be re-evaluated prior to image acquisition.

The growing season and intensively managed land. The growing season in the east of England is much longer than in Wales and Scotland. In the west and north of the UK land is generally not worked in winter. This distinct cycle of management can be used as a distinguishing feature to separate agricultural areas from areas of semi-natural habitat within the landscape. At the start of the growing season (late February/ early March) intensively used land has either been ploughed and reseeded meaning the ground is bare, or fertilised so is much more productive than the semi-natural grasslands. This difference in productivity and cultivation within a few weeks of the start of the growing season can be easily distinguished in a March satellite image. The major land use in Norfolk is arable and land can often be worked all winter. As a result, arable land has many different cover stages throughout the year. In the east ploughing and fertilising of grasslands could occur all winter and therefore there may be so much difference in the growth or productivity within the arable areas that this cannot be used to effectively separate all of the intensively used sites and natural sites.

Scale of the features. Within the Norfolk landscape, habitats occur at both a much larger scale and smaller scale than they do in many other parts of the UK. Arable fields can be tens of hectares, however, semi-natural habitats, can be only a few metres across (e.g. species rich ditches). There is therefore a need to acquire imagery that is suitable for both of these features.

Terrain: Where steep hilly and mountainous terrain is present, the low sun angle during the winter results in large shadows in the imagery cast by the topography. It is therefore not normal practice in the North and West of the UK to use imagery gathered between mid-October and early March. In the flat open environment in Norfolk there is much less of a topographical constraint with winter imagery however, sun angle still affects shadowing within the vegetation.

“Leaf on - leaf-off”. The imagery acquisition was driven by the findings of the Welsh habitat mapping, where it was found to be essential to have both a spring and summer image available within the set of images used for classification. This provided images at a “leaf-on” and “leaf-off” time of year, allowing for the separation of habitats that appear in a similar way throughout the growing season, from those that have a strong growth cycle.

When choosing imagery to undertake habitat analysis it is necessary to understand how important these factors are within the landscape of interest and how they vary in different settings.

4.6.2 Choice of satellite imagery for landscape scale mapping

In Norfolk the satellite imagery requirements were driven by the arable variation, and the need for imagery at a selection of scales. When there is a large arable variation there is much more “confusion” between arable land and semi-natural habitats throughout the year, as the growing season generates many situations during the year in which the reflectance of agricultural crops might be similar to the reflectance properties of semi-natural habitats. This has been documented in Germany (Franke *et al*, 2012) and in accordance with the findings of that study, it was decided to try and obtain images from at least four times during the year rather than two (excluding mid-winter as there can be little vegetation information in satellite imagery from this time for the habitats of interest).

A good range of satellite imagery was acquired for the Norfolk study areas and these are listed in Table 4:4 with their spatial resolution and the timing of the imagery. All of these types of satellite imagery were assessed for use in the mapping and used to a lesser or greater degree in the landscape scale and site based analysis.

Table 4:4: Satellite imagery acquired for the Norfolk pilot study

Sensor	Spatial Resolution (m)	Scene size	Spectral resolution	January	February	March	April	May	June	July	August	September	October	November	December
Landsat	30	180x170km	B, G, R, NIR, SWIR				2011	2011	2011	2011		2011	2011		
DMC	30	600x600km	G, R, NIR, SWIR (pre-2008), TIR		2011										
IRS	20	150x150km	G, R, NIR, SWIR					2011							
ASTER	30	60x60km								2011	2005	2003			
SPOT	10	60x60km	G, R, NIR, SWIR			2011 2012									
RapidEye	6.5	Swath width ~80km not sold by scene	B, G, R, Red Edge, NIR						2011						
GeoEye-1	1.65	5x10km, 5x10km, 5x15km, 5x5km	B, G, R, NIR								2011		2011		

In addition to the satellite imagery it was also necessary to obtain very fine resolution image data from aerial photography to help identify fine-scaled and linear features, such as hedges, field margins and ditches. The 25cm RGB and CIR aerial imagery was captured between May and July 2010 and was supplied by Defra.

4.6.3 Choice of imagery for the site-based case study areas

With so many Annex I habitats being at a very fine scale, especially in Norfolk and covering comparatively small areas, compared to the upland mosaics present in other areas of the UK, it was felt that ultra-high level detailed imagery from flights by an Unmanned Aerial System (UAS) may be the best means of acquiring imagery at an appropriate scale to delineate habitat extent and particularly condition features relevant to Annex I SAC sites. UAS imagery has been acquired in four of the site-based study areas.

4.6.4 Image processing

Image processing is an important pre-requisite to using the imagery for analysis. It combines a series of steps, summarised in Figure 4:3, which correct the imagery to remove external variables. The first stage adjusts the image so that the whole image occurs in the correct location; the second takes the Digital Numbers (DN) produced by the sensor and adjusts them to reflectance values and the third step takes account of variation caused by atmospheric conditions such as dust.

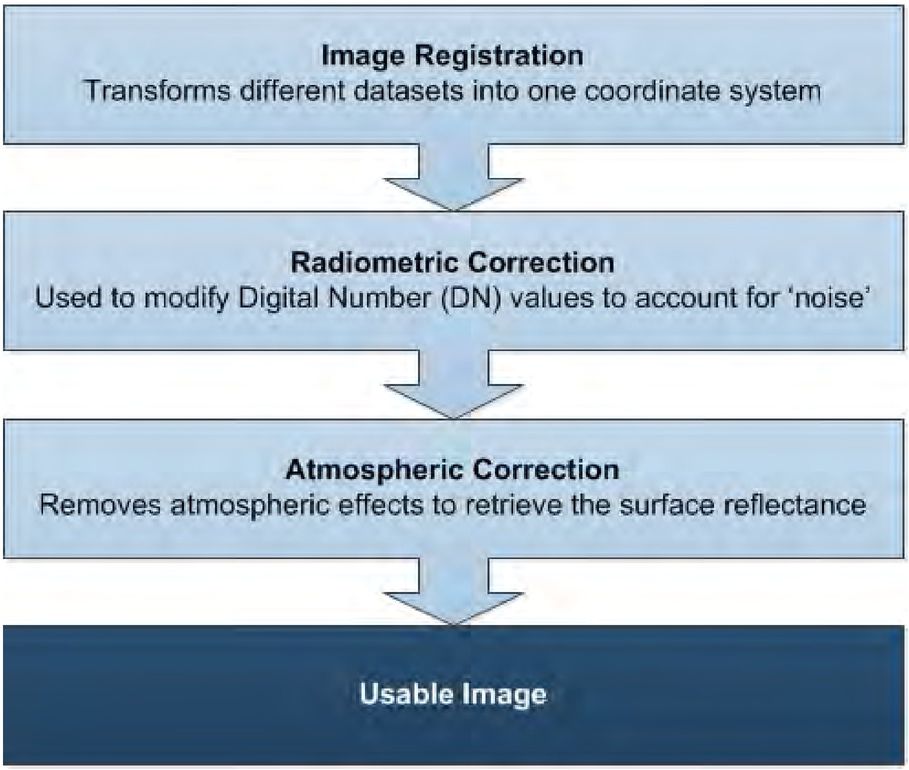

Figure 4:3: Summary of image processing requirements for most imagery

Image registration processes the imagery against a Digital Terrain Model (DTM). Imagery can be purchased partially or fully processed however, any processing will have been against a global, broad scale DTM. This often means that images from different sensors may not overlay correctly with one another and artefacts in the image can be created. For a good quality imagery product, it is often necessary to start processing imagery from as raw a start point as possible (e.g., before image registration, referred to by the suppliers as Level 1a or 1b) and using a suitable DTM. A high resolution DTM (5 or 10m) should be used for all images being analysed together although the DTM must cover an area larger than the imagery being processed.

Once all the imagery from the different sensors has been registered it can be incorporated into an image stack. A final QA is needed to ensure exact co-registration. Without high quality processing, when imagery is combined objects will not line up exactly and will therefore appear to have multiple edges. For the identification of Annex I and BAP habitats within Tiers 2 and 3 of the Crick Framework, multi-seasonal images with 'leaf-off' and 'leaf-on' imagery is essential.

4.6.5 Using Unmanned Aircraft Systems (UAS) and data

An Unmanned Aircraft Vehicle (UAV) is an aircraft designed or adapted to operate with no human pilot on-board which, when combined with some form of payload, avionics, and appropriate (ground-based) infrastructure, is termed an Unmanned Aircraft System (UAS). Initially, UAVs were developed for military use, but the enormous potential for UAV-based commercial services, including imagery in support of a variety of land-management activities (e.g., precision agriculture, forestry, environmental monitoring) is now being recognised.

Recent technological developments have helped to make UAV-based solutions for such applications more feasible. In particular:

a) There have been major developments in UAV technology, accompanied by a growing understanding of UAV operational issues. These have arisen largely from the widespread military use of such systems; and commercial incentives to further develop and harness this technology.
b) There has been significant miniaturisation of the type of sensors needed for land management applications, making the integration of these with small unmanned aircraft more feasible.
c) Development in software both on the ground in the form of ground stations and onboard the UAV is increasing the ease at which these platforms can be deployed and used more routinely.

UAV operations

UAV operations during this project were conducted by Callen-Lenz Associates (CLA) at Dersingham Bog, East Wretham Heath, around Rockland and Surlingham Broads and a coastal location near Brancaster.

Wide operation of UAV systems requires much planning and consideration of operating regulations. These are summarised here and further details are contained in Appendix 2: UAV additional operational.

Regulation considerations

Within Europe civil operations of UAVs with a mass less than 150kg are regulated at a national level. In the UK the Civil Aviation Authority (CAA) has this responsibility. The current CAA regulation is actually amongst the most accommodating in the world for the competent operator, whereby regular commercial use of UAVs is encouraged and managed effectively. The UK CAA have long provided a framework under which it has been possible for competent organisations to conduct commercial operations of unmanned aircraft and this policy has been published as CAP722. The operating organization is required to have competent staff, appropriate processes for safety management and be able to integrate with the wider air traffic and airspace user community.

Flight planning

The location of the case study sites in this project required operations in close proximity to Norwich Airport. This represented a typical scenario since it is an international airport with all the airspace and air traffic management infrastructure typically found at all major airports. Commercial operational work around Norwich Airport required the granting of a UK first, permission to undertake commercial UAV operations within controlled Class D airspace.

Flight operations

All UAV operators in the UK are required by law to obtain CAA Aerial Work Permissions for commercial operation within UK airspace. This gives the operator accreditation and relates to elements such as:

- commercial operation of the UAV platform,
- advance planning and assessment of target data acquisition sites to identify any aviation or safety management issues or other permissions required,
- issue of a navigation warning (NOTAM) which publishes the activity to other airspace users and provides contact details for further information,
- an Operating Site Safety Assessment to identify and assess any hazards associated with a particular operating site and a safety briefing is given to any observer or bystanders.

The imagery data was captured in combination on-board the ‘G2’ UAV, a bespoke platform manufactured by CLA. The G2 is a 2.1m span electric tailless UAV with a maximum operating mass of 6kg. It can be configured to carry a variety of payloads with flight duration of up to 45 minutes. CLA hold CAA Aerial Work Permissions for the commercial operation of this system throughout the UK and operations of the G2 are in accordance with the CLA Flight Operations Manual.

UAV image capture and correction

UAV data capture is very similar to that of traditional aerial survey as individual image frames are captured at defined intervals on each flight line. These images captured with a 60% overlap on both the adjoining flight lines and adjoining images are then processed to form a mosaic of the entire Area of Interest (AOI) which has subsequent geometric, radiometric and atmospheric corrections applied. The MS data involves taking the raw sensor data and converting it into a radiometrically calibrated product. This is calibrated against known reluctance targets positioned in the AOI prior to the UAV flight. A typical UAV data processing workflow is shown in Figure 4:4.

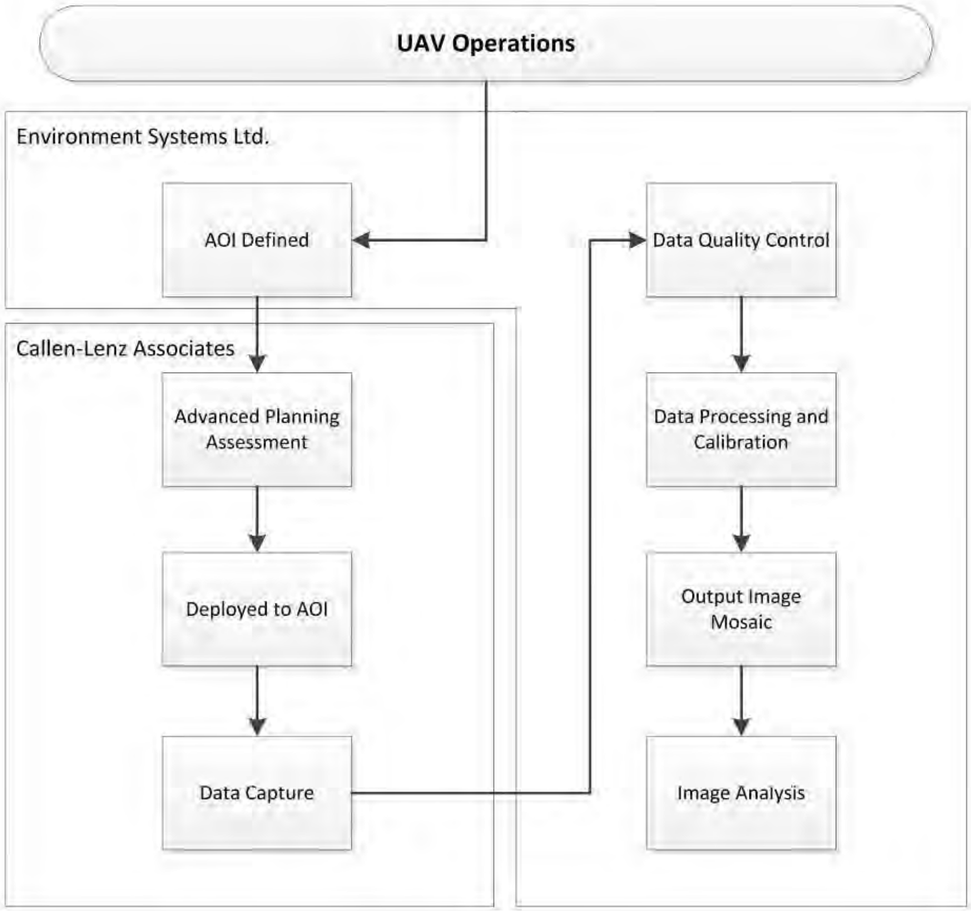

Figure 4:4: Flow chart of the UAV operations

Data was captured at key points and locations to understand the habitat composition of the areas under consideration. Figure 4:5 contains examples of the raw image tiles that were captured by the on-board camera. Flights within 2012 were flown at 600ft and 1000ft and provide a spatial resolution of approximately 5cm (RGB aerial photography) and 12cm in Multispectral. The detail is immediately evident and when compared to standard aerial photography imagery, the information that can be extracted from such scenes is far more detailed.

A flight can produce anywhere between a few hundred to one thousand individual images. These are subsequently stitched together to form an image mosaic.

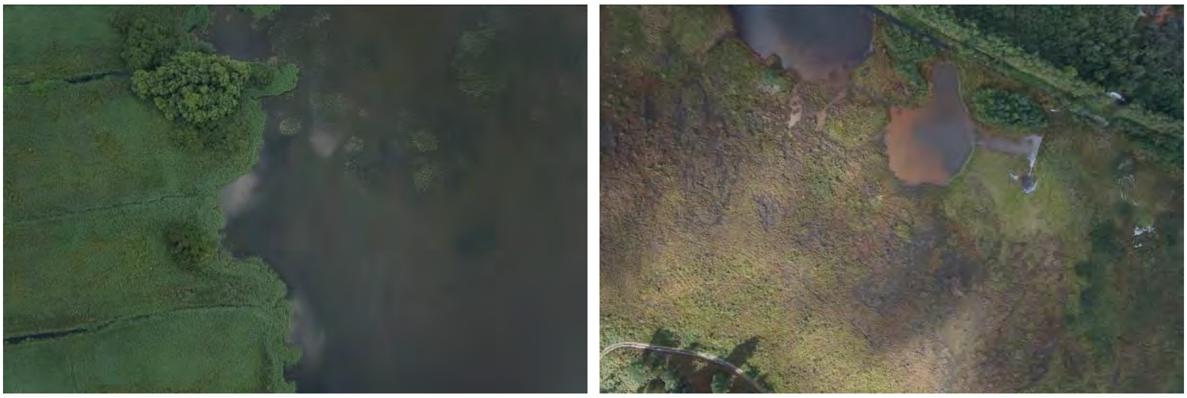

Figure 4:5: Raw image tiles captured by the UAV, Surlingham broad (left) and Dersingham Bog (right)

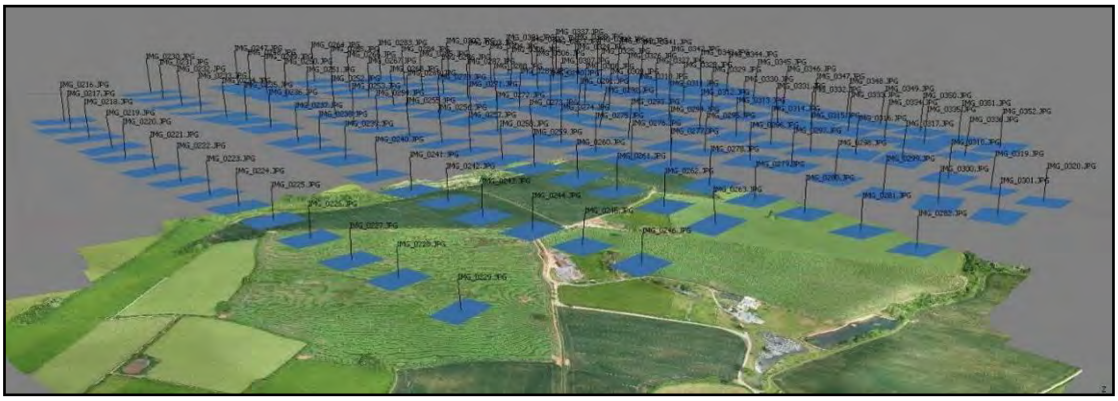

Figure 4:6: Example of how individual images (in blue) are stitched together to form an image mosaic

The output ‘true colour’ and multispectral images are then able to be analysed to investigate the state of the habitat imaged. Areas of species differentiation, or areas under stress not necessarily evident from the ground or indeed the ‘true colour’ mosaic become obvious from the multispectral image.

The imagery captured by the multispectral sensor is specifically calibrated for the production of vegetation indices, rather than straight spectral values as this reduces the ambient condition variables present when considering data at such a fine scale. The outputs from this sensor are therefore typically presented as a series of ratios and indices.

A by-product of the photogrammetric processes used to produce the mosaics is the production of high resolution digital surface model (DSM) through a process known as ‘structure from motion’ undertaken within a Commercial off the Shelf (COTS) software package.

Flights within 2012 also saw the first acquisition of thermal data onboard UAV by CLA for use within habitat assessment. A thermal video has been captured for Dersingham to give an overview of what types of feature show up with thermal imagery at this wetland site. The data though was captured under more of an exploratory ethos and is therefore only indicative and not suitable for use in any analysis. To achieve fully calibrated thermal data would require the sensor to be calibrated and the functionality changed to capture still frames rather than video, something which CLA are currently in the process of undertaking.

UAV data assessment

Data captured during the 2012 flying season from a UAV by CLA has been highly successful, but key considerations need to be taken into account given the innovations in capture, processing and analysis which are being developed. These include:

- The RGB aerial photography captured in conjunction with the multispectral data have been noted to be highly useful for both visual assessment of the habitats under consideration and for use within some of the processing routines applied to the multispectral data. The RGB data can be used spectrally but only when there are significant differences in ground cover type, i.e., very useful for bare ground at East Wretham.
- The visual quality of the data captured during UAV operations is very subjective to changes in illumination that can occur during the flight. This does not impact upon the spectral values attainable, but may cause subtle visual discontinuities within the output mosaics. The creation of spectral indices using band ratios significantly reduces or completely removes the affect.
- Geometric alignment of the very high resolution datasets captured using a UAV to make robust output mosaics is a very demanding process. The photogrammetric processes used to create the output mosaics give rise to image warping increases towards the edge of the image mosaic as there are less overlapping images to generate the point cloud from. Further manual geometric corrections have been applied but subtle mis-alignment may still be evident.
- Detailed topographic data (DSM) created from the RBG imagery is really useful for separating features based on height and identifying slope dependent features. Initial findings from exploratory work comparing the output DSM to ground survey and high resolution airborne LiDAR has found very comparable height measurements for the DSM produced from the UAV data.

4.7 Ancillary Data

The addition of ancillary data into the rule-based approach allows the system to be ‘trained’ to understand where in the landscape it is for example with masks, its topographic setting or proximity to pre-defined features such as waterbodies. This limits the confusions with other vegetation types which may have similar spectral characteristics but occur in different locations.

Many ancillary data sets are available within Norfolk (Table 4:5). They are useful for both scales of the classification.

Table 4:5: Types of ancillary data used in the analysis

Type of data	Dataset and source	Use	Landscape scale	Site-based scale
Digital Surface Model	Geoperspectives (5m)	Imagery processing.	X	
	Environment Agency Airborne LiDAR (0.25m, 0.5m, 1m and 2m depending on the area)	Topographic setting.	X	X
	UAS acquired DSM (~0.25m)			X
OS MasterMap	OS MasterMap	Urban features,	X	
		Water features,	X	X
		First split of the heavily managed landscape from the semi-natural areas	X	X
Geology and Soil	BGS DigMap data (1:50,000)	Superficial and solid geology for context	X	

Type of data	Dataset and source	Use	Landscape scale	Site-based scale
Masks	**Coastal mask –** defined by proximity to the coast and limit of arable fields	Limit of the habitat extent to focus the classification within suitable areas.	X	
	Grazing marsh mask – defined by height above sea level and proximity to water		X	
	Arable mask –analysis defining field boundaries and time series to pick up cropping cycles		X	
	Hedgerow mask – area of search for hedgerows limited to proximity to field boundaries using the arable mask		X	

4.7.1 OS MasterMap

Ordnance Survey (OS) MasterMap Topography Layer is a large-scale digital database that provides a highly detailed and accurate view of Great Britain's landscape, with some 400 million man-made and natural features, including individual buildings, roads and rivers and fields, each with its own unique identifier for reference.

OS MasterMap features have defined life cycles linked to real-world object life cycles. Some features of most importance, such as areas of construction in urban areas are under continuous revision and MasterMap is therefore constantly updated especially in urban areas. In rural areas, cyclic revision is undertaken to capture changes to the natural environment, which tend to be slower and less evident than additions to the built environment. Rural areas of Great Britain are updated on a five-yearly cycle. It incorporates longer term field boundaries features.

In this pilot project it is used as a contextual layer to define urban and water features. It is also used as a first split of the heavily managed and semi-natural environment using the 'general surface' and 'natural environment' classifications.

The study explored its uses and the final report will contain a section on how OS MasterMap could provide even more information pertinent to habitat mapping.

4.8 Landscape splitting

The application of an object-orientated rule-based approach when dealing with the landscape from an ecological perspective, involves finding parts of the landscape that have generally distinct spectral or other characteristics that can be identified with satellite imagery and/or ancillary data and to "separate these off" for further analysis. This is done in a hierarchical process until particular "objects" in the landscape have been identified. Typically this process of "landscape splitting" when applied to find and separate out the semi-natural habitats of interest has about four stages and can be presented diagrammatically as a conceptual tool (Figure 4:7). By using a hierarchical approach, the potential for confusion is reduced as a more limited area for further sub-division is considered as each class is separated off.

Rules are developed to assist with distinguishing particular objects that are real-world objects (i.e., the habitats, land cover types or other features of interest). Off-the shelf software products can assist with the creation and application of the rule-base to the imagery.

The actual process of landscape splitting is driven by knowledge of the landscape and of the imagery and ancillary data available. It is very important when carrying out the process to take into consideration the size and shape of the objects that you are trying to map and balance this with the type and resolution of the imagery available. Ancillary data may form a very important input to the analysis.

There is no fixed-solution or standard set of procedures that should be followed and it is important to have a good understanding of the way the features that are being mapped appear on the ground.

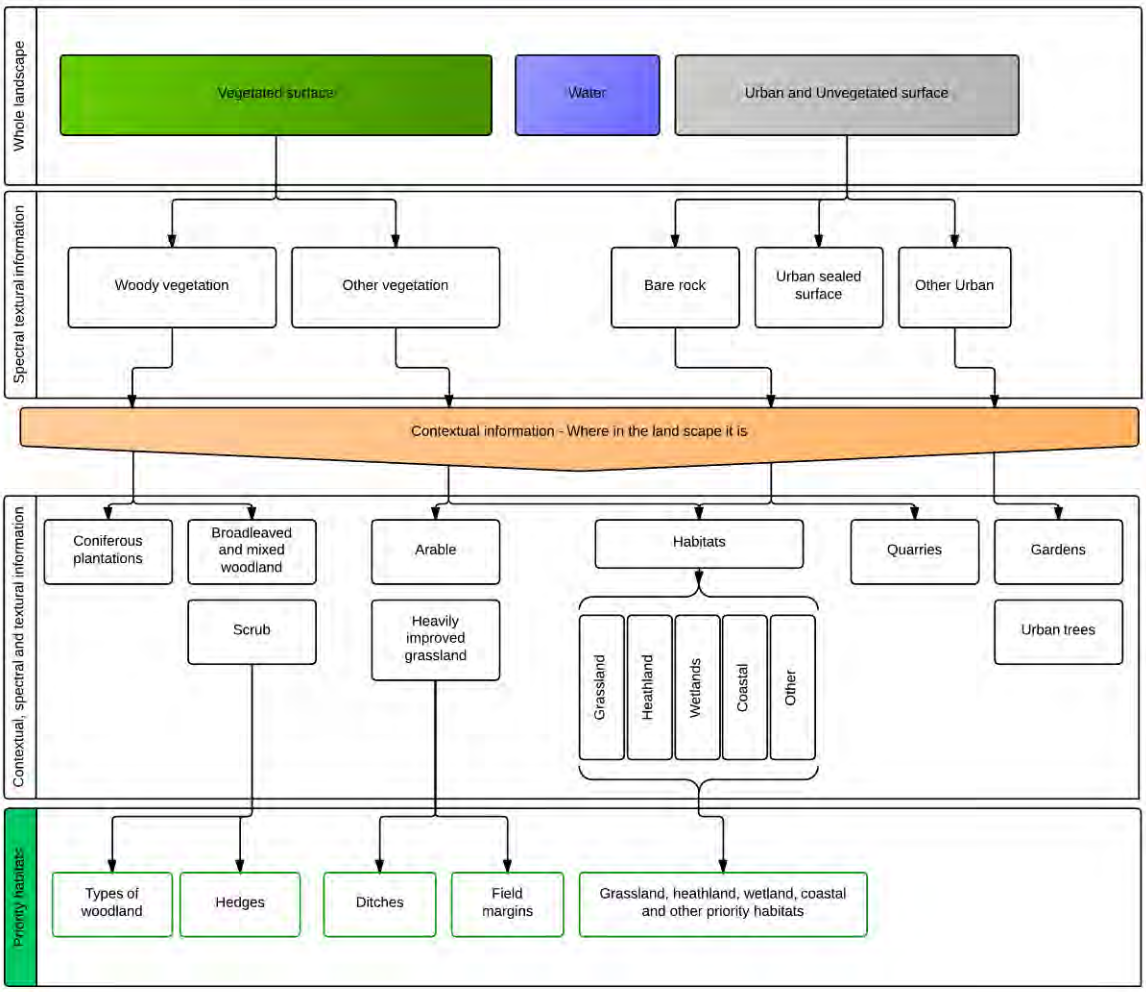

Figure 4:7: A conceptual approach to landscape splitting

4.8.1 Segmentation of objects

The process of image analysis used in this pilot is described as "object-orientated". The operator uses the image processing software (in this case eCognition) to look for groups of pixels with similar spectral characteristics – with the user defining the spectral characteristics and the maximum number of pixels that can be in the object. The process is seeking to divide up the landscape in accordance with real world objects or part objects.

Ancillary data can assist with this process of object definition. So for example, OS MasterMap field boundaries can be "burnt" into the imagery and segmentation can be confined to occur only within these polygons (e.g., a field).

It is usually necessary to have at least five pixels as a minimum per object when setting the criteria, to allow the object to contain sufficient information for subsequent classification, and to reduce the natural variation of the vegetation which would appear as noise in the classification. The whole landscape does not have to be divided into segments of the same size, more spatially detailed areas can undergo a more detailed segmentation to create objects that are meaningful for that environment. This is known as multi-resolution segmentation, as different resolution imagery is used to create objects in different areas.

4.8.2 Creating and using masks

Masks are used in the classification process to add landscape contextual information into the rule-base in addition to the spectral information from the imagery. OS MasterMap is used to identify urban and water features and then to broadly focus the classification between heavily managed and semi-natural environments.

From a habitat perspective, a mask can be applied so that the rule base only identifies habitats that are very spatially constrained within the environments in which they occur. This prevents erroneous classification from occurring in the wider landscape where there might be spectrally similar objects but where it is already known the habitat would not be found.

An example of this was the creation of a number of masks to target the area of search for specific, geographically restricted areas of habitats. Topography and other contextual information was used to identify low lying areas within a certain distance of different water features to identify areas where grazing marsh and coastal habitats would be found. In Norfolk arable cropping occurs all year round and can appear very differently depending on what imagery is being used. A separate analysis to define the arable field boundaries and clarification of areas that are arable has then allowed these areas to be ignored during the identification of semi-natural habitats, and targeted for searching for specific habitats occurring within them.

4.8.3 Developing the ruleset

The ruleset was developed in the eastern landscape-scale study area. This was then transferred to the West Norfolk project area, where it was further amended; with existing rules refined to accommodate differences in the environment and classes added to enable identification of additional vegetation types.

The rule-sets utilised a range of image data available to the project (see section 4.6), including: IRS, SPOT, Landsat and RapidEye. Endmembers (including photosynthetic vegetation (PV), non-photosynthetic vegetation (NPV) and shade) were derived from the multispectral imagery. Band ratios as well as indices such as the NDVI were used frequently. These allow more information about vegetation to be described by the imagery and included in the rules. Elevation, slope and aspect layers were used at a range of scales, Geoperspectives DTM, LiDAR and UAS DTM datasets were used, with elevation and slope proving the most useful in this landscape setting.

4.8.4 Application in Norfolk

Carrying on from the conceptual approach to landscape splitting in Figure 4:7, Figure 4:8 shows the process that was followed to “split up” the landscape in order to separate out the semi-natural habitats in the East Norfolk and West Norfolk landscape-scale study areas. The landscape splitting process was carried out as a separate process in these two study areas as each had a different set of data sources (e.g., different dates of imagery). However, in each the process depicted in Figure 4:8 was followed with the landscape splitting taking place in four distinct stages.

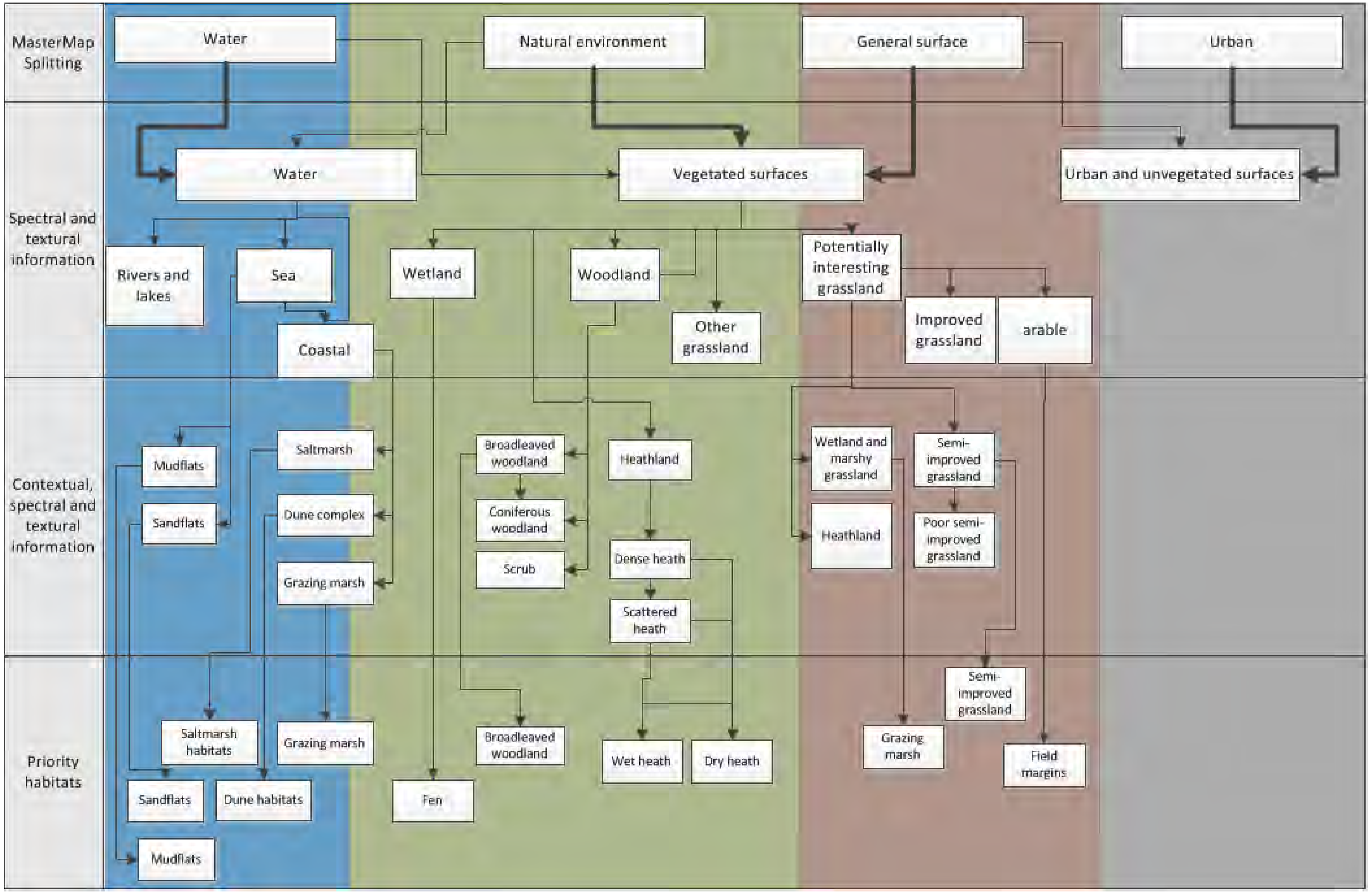

Figure 4:8: Landscape splitting approach used in Norfolk pilot

The habitats of interest to this study lie out of urban areas (with the exception of the Open Mosaic priority habitat). The first, highest level of splitting the landscape sought a high level split with the aim of distinguishing vegetated areas from water and non-vegetated areas. This high level split forms a start point for narrowing down the area of interest in which it is likely to find most semi-natural habitats. Carrying this splitting at the outset allowed a high level distinction to be made between the terrestrial vegetated environment, the freshwater environment, the marine environment and areas that are within an urban envelope. These divided areas are further separated based on spectral differences within the imagery until ecologically meaningful areas of habitat and component parts of habitats (which can be later lumped back together) have been identified. How well these habitats can be described relates to the scale and suitability of the imagery data available and therefore where they sit in the Crick framework.

4.8.5 Hybrid pixel and object-based approach (scene component analysis)

A hybrid pixel and object-based approach to landscape splitting has been developed and demonstrated for a case study area containing wet grassland (BAP priority habitat Coastal and floodplain grazing marsh) in the Halvergate marshes of the Norfolk Broads. The technique seeks to create real world objects (e.g., fields) and capture the variability within each object, thereby making fuller use of the spectral information available from the imagery.

This is another OBIA approach which presents another way of looking at objects and how they are classified, it was included in this study as part of the transferability investigations. It is considered in the work on grazing marsh in section 6.5.5, looking at aspects of habitat identification and condition monitoring.

Pixel-based approaches consider each image pixel in relative isolation using its spectral measurements and sometimes those of immediately adjacent pixels. The results rarely adequately describe the structure of the landscape and suffer from high spatial variation in the classification giving a “salt and pepper” effect. This can be caused by system noise, mixed pixels and other uncertainties. However, pixel-based approaches do capture landscape variability at the scale of the spatial resolution of the image and can provide useful descriptions of “within-feature” variability and transition zones which is particularly useful in semi-natural areas where vegetation is not uniform. Object-based approaches (see section 4.8.1) attempt to extract the actual landscape structure as seen in the image by applying a segmentation which identifies relatively homogenous features.

For this hybrid approach, the EO data used was derived from a multi-date stack of Landsat TM scenes from April, May, June, July, September and October 2011.

The processing steps applied included:

- the creation of scene components (cover classes and their sub component classes) from a dual date image composite;
- the production of a set of land parcels from existing digital cartography;
- linkage of attributes describing the scene components to the land parcels; and,
- linkage of attributes describing further surface characteristics (moisture) from a multi-date stack of images.

For the image analysis (identifying cover classes and their sub component classes) the bands 3, 4 and 5 were extracted from the May and October scenes and combined into a dual date image composite.

OS MasterMap data was used for the land parcel objects (see section 6.1.2 for the issues with this). The cleaning process was not exhaustive so some errors remain in object creation. Once the land parcels were created it was possible to aggregate and attach attributes generated during the classification process; these were divided into three groups:

1. **Basic properties** of the aggregation of the per-pixel results onto the land parcels (e.g., information on processing, number of image pixels in the land parcel)
2. **Aggregation of the spectral subclasses** and some extended analyses: number and type of subclasses within an object and their proportions, proportion of the object represented by the dominant subclass, measure of heterogeneity (relative entropy)
3. **NDWI results** comprising average NDWI within the object for each image date and dates of the minimum and maximum values of the NDWI.

The attributes attached to the objects represent a rich set of information which can be interpreted by habitat practitioners with local knowledge.

5 Results: Further development of the Crick Framework

The Crick Framework was developed in Phase 1 of the project as a conceptual grouping of habitats into Tiers depending on their data requirements for classification within an EO analysis. The Framework Tiers have been updated as part of this project and are shown in Figure 5:1.

Tier 1	**Likely to be classified solely using EO**			
Tier 2	**Likely to be classified using EO and ancillary data**			
	Tier 2a - Likely to be classified using EO together with ancillary data	**Tier 2b** - Likely to be classified using VHR EO together with ancillary data	**Tier 2c** - Likely to be classified using EO data (in some cases VHR) but ID dependent on good geological data	**Tier 2d** - Likely to be classified using EO including LiDAR to give detailed information about vegetation structure
Tier 3	**Likely to be classified using EO, ancillary data and dependent on availability of time series imagery**			
	Tier 3a - Likely to be classified using EO together with ancillary data and needing time series imagery	**Tier 3b** - Likely to be classified using VHR EO together with ancillary data and needing time series imagery	**Tier 3c** - Likely to be classified using EO data (in some cases VHR) but ID dependent on good geological data and needing time series imagery	**Tier 3d** - Likely to be classified using EO including LiDAR to give detailed information about vegetation structure, and needing time series imagery
Tier 4	**Currently unlikely to be classified 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 classified using EO**			

Figure 5:1: The Crick Framework Tier system

An initial characterisation of the priority habitats classified under UK BAP and Annex I habitats was also undertaken to provide evidence for their allocation to Tiers of the Framework and therefore the most appropriate mechanism for monitoring and surveillance. In this characterisation a substantial initial analysis occurred to describe the ecological characteristics and remote sensing requirements of the 124 Annex I and BAP priority terrestrial, freshwater and intertidal habitats.

The conceptual approach of the Framework was considered a promising basis for progressing to Phase 2 of this research. It was recognised that the Framework and the habitat characterisation required both independent peer review and the addition of further content so that it could provide a complete and current statement of known relevant information. The main benefits formal review would bring were:

- To increase the value of the framework as an effective tool for communicating and discussing EO capabilities and habitat requirements; and,
- To enable coherent analysis and a consensus view to be reached on how best to proceed with monitoring and surveillance of individual, or groups, of habitats across a variety of geographic contexts.

This section explains the nature and outcomes of the review, making clear how the Framework has improved as a result. This section also outlines the content of a "User Manual" created to support and encourage use of the Framework. The need for a user manual was identified at an early stage following initial discussions between the project team and peer reviewers.

5.1 Review of Crick Framework

A desk based review by two independent specialists (Dr Geoff Smith and Dr Lex Comber) confirmed the validity of the Framework approach, with the main work focused on checking the structure and content of the supporting habitat tables and the allocations of habitats to the Tiers of the Framework. The documents produced in this part of the project are available from the project pages on the JNCC website (http://jncc.defra.gov.uk/page-6281).

5.1.1 Review of the Framework content

The framework was considered to be a good way of describing the different requirements of habitats to be classified using EO. It was decided during early discussions between the project team that the framework needed to be well supported by documentation and so the need for a User Manual was identified, aimed at habitat specialists.

The manual provides a detailed description of all aspects of the Crick Framework, supporting these with examples, explanations and illustrative scenarios of how the framework may be used to support the evaluation of opportunities for mapping different types of habitats using a range of types of EO and ancillary data. It includes a glossary of commonly used terms and a list of the references that form part of the evidence for the content of the Crick Framework supporting tables.

Specific ecological habitat information was broken down in supporting tables to add evidence to the allocation of the habitats to Tiers. A detailed review of content identified specific cases where there was inconsistency, confusion, overlap in the information presented, or lack of clarity. Suggestions were provided on how many of these issues could be overcome, including restructuring the supporting tables and subsequent restructuring of the content as well as the addition of further content.

The framework supporting tables were further developed and restructured to present the available information in a more thorough and systematic way. The new structure and descriptions of these are fully detailed in the User Manual. The tables now include sections on biogeography, habitat character, details of the minimum EO and ancillary data requirements for the habitat, along with any examples of known work and indicators of confidence, specificity of habitat description and understanding of the habitat interactions.

5.1.2 Changes to the content

Existing habitat descriptions were systematically reviewed and any missing habitat character information was included from the relevant UK habitat classification description documents. The peer reviewers added and amended the information in the new framework tables to take into account their experience and knowledge of additional features of interest or findings from relevant studies.

The reviewers highlighted a number of difficulties in allocating Crick Framework Tiers to habitats that arise as a result of the differing characteristics of Annex I and priority habitats classified under UK BAP, these are summarised in Box 5:1.

Box 5:1: Common difficulties encountered in the characterisation of Annex I and BAP priority habitats

Habitat classification system issues

- It is difficult to allocate some priority habitats classified under UK BAP to a Tier as some of the habitats can be highly geographically variable and not just based on specific species assemblages or a specific contextual location.
- For all Annex I habitats, the scale at which they occur determines how well they can be detected by EO. They are often defined by fine scaled features which are reliant on the presence of specific indicator species. When this is the case, the habitat has been given a 4a Tier score.

Separability

- Separability is the key to habitat differentiation with EO; what surrounding vegetation are you trying to separate the habitat from. This can be a consistent factor or it can be variable. Some habitats can be easily separated from their neighbouring land cover in many situations but will sometimes be more difficult if the surrounding vegetation has similar characteristics from above. When separability is variable the ‘worst case scenario’ Tier has been used.

Tier 4 habitats

- For habitats which fall into Tier 4, classification is not possible just using EO and geoinformatics however, the potential for the specific habitat to be there can be identified and can be used to effectively target fieldwork.

The allocations of all the Annex I and priority habitats to these Tiers were checked in light of the additional information and evidence provided in the tables. This was included in a ‘New Tier’ column in the supporting tables. It was also recognised that the results of the Norfolk pilot might lead to further changes in Tier allocations.

Together, the User Manual and Crick Framework provide resources for users to decide whether a particular habitat can be mapped from EO data (as part of a “toolbox” of techniques) and if so:

a) What kinds of EO data are required (type, resolution, time series frequency, etc.),

b) What other *contextual or ancillary* data are needed to support EO analysis of the habitat (e.g., soils, elevation, etc.),

c) Whether there has been any work using EO to monitor a particular habitat

d) If the habitat cannot specifically be classified how resources can be effectively targeted to field validate it.

6 Results: Norfolk pilot

This section covers:

- Landscape splitting
  - Using OS MasterMap to create landscape masks
  - Image segmentation
  - Spatial scale considerations

- Habitat specific results. These are presented in 5 sections:

  Habitats dominated by woody vegetation
  - tree canopy cover
  - scrub canopy cover

  Habitats dominated by non-woody vegetation
  - dry grasslands
  - wet grasslands dominated by brackish and saline water influence
  - other wetlands and waterbodies

  Each of these habitat specific sections starts with a summary of the key findings, covering both what worked well and what worked less well. The habitats that have been considered are identified, followed by how well they were identified from the EO analysis at the broad scale and more detailed case study level, then addresses what the key findings mean for the transferability of the methods.

- Condition measures tested

6.1 Landscape splitting

The first stage in the Norfolk pilot was to develop an understanding of the landscape context in which the main semi-natural habitats are located and to devise a high-level mechanism for landscape splitting that allowed for the maximum information to be built into the EO modeling. OS MasterMap was the key dataset used for this purpose (as described in Section 4.7.1).

In addition to the direct use of OS MasterMap themes for defining areas in which to look for particular habitats (see Figure 4:8). Further masks were derived for the project partially using other information contained within the OS MasterMap dataset:

- **mask to assist with identifying coastal features** – created using height above sea level (from the DEM) and proximity to the sea (derived from OS MasterMap and spectral information)**;**
- **mask to assist with identifying wetland features of the Broads** – created using height above sea level (from the DEM) as well as the proximity to water bodies (taken from OS MasterMap) to identify areas likely to contain habitats such as Coastal and floodplain grazing marsh, fens and marsh;
- **urban and road mask** – created using OS MasterMap themes;
- **arable and grassland masks** – created through re-segmentation of OS MM boundary layers using multi-date spectral information described in more detail in section 6.1.3.

6.1.1 Findings: landscape splitting - what worked well and what didn't

Summary of key findings and observations: <u>things that worked well</u>

KF1. The use of landscape masks to delineate areas in which to search for a more limited range of features and habitats than is found in the wider landscape worked as well in Norfolk as it did in previous studies.

KF2. Overall, OS MasterMap provided a very precise dataset for the identification of water features boundaries, roads and urban areas.

KF3. Despite some inconsistencies with content, the OS MasterMap themes were of sufficient quality to act as a "high-level" mask to separate the landscape for classification.

KF4. Understanding the landscape context of the wetlands around the Broads enabled a successful mask to be created delineating the area of search for fen, grazing marsh and other wetland habitats.

KF5. A coastal mask provided a successful tool for separating Atlantic salt meadows from species-rich grassland types that are not associated with a saline influence.

Summary of key findings and observations: <u>things that didn't work so well</u>

KF6. Inconsistencies in the types of land cover encompassed in the MasterMap layers made the construction of the ruleset complex and increased processing time.

KF7. These inconsistencies were widespread and a particular issue for semi-natural habitats.

KF8. Small areas of OS MasterMap are unclassified requiring additional rules to be created.

KF9. OS MasterMap boundaries gave a precise but incomplete segmentation of arable fields.

KF10. "Gaps" in the polygons surrounding fields (e.g., where there is a field entrance) limited the usefulness of OS MasterMap as a tool for image segmentation of the arable fields. This is likely to remain the case for the foreseeable future, and is a good starting point, but requires some additional segmentation of the objects to define all the field boundaries.

6.1.2 Observations and findings: MasterMap layers

Inconsistencies in OS MasterMap (MM) broad class designation have been found across the whole project area, affecting all habitats. The majority of habitat objects are classified by MM as Natural Environment; however, it is common to find areas of habitat classified as General Surface (this affects all habitats; wetland, woodland, heath, semi-improved grassland, saltmarsh and sand dunes).

A very small number of polygons had no MM class ("unclassified") and the ruleset had to be adapted to account for this.

These inconsistencies made the landscape masks much more complicated to use, often with separate rules for finding the same habitat in each MM class. In future studies it is recommended that a more sophisticated analysis is carried out using some of the more detailed classes within MM to form the initial landscape split and try to avoid some of the issues outlined below. Alternatively, if the broad classes could be re-worked in MM, in line with the findings of this project its use in this type of modelling would be greatly enhanced.

By way of example, the majority of Norfolk saltmarshes were classified by MM as 'Water', with some small areas classified as General Surface or Natural Environment. Screenshots of Brancaster (Figure 6:1), on the North Norfolk Coast show the majority of the saltmarsh is classified in MM as Water, while smaller areas are classified as Natural Environment and General Surface.

Figure 6:1: Aerial photograph of an area of coastal habitat at Brancaster and its representation in OS MM layers, where on the RHS image: blue is water, yellow General Surface (small areas in the centre of the image) and pink Natural Environment.

In the north east corner of Figure 6:1 the vegetated sand dunes are classed as both General Surface and Natural Environment. This meant that the rulebase for this area became extremely complicated to build, as it required the team to develop and apply a ruleset to look for a particular habitat type in each of the MM layers in order to find all the dune vegetation. This makes the OS mask much less effective as a tool than it might otherwise be. One possible way forward with this is to make use of the "sub-level classes" within MasterMap. Using the more detailed description may take more time in creating a 'mask' but might give a better result.

6.1.3 Observations and findings: Segmentation of objects and use of MasterMap polygons

OS MasterMap boundaries gave precise but incomplete segmentation of arable fields with many cases where either permanent or temporary fields were in cultivation. This included both fields with and without natural and manmade boundary features such as hedgerows and fences.

Another issue encountered was when polygons in the vector layer did not fully enclose the parcel. This is illustrated in Figure 6:2 and here occurs where the OS MM parcels around fields lack gates or closing features. The result is that several separately managed field parcels are formed into one very large polygon with several land cover types.

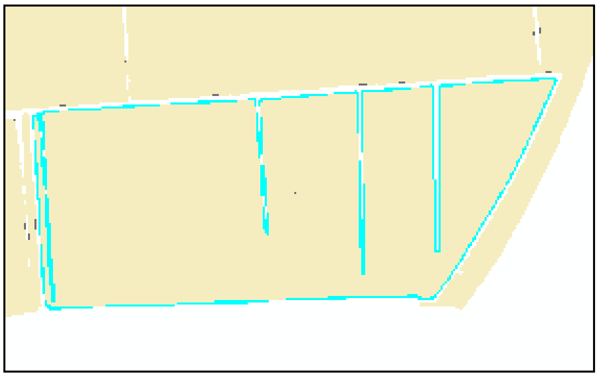

Figure 6:2: OS MasterMap and the delineation of individual field parcels

To improve these land parcels satellite imagery was used to further segment these polygons to assist with creating further field boundaries, so that the classification conformed to real world objects. Initial attempts were affected by within-field heterogeneity creating several polygons within arable fields, meaning that areas where the crop is not growing well could become confused with other land cover types, including semi-natural habitats. Further work has been done on this segmentation and the results can be seen in Figure 6:3, comparing this improved arable segmentation, with the aerial photography and the OS MM for the same area. A multi-resolution segmentation of the CIR aerial photography creating large scale objects was used, with a greater weight placed on the compactness and slightly less weight placed on the shapes created (in this case using eCognition). The classification of the arable fields looked for a very low productivity value in any of the imagery (Landsat, SPOT and CIR) to identify if the land parcel had been ploughed. This arable layer was then incorporated into the rule base.

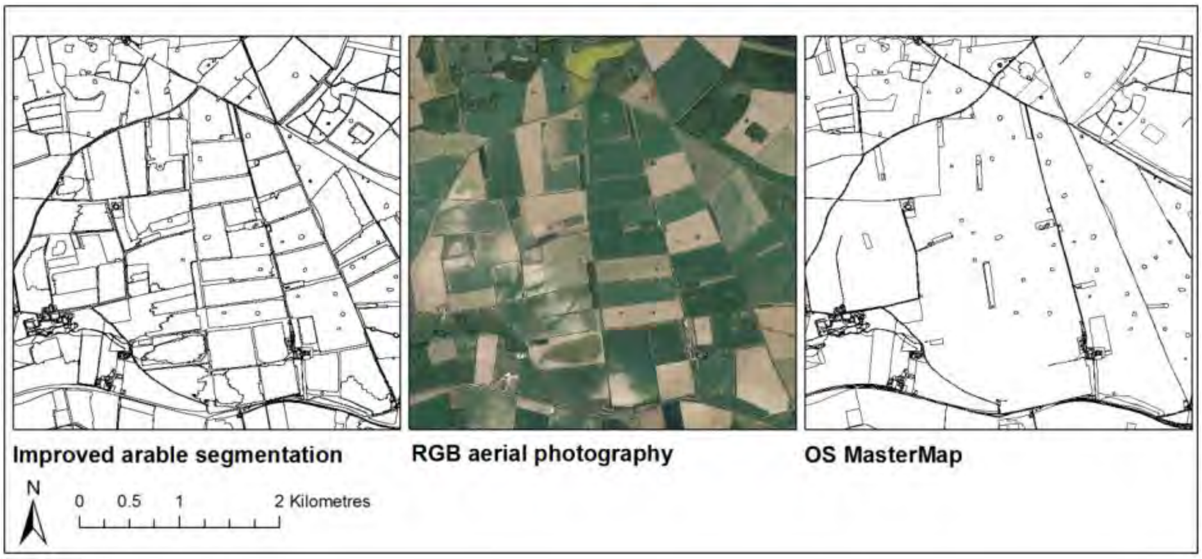

Figure 6:3: OS MasterMap information on field boundaries in arable landscapes

6.1.4 Observations and findings: the need for the correct spatial scale in describing the object of interest

One of the key findings of this project is the difference in the spatial scale at which habitats occur in Norfolk compared to Wales. In Wales, semi-natural habitats occur in large upland blocks: mosaics of semi-natural habitats form spatial patterns across whole valley systems or hillsides. By contrast, in Norfolk the pressures on the land for arable use, and the character of the aquifer fed habitats have resulted in semi-natural habitats being restricted to a much smaller spatial scale with far more intricate mosaics. Norfolk on first consideration is broad scale relatively flat land and it may be considered that high resolution SPOT and IRS imagery (10m and 23m pixel size) would describe the habitats as well as they did the upland blocks of Wales. However, it was almost always found to be the case that accurate identification of the Annex I and priority habitats involved the inclusion of more detailed imagery, because of the complexity and fine scale of these features.

The following example (Figure 6:4) outlines how the correct spatial scale of imagery is needed in order to identify the correct habitat type. In this case the purple area represents an area of wet woodland, within a dry woodland (blue) and scrub (yellow). The wet woodland is a priority habitat, but the controlling factor in its identification is the combination of pixel size (i.e., image resolution) and the woodland size.

In the first image (on the left of the page) all of the wet woodland could be discriminated from the surrounding vegetation as it contains many pixels and the variation within the habitat could be well described. In the middle image some of the woodland around the edge of the main block and the spur of woodland would be less well identified as the reflectance value for these pixels would contain a mix of vegetation cover types. In the final image, it would be unlikely that the woodland could be identified at all. This is a particular issue for identifying small irregularly shaped blocks of habitat at the landscape-scale using satellite imagery.

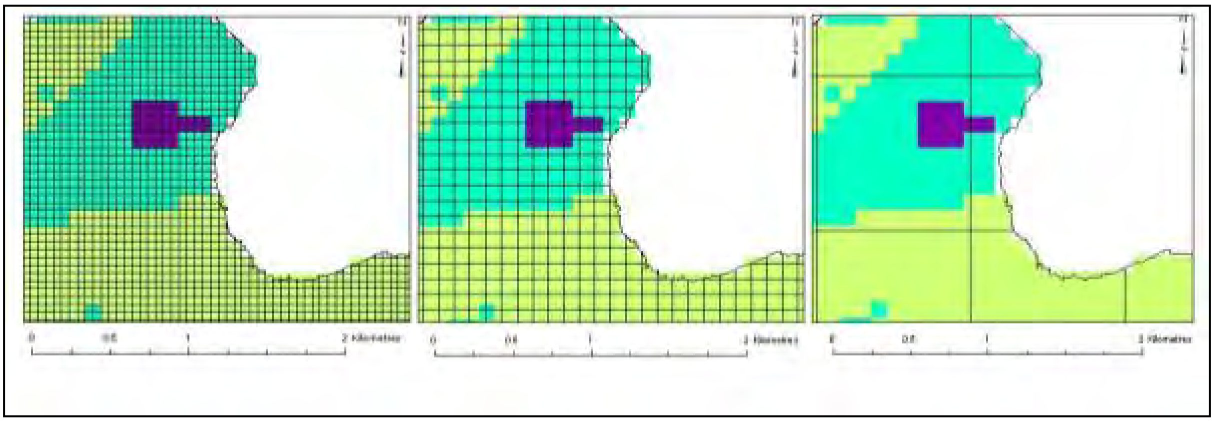

Figure 6:4: Diagrammatic representation of the effect of pixel size on habitat feature recognition

Transferability

Summary of what these findings on landscape splitting mean for transferability

T1. OS MasterMap road, river and urban polygons are extremely suitable for use in landscape splitting; they are consistently and accurately mapped throughout Great Britain. In areas where OS MasterMap is not available (such as Northern Ireland) it might be possible to use other mapping (such as LPIS) to extract features such as field boundaries to use in the analysis.

T2. Field boundaries from OS MasterMap do give useful information for the production of arable and grassland masks however, they are not as robust as high quality LPIS field parcel datasets. Where these are not available, time spent improving the content of the OS dataset as described in 6.1.3 would yield a better result.

T3. With knowledge of landscape context, it is possible to create masks that successfully delineate areas in which particular habitats are restricted.

T4. It is necessary to have a high quality topographic model for landscape splitting even in a flat country, as proximity to water and height above sea level are still key ecological drivers that need to be incorporated into the rule-base. These types of datasets are available across the country under current Public Sector Mapping Agreements (PSMAs) and One Scotland Mapping Agreement (OSMA).

The use of landscape masks to delineate areas in which to search for a more limited range of features and habitats than is found in the wider landscape worked as well in Norfolk as it did in previous studies in Wales (Lucas *et al* 2011). Such an approach provides ecological and landform context and significantly aids the robustness of the modelling by dismissing from the analysis combinations of habitats that cannot occur.

Some of the masks used in Norfolk were the same as those used in Wales, namely the water, urban and road layers from MM. The work in Wales however, used a more sophisticated field boundary dataset based on information from the IACS system. This did not suffer from unenclosed polygons. Further work on the field boundaries and arable mask in the Norfolk area would significantly enhance the final product by removing confusion produced by the more unusual crops in very early or late growth stages, which have a similar reflectance to semi-natural habitats.

6.2 Findings from the Norfolk Pilot:

The following section outlines the findings of the Norfolk pilot study. It describes the landscape-scale habitat classification and the site-based case studies.

The results are divided for convenience into five sections. These sections describe the results for groups of habitats with similar cover features that dominate the spectral signature as described in Section 4.4. The first section deals with habitats dominated by woody vegetation. Wet woodland has been included in this section as the spectral signature from above is totally dominated by the tree canopy, although it is the understory and ground conditions that would be key for identification of this habitat by fieldwork.

Identification of many of the Annex I habitats are showing initial positive result using the very-high resolution imagery types, although they are not readily identifiable from the landscape-scale classification.

6.3 Findings: Habitats dominated by woody vegetation

6.3.1 Environments dominated by tree canopy cover

For the purpose of this report, the results for all habitats dominated by the presence of a tree canopy are considered in this section. In Norfolk, habitats dominated by woody vegetation include coniferous, broadleaved and mixed woodlands, plantation woodlands, wet woodlands, scrub and hedgerows. Norfolk contains many important woodland habitats and sites (Table 6:1).

Table 6:1: Annex I and BAP priority habitats dominated by trees species found in Norfolk

Type of feature	Priority habitat	Annex I Habitat
Woodland	Lowland mixed deciduous woodland	**H9190.** Old acidophilous oak woods on sandy plains
	Traditional orchards	**H9120.** Atlantic acidophilous beech forests with *Ilex*
	Wet woodlands	**H9160.** Oak-hornbeam forests
	Wood-pasture and parkland	**H91E0.** Alluvial forests with *Alnus glutinosa*
Scrub		
Hedges	Hedgerows	

At a landscape-scale the research sought to map all types of woodland in the table above. The case study for this environment considered an area of the Broads (in the Eastern Landscape study area) which contains a mix of scrub, wet woodland and dry mixed woodland. It also sought to identify evidence of woodland management.

Although scrub is not an Annex I or priority habitat, it provides refugia for insect and bird populations and the understory is often important as a seedbank. It is also often a feature used to describe the condition of sites containing semi-natural habitat. It has therefore been included in the mapping exercise in order to help inform the wider landscape context.

Summary of key findings and observations: <u>things that worked well</u>

KF11. Identification and separation of broadleaved, coniferous and mixed woodland stands at the landscape-scale (see sections 4.6.2).

KF12. The use of specific landscape features mask created using OS MasterMap to guide the identification of hedgerows.

KF13. When identifying scrub it was necessary to use a segmentation consistent with the size of the feature, so for scattered bushes with a canopy of less than a metre, a much finer resolution image than the 10m SPOT was necessary. This was successful in the coastal area where the CIR was used for the segmentation.

KF14. Woodland habitats are considered generally to be Crick Framework Tier 4 habitats. Initial work with VHR satellite imagery (<5m resolution) suggests it may be possible to identify some types of Annex I woodlands from the tree crowns.

KF15. Felled woodland could be identified and the ground cover classified based largely on multi-temporal satellite imagery, spanning one year.

Summary of key findings and observations: <u>things that did not work so well</u>

KF16. At the landscape scale it was not possible to identify individual tree species.

KF17. It was not possible to identify priority habitats such as wet woodland, and Annex I habitats such as “Alluvial forests” from the woodland mosaic using Spot (10m) and IRS (23m) data. *NB: on-going work suggests that with finer resolution data these habitat types can be identified.*

KF18. It was not possible to identify woodland priority habitats that are characterised by their understory vegetation.

KF19. Small objects need a suitably fine resolution of imagery to successfully identify them. For example, SPOT imagery was not suitable for hedgerows and mapping these at the landscape scale was not successful.

6.3.2 Woodland Types in Norfolk

Norfolk contains many important woodland sites, including ancient oak and oak-ash woodland areas. These support a wide range of vertebrate and invertebrate species and in spring have bluebell dominated ground flora. There are also a number of important Annex I habitats such as 9160 – Oak-Hornbeam forests where Hornbeam and Poplar from part of the tree canopy.

A number of plantation woodlands were established in Norfolk, mainly by the Forestry Commission and generally on land of poorer agricultural quality. Thetford Forest, the largest pine forest in England, is located on the poor sandy soils of Breckland. Other important sites include Reffley Wood, an ancient woodland of 130 acres, which lies east of Kings Lynn in an Area of Outstanding Natural Beauty. Whilst the site is dominated by conifers (such as Corsican Pines, Douglas Firs and Scots Pines), veteran oaks survive at the north-eastern edge of this woodland.

The Broads contain many wet woodlands. These form around the water’s edge, in areas subject to seasonal flooding and/or with a high water table. Wet woodland plays a significant role in flood attenuation, reduction of siltation and the improvement of water quality. It also provides a unique habitat, being diverse and variable. Wet woodland can contain a mosaic of mature trees, a shrub layer, ground flora, open ground, boggy areas, open water and seasonal flushes. The wet woodlands grade into dry woods and scrub further inland. The species composition of wet woodland varies, and there are both alder and willow dominated areas. The diversity of the wet woodland cover type and the scale of change within them is a challenge to landscape-scale habitat mapping from EO and therefore the identification of this important priority woodland type became the subject of a more detailed case study looking at what could be discerned with higher resolution imagery.

In terms of reflectance, the woodland canopy is very different from all types of grassland and land under arable cultivation. Woodland, whether broadleaved or coniferous, has a strong shade signal and distinct spectral signature. All woodland features are identified as a habitat set as a second order in the landscape splitting. Following this, individual types of woodland were identified.

Once areas of woodland have been located, coniferous woodland can be separated from broadleaved woodland using "leaf-off" imagery (e.g. in March). At this time of year the characteristic SWIR and shade signature common to both woodland types is not present for the broadleaved trees. Larch trees are easily identified by their very high SWIR and shade fraction in summer imagery.

If it is necessary to identify individual tree species, which is the case when identifying certain Annex I habitats (e.g 91E0 – Alluvial forests with *Alnus glutinosa*) imagery with a relatively small pixel size is needed, such that one tree is ideally formed of at least one and possibly several pixels. In these circumstances, high resolution satellite imagery, such as SPOT at 10m resolution does not meet this need and very high resolution imagery is required.

Woodland can be difficult to classify to Annex I types using EO, even when the canopy species are the qualifying feature for the habitat, as a block of woodland can produce a quite mixed spectral signature. Not only do the different tree species have slightly different spectral signatures, the heights of the trees can add significant amounts of variability to the signature. Tall trees will cast shadows on those around them. The crown of the tree can have a much brighter reflectance on the side nearest the satellite sensor and a signal associated with shade on the side of the canopy facing away from the sensor. Research is underway (e.g. Bunting and Lucas, 2008 and Niccolai *et al,* 2010) at the moment into identifying individual tree species and tree crowns, and with the increasing resolution of imagery and sophistication of the models this is an area that would benefit from further study in a follow on project.

General overview of landscape scale mapping of woodland habitats

Within the rule-base the distinct characteristic of canopy shade and reflectance is used as the high level rule for identifying areas of woodland. Broadleaved woodland is then separated from coniferous woodland using the seasonal images and the difference in the "leaf-on" and "leaf-off" condition. Figure 6:5 shows the results of application of the rule base at the landscape scale. The early spring SPOT imagery shows the complexity that can be characteristic of woodland types within Norfolk. Within this example the coniferous woodland is in places bounded by strips or areas of broadleaved woodland species, which may be more mature or a similar age to the coniferous plantation areas. Scrub occurs in felled areas or larger clearings. Some of the most diverse dry grasslands seen within Norfolk were within the forest rides (see Figure 6:6).

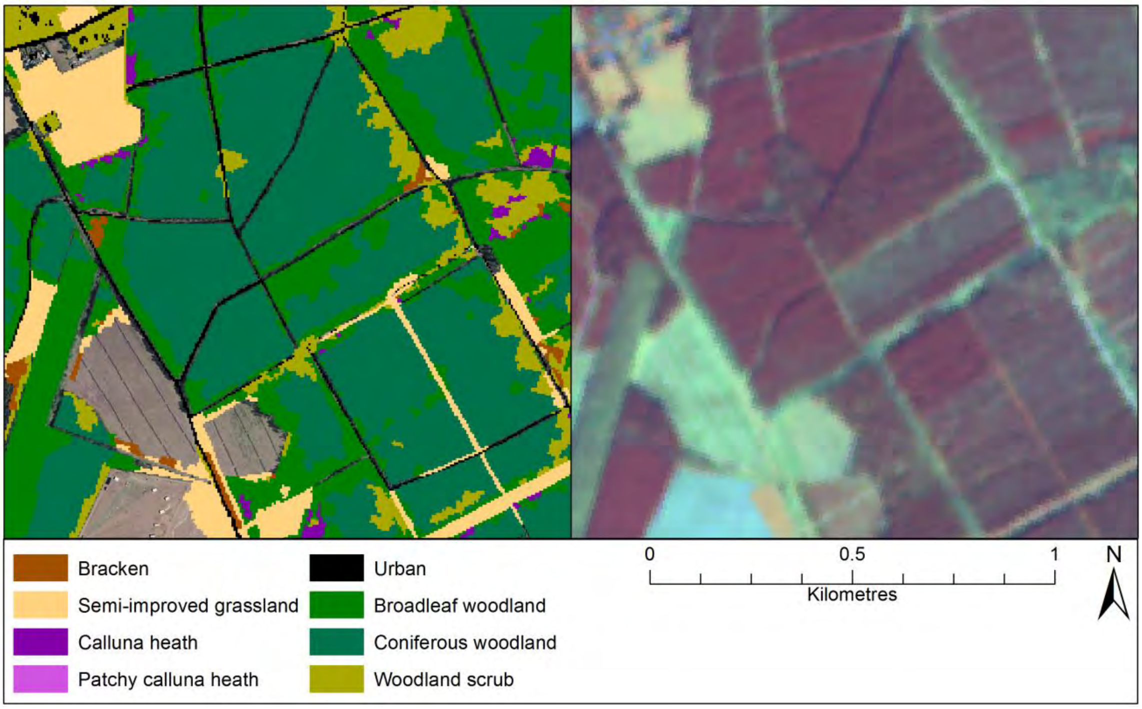

Figure 6:5: Landscape-scale woodland classification and SPOT imagery

Species-rich neutral grassland within the forest rides.

Scrub dominated area, with Broom *Cytisus scoparius* and European gorse *Ulex europaeous* in a plantation woodland clearing.

Figure 6:6: Photographs showing the species present in clearings in forestry in Breckland

Common confusions and limits with landscape-scale mapping of woodlands

The majority of the landscape-scale mapping of woodland was carried out using SPOT imagery with a 10m pixel size. Many tree crowns have a narrower diameter than this meaning that each pixel always has a signal associated with the reflectance of several trees. This is adequate for identifying stands or areas of woodland that are broadleaved, mixed or coniferous, but means that it is not possible to determine the presence of individual tree species. Many woodlands in Norfolk are assigned to the Crick Framework - Tier 4 (i.e., they are characterised by their understory species, or mosaic of canopy species). It proved extremely difficult to obtain "leaf-off" imagery within the short window where the ground flora is at full development but tree leaves are not yet fully out. In Norfolk this can occur between approximately mid-April to the end of May and lasts for approximately three to four weeks but varies depending on the year. "Leaf-on" imagery mostly tended not to include much of a reflectance signal from the ground flora. Broadleaved priority habitats could not be identified at the landscape-scale mapping and were then the focus of more detailed case-study work.

The exception to this was pine forests near Thetford, in the Western study area. Pine trees within well-established coniferous plantations had an extremely productive, dense and widespread understory of nettles (see Figure 6:7). The pine trees themselves were in poor condition with few needles and therefore the nettles influenced the overall appearance of the forestry in the imagery. The signal from the nettles was much stronger in the summer image when they were growing at full productivity, and less in the early spring image, almost mimicking the effect of broadleaved tree canopy, leading to initial classification confusion. A specific rule was necessary within the rule base to prevent this confusion being carried over into the final analysis. This type of misclassification was not encountered when mapping in Wales using similar methods, and is potentially a localised issue. Ground truthing during the initial stages of the development of EO mapping products is essential to identify confusions and localised issues such as this.

Figure 6:7: Photograph showing very dense tall cover of nettles *Urtica dioica* under pine trees with a very thin canopy which produces an unusual reflectance value.

Felled woodland

Changes in woodland management, such as those associated with felling, can have a dramatic impact, particularly in open landscapes. Coniferous plantations are often managed on rotation with areas felled and then replanted. In recent years, replanting schemes have taken more account of landscape aesthetics and the needs of wildlife and include a mix of broadleaved species and wider clearings.

From an ecological perspective, it was considered important that woodland areas that were felled and that had regenerated be classified according to the ground cover currently present, as the ecological characteristics of established woodland differ from those of regenerating or replanted areas that in their initial years are likely to be dominated by disturbed ground, grassland or scrub cover.

In Wales, the mapping of areas that had been felled was achieved by compiling an image stack that included images acquired up to three years apart. Felled woodland was identified as woodland in one image and disturbed ground, scrub or grassland in another. In Norfolk, the majority of the imagery available to the project was recent (within a two year window) so a different approach needed to be adopted. Here the felled woodland areas were described by looking for spectral characteristics that equated to the presence of ruderal species, brashing and bare ground. There is a chance that these areas could confuse with certain arable characteristics and the inclusion of an older image would reduce this risk.

Results: Site-based case study of environments dominated by tree canopy cover – the effects of introducing higher resolution imagery for the mapping of "wet woodland"

The area around Rockland and Surlingham Broads is covered by many citations (as identified in Table 4:3 section 4.5.5), it contains the Annex I habitat 91E0 Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* which is contained within the BAP priority habitat, wet woodland.

Wet woodlands are identified by a mixture of the canopy species present and the composition of the ground flora. In comparison with many other stands of semi-natural woodland, wet woodlands can have a much more open canopy. Therefore a larger component of the reflectance signal received by the sensor is due to the ground flora. It was therefore hypothesised that we may be able to separate wet woodland from dry woodland because there should be a difference in their reflectance. The photo in Figure 6:8 shows the strips of wet and dry woodland vegetation present at an extremely fine spatial scale that form the wet woodland priority habitat type.

Figure 6:8: Wet woodland at Wheat Fen, Rockland Broad NNR.

How we mapped it in the case study

The case study investigates what can be achieved, comparing the results of mapping the area at differing scales, making use of differing imagery types and ancillary data:

1. Imagery of a "medium" resolution - using both SPOT (10m resolution) and IRS (25m resolution) satellite data in the image stack;
2. Very High Resolution (VHR) imagery from both VHR Rapid Eye satellite imagery and a ultra-high resolution acquisition at 10cm (resolution) acquired with a UAS;
3. Using detailed DEM from LiDAR data and the UAS.

Figure 6:9 shows the results of the use of 'medium-high' resolution SPOT and IRS imagery. Different rules were trialled using this imagery to try and establish a 'wetness' and 'ground flora' signal from the general deciduous woodland canopy signal. However during this work it was not possible to establish a robust and repeatable 'rule' at this scale. The landscape classification therefore tends to classify the more open areas as 'woodland scrub' and those with a closed canopy as 'broadleaved woodland.

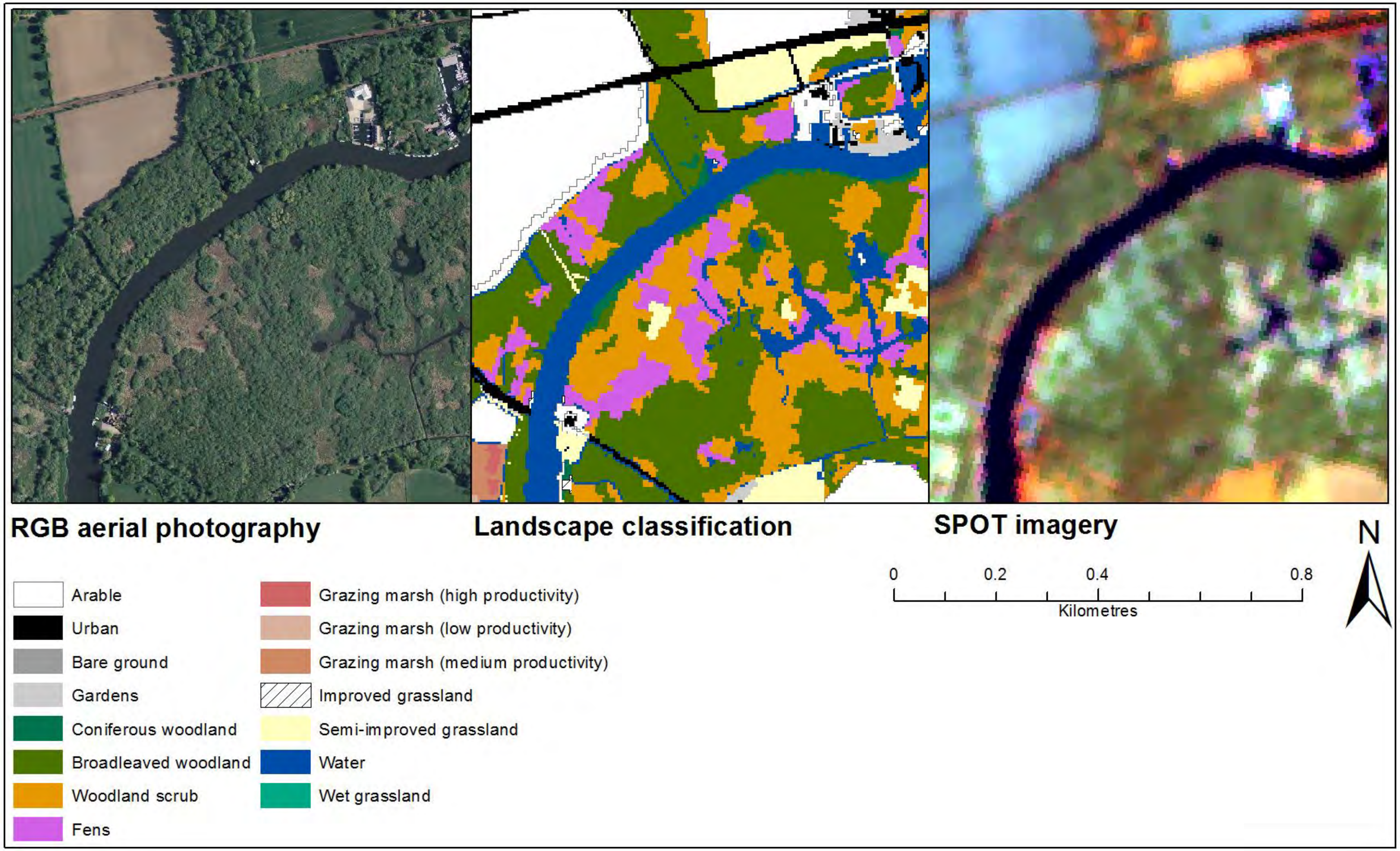

Figure 6:9: Landscape scale classification of an area of wet woodland which is classified as woodland scub in a mosaic with fen and woodland

The second aspect of this case study considered the Very High Resolution (VHR) imagery from both VHR Rapid Eye satellite imagery and an ultra-high resolution acquisition at 10cm (resolution) acquired with a UAS. The use of the very high resolution satellite at 6.5m spatial scale and the SWIR band from the SPOT was sufficiently detailed to begin to identify a wetness signature. This analysis and mapping is outlined in more detail in section 6.5 on condition monitoring, as the wetness of the woodland could be an important site management tool.

Imagery from the UAS at 10cm resolution showed potential for tree discrimination as can be seen in Figure 6:10, a flight from August 2012. The RGB bands on the left of the figure show visible differentiation between different tree species, which is more pronounced in the red edge bands from the MCA on the right. The detail of the digital surface model collected by the UAS as part of the information gained from the site is shown in the middle image. The taller the trees the lighter the colour, lower areas are shown as black. It would be possible if some actual individual trees were identified by species to see if this data would allow the identification of individual trees, however, this level of field data was not obtainable by the project within the time frame of the work. Utilising the tree height and shape data with the red edge signal could result in a very detailed classification.

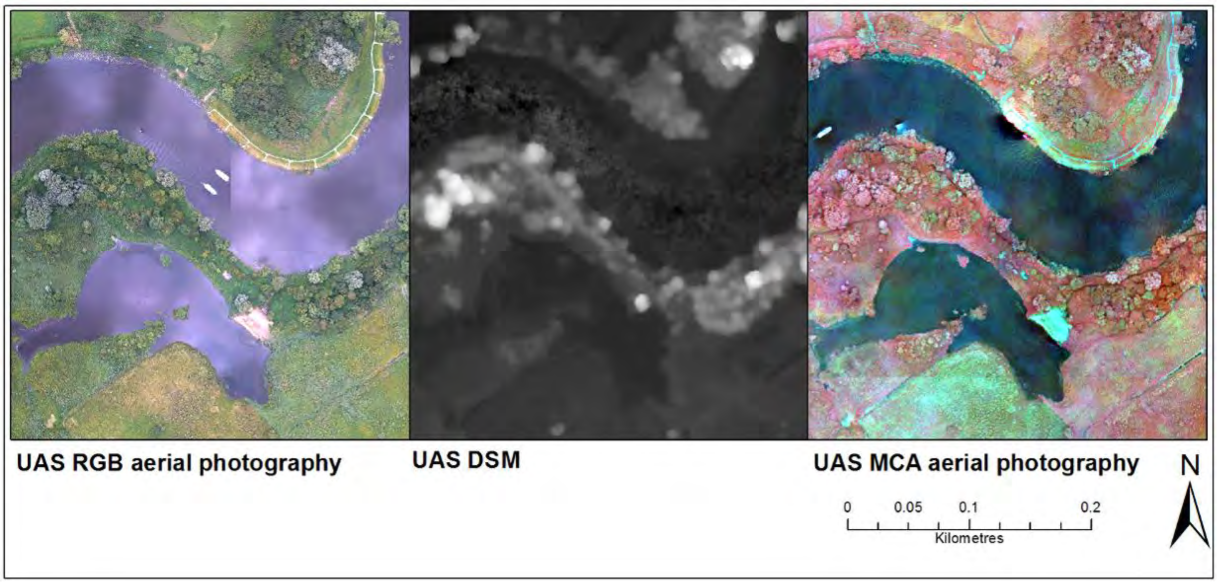

Figure 6:10: UAS imagery and derives DSM captured in the Broads

Figure 6:11 shows a visual comparison between the DSM created from the UAS flight and the 1m LiDAR. The 1m LiDAR image from January 2009 has captured the vegetation in "leaf-off" conditions. Much of the LiDAR coverage currently available for the UK from the EA has been flown in winter in order to maximise the possibility of getting true ground surface values for flood risk identification. By using a "leaf-off" image much of the information on vegetation type and structure, which could be available through the LiDAR has been lost. In comparison the UAS DSM image shows how much height and vegetation structure variation it is possible to capture and therefore include in any analysis from a detailed DSM captured in "leaf-on" conditions, here in mid-summer. The high resolution of the image shows the presence and also how the shape of individual trees and bushes can be seen from above.

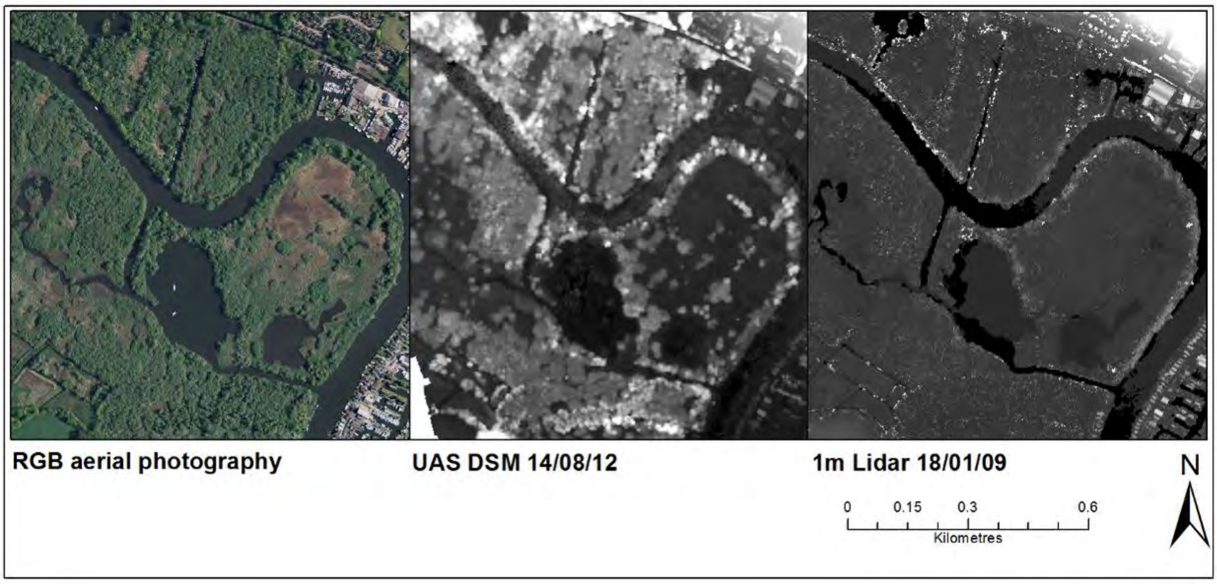

Figure 6:11: Comparison of RGB aerial photography, UAS DSM and 1m LiDAR for an area of the Broads

Results: Landscape-scale mapping: identification of hedgerows

Hedgerows are important landscape features having significant roles in biodiversity and water regulation and are a priority habitat. Many hedgerows were removed from the Norfolk landscape to accommodate the large intensively managed arable fields. Where hedgerows survive within the wider arable landscape, they have an important role in regulating water movement through the soil and provide refugia for insect and bird populations. In some areas, notably around the Broads, species-rich hedgerows have been retained and comprise a range of flowering and berry forming species that are an important component of the landscape. Elsewhere hedgerows are rarer and often heavily managed leaving them thinner, species-poor and often with gaps.

Species-rich hedgerows particularly with mature trees are a priority habitat. They also form an important landscape component for Annex II species.

Within the Welsh landscape the presence of hedgerows can be identified with landscape-scale mapping using SPOT imagery, although at this scale they are not well defined. In this setting hedgerows have enough of a spectral difference to the surrounding grassland to be distinctive, they have a characteristic high value in the SWIR band and the signal caused by the shade they cast. Similarly, within the landscape-scale mapping in the Broads, permanent grassland is common, so hedgerows can be found by applying similar rules to those used in Wales. However, the intensively arable environments elsewhere in Norfolk this separation was much less apparent in the reflectance characteristics of the imagery. The sheer variety of arable crops and cropping cycles means land in arable production can be at many different growth stages resulting in wide variation in the spectral characteristics of the land. This masks the hedgerow signature, particularly in cases where the hedgerow is small, gappy and heavily managed.

The presence of larger hedgerows could be identified in Norfolk using SPOT imagery however, they were over-represented due to the resolution of the SPOT imagery (10m x10m for each pixel). Smaller hedgerows however, tended to be missed. Many examples of this effect can be seen in Figure 6:12, comparing the classification to the aerial photography.

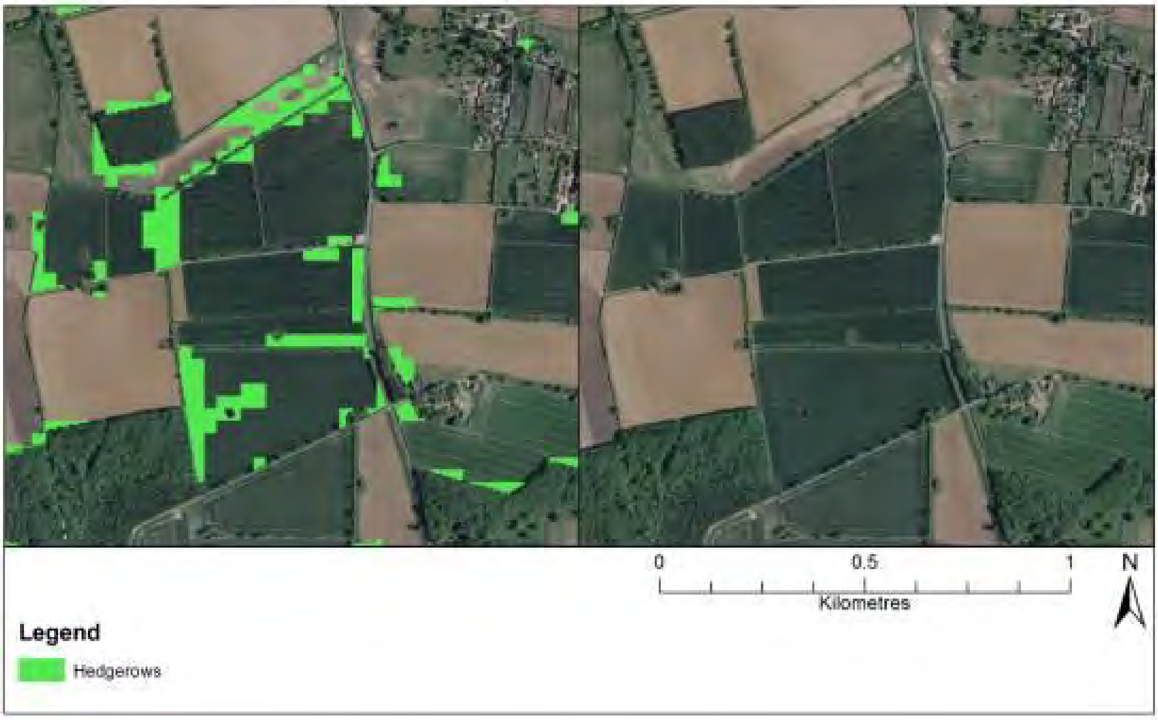

Figure 6:12: Results of hedgerow identification using SPOT imagery (left hand image). Right hand image is aerial photograph of the same area for comparison.

Results: Case study: further developing techniques for the identification of hedgerows

In a small case-study area, hedgerows were identified using a similar approach developed to refine the hedgerow mapping across Wales, where CIR aerial photography was segmented within a mask derived from IACs boundaries to find hedgerow features. A recent study in Ireland (Medcalf *et al*, 2010) used field boundaries from old paper maps which had been scanned in and geo-rectified within the rule-base to create a mask within which features with 'tree' like signatures were identified. Elements of these two approaches (the use of aerial photography and the use of field boundary information) were combined for a small case study area in Norfolk to see if it improved the detection and scale of mapping of hedgerows.

Initially the field boundary mask was created from MM. This picked up most but not all field boundaries in the areas. A few of the field boundaries that were not identified by MM did contain hedgerows, so with the better arable mask, a better hedgerow mask could be made. This is illustrated in Figure 6:13.

The combination of the mask and CIR aerial photography gave a much more successful result in comparison with the landscape scale mapping of hedgerows. The finer resolution segmentation using the aerial photography better delineated the features. However, as MM did not adequately include all the field boundary areas the mask was not accurate enough to pick up all the hedges. Further development work will be needed to create a mask of fields in order to accurately pull out the hedge features.

Figure 6:13: Hedgerow mapping using CIR aerial photography

To successfully identify hedges the following findings were found to be of particular significance:

- Hedge objects can often be only a metre wide and need a finer resolution of imagery to successfully identify them. For these hedges, SPOT imagery was not suitable.
- An additional landscape feature mask such as that created using OS MM is required to guide analysis.

Hedgerows with tall trees are increasingly being shown to be an extremely important resource for bat species (Boughey *et al*, 2011). Where finer resolution imagery is available the canopy of individual trees can be identified and it is very likely that this would allow identification of these important biodiversity features.

Results: Landscape-scale mapping: identification of scrub

Scrub is not a priority habitat, nor does it occur within any Annex I habitats however, it is important in the landscape context, it can be a positive or negative feature of the biodiversity. In terms of its positive ecological role, scrub provides refugia for small birds and insects; its understory can be a native seed bank. In its negative ecological role, it is found on undermanaged natural habitats and can be a sign that the site is no longer in good ecological condition. For these reasons it was felt to be important to identify scrub within the wider landscape.

There are three types of scrub that are commonly found in Norfolk: scrub dominated by European Gorse, scrub dominated by bramble and ruderal species and scrub dominated by hawthorn and other small trees. These three types of scrub have differing and distinct spectral characteristics:

- **Scrub dominated by European gorse**. In most cases, stands of gorse are large enough so the reflectance of gorse can be distinguished from other vegetation types. The main confusion with dense gorse scrub is with coniferous forest plantations which have a similar reflectance.
- **Scrub dominated by bramble and ruderal species**. These areas often have a very high NIR or productivity spectral value and therefore are best distinguished by the difference in 'texture' to other heavily improved areas.

- **Scrub dominated by hawthorn and other small trees**. This is the most demanding type of scrub to pick up, as the species occur in similar proportions in both hedgerows and woodlands and the classification of 'scrub' would only be relevant in different landscape settings, scrub being lower to the ground and in smaller patches. These features are difficult to build into a rule base.

Large stands of scrub dominated by European Gorse can be identified. Scattered bushes need an ultra-fine resolution image to be identified. Gorse scrub is also the subject of the case studies looking at condition monitoring and will be reported on in more detail later in the study. Scrub dominated by bramble and ruderal species is often very small in spatial scale and is therefore not readily identified at the landscape scale. Where it occurs with gorse scrub or small trees it is easier to identify. Scrub which comprises small trees requires spectral rules which take into account the density of the tree crowns. It is not possible from above to judge the size of trees, so this scrub type has most confusion with other woodland habitat types. If this type of vegetation needs accurate identification then it will be necessary to use LiDAR information to provide information on vegetation height.

Transferability

Summary of what these findings for woody vegetation mean for transferability
T5. Results from Wales and Norfolk suggest that splitting woodland into basic types of broadleaved, mixed and coniferous woodland should be achievable at the landscape-scale in all types of UK environment (with the proviso that suitable seasonal images of "leaf on / leaf off" conditions can be acquired, free from cloud and not obscured by shadows on north facing slopes). T6. If a suitable mask can be created and very high resolution or aerial imagery is available it is possible to map hedgerows. Datasets used to create the mask (e.g. OS MasterMap or a national Land Parcel Information System) must be well understood as they may not pick up all real-world field boundaries containing hedgerows.

6.3.3 Environments dominated by dwarf shrub canopy cover

Summary of key findings and observations: <u>things that worked well:</u>
KF20. The Lowland heathland priority habitat could be mapped at the landscape-scale. KF21. Wet and dry heathland types (required for mapping Annex I habitats) could often, but not always, be mapped at the landscape scale with the use of contextual data. KF22. LiDAR improved the identification of all heath types and reduced confusion with scrub. KF23. Use of high resolution imagery improved boundary delineation and the description of areas of mosaic.

Summary of key findings and observations: <u>things that didn't work so well:</u>
KF24. Mapping heathland sites with substantial amounts of European gorse was problematic.

Heathland habitats

Heathlands within Norfolk are extremely important for the species they support and the habitat they provide for wildlife. They support a wide range of birds, including stone curlew *Burhinus oedicnemus*, woodlark *Lullula arborea* and nightjar *Caprimulgus europaeus*. In addition they host significant insect and reptile species such as adder *Vipera berus* and common lizard *Zootoca vivipara*. Heathland in Norfolk was much more extensive in the past, but losses due to agricultural improvement and coniferous woodland plantations have resulted in this habitat becoming fragmented and confined to relatively small areas, many of which are now designated as SACs, SSSIs or Local Nature Reserves.

The Annex I and priority habitats considered within this section are listed in Table 6:2. The dry heaths are dominated by heather as a canopy forming species. Wet heaths can be dominated by grasses and sedges with heathers as subdominant within the sward.

Table 6:2: Annex I and priority habitats within environments dominated by dwarf shrub canopy cover

Type of feature	Priority habitat	Annex I Habitat
Dry heaths	Lowland heathland	**H4030**. European dry heaths
Wet heaths	Lowland fens	**H4010**. Northern Atlantic wet heaths with *Erica tetralix*; Wet heathland with cross-leaved heath

Breckland heathland is unusual in that it contains very little dwarf shrub cover and it is therefore included in the section on dry environments dominated by graminoid species. The other two types of heathland are:

Heathland dominated by a significant component of heather species, including, bell and cross-leaved heather, gorse and western gorse. This type of heathland occurs throughout Norfolk on the terraces above river valleys and on the sand and gravel ridges around Cromer, on the northern coast and to the north-west of King's Lynn. The picture in Figure 6:14 shows dry heath at Roydon Common.

Figure 6:14: Dry heath in Norfolk

Wet heaths: There are a few scattered examples of wet heaths for example at Buxton Heath. Here coarse grasses and sedges can be co-dominant or dominate. The heather species form a much smaller component of the sward and moss is an important understory. Figure 6:15 shows an area of wet heath at Dersingham.

Figure 6:15: Wet heath in Norfolk

Results: Landscape-scale mapping: identification of habitats dominated by dwarf shrub cover

Lowland heaths, where heather species dominate, are the most straightforward to map using EO. The Lowland heathland priority habitat is characterised by the presence of heather species at dominant or sub-dominant levels and this habitat was successfully identified by a landscape-scale mapping approach. Within Norfolk all heathland is classified as lowland heathland, so there is no potential for confusion between lowland and upland heath. In previous habitat mapping work in other regions, most confusion arose between dry heath and ling heather *Calluna vulgaris* dominated bog however, some relationship to wetness, where sphagnums are a significant component of the bogs could help tell these apart.

Wet heaths occur in complex mosaics with dry heath, semi-natural grasslands and fens. These habitat types do not have hard boundaries but instead grade into one another dependent on peat depth. When mapping for Article 17 reporting, a peat probe would always be used to assign the habitat to the correct class. Peat depth is not possible to separate out spectrally, so if the canopy is very similar, and the peat becomes deeper, the transition to bog may be unrecorded, until the species assemblage changes sufficiently to be spectrally different. Where peat depth is already well understood then landscape scale spectral mapping should be sufficient to identify these habitat types.

Another confusion arises when dealing with areas which have a component of European gorse *Ulex europaeus* within the heather. European Gorse can be a component of dry heath in its own right, therefore spectral separation can be quite difficult to pull out dense stands of gorse that do not form part of the BAP priority or Annex I habitats.

Results: Detailed case study results – Dersingham Bog

Dersingham is a valley mire complex consisting of three Annex I classes:

- H4010 – Northern wet heaths with *Erica tetralix*
- H4030 – European dry heaths
- H7150 – Depressions on peat substrates of the *Rhynchosporion*

And two BAP priority habitats:

- Lowland heathland
- Lowland fens

How we mapped it in the case study

Three assessments were carried out as part of a site-based case-study for heathland and wetland habitats that took place at Dersingham Bog, which contains a mosaic of heath, fen, grassland, bog and woodland. The assessments involved mapping the vegetation communities using:

1. OS MasterMap, very high resolution aerial imagery (colour infra-red photography)
2. OS MasterMap and high resolution satellite imagery (Geoeye); and LiDAR;
3. Very high resolution UAS aerial imagery and UAS DSM (Figure 6:18)

Figure 6:16 shows the results for approaches 1 and 2 (on the left and right respectively) for heathland and wetland communities at Dersingham. The classification on the left used CIR aerial photography and the 5m DTM used in the landscape scale mapping for the topographic setting. The classification shown on the right used GeoEye imagery and LiDAR, increasing the spatial resolution of the DSM. The addition of the 1m LiDAR gives more detailed height data, providing information to the classification about vegetation structure. The GeoEye imagery shown in the centre was captured in October 2011 while the CIR aerial photography used in the creation of the classification on the left was captured in May 2010, therefore classification 2 presents a more recent view of the situation on the ground. This accounts for some of the variation between the classifications, such as the cleared woodland towards the top right of image which occurred between the images being captured. .

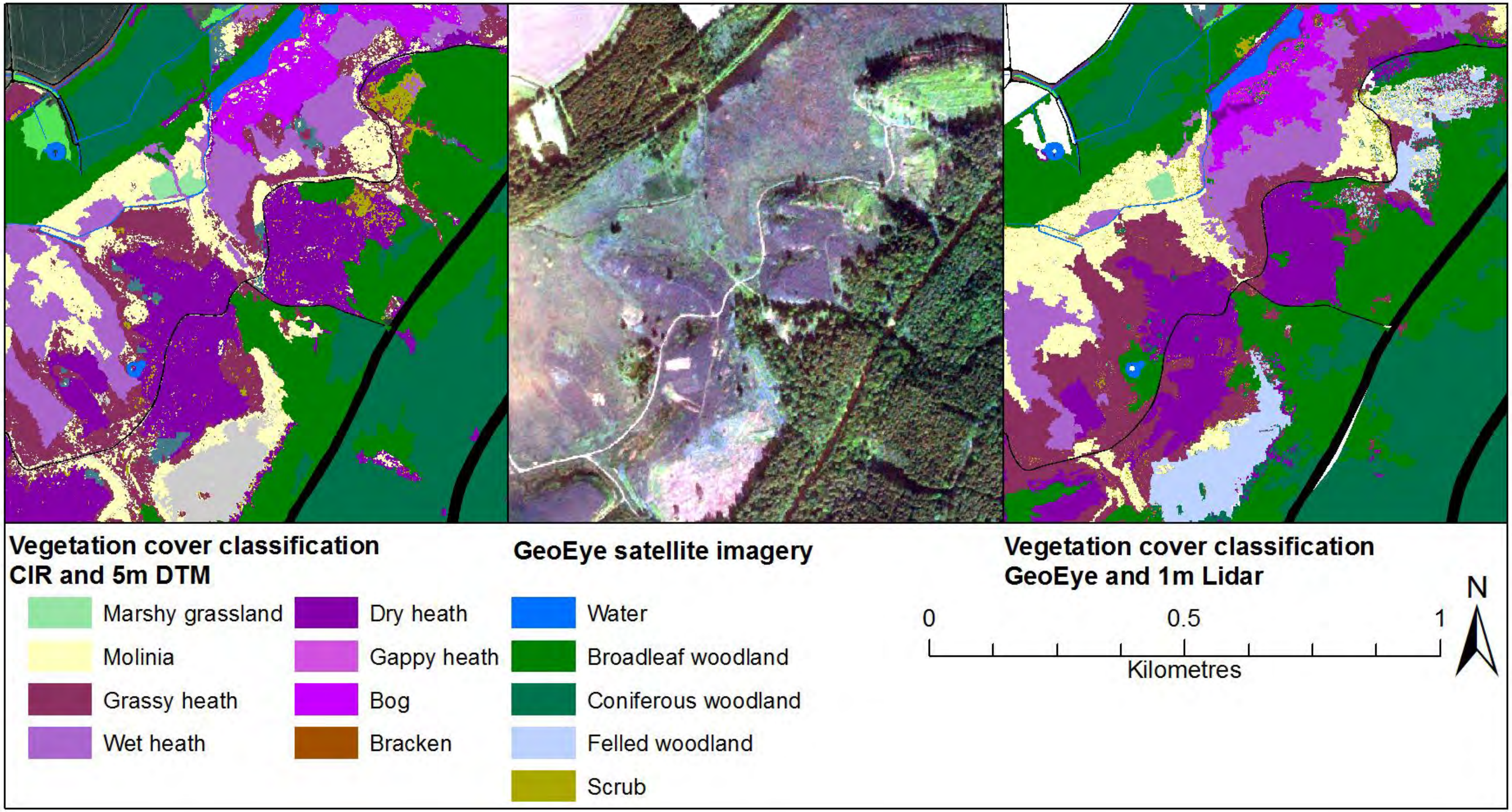

Figure 6:16: The results of two different heathland classifications, classification 1 on the left using CIR aerial imagery 5m DTM and classification 2 on the right using GeoEye and 1m LiDAR. It highlights the increase in spatial resolution of the classification when high resolution LiDAR data is included

Figure 6:17 shows how the remote sensing classifications have been resolved up into the BAP priority and Annex I habitats.

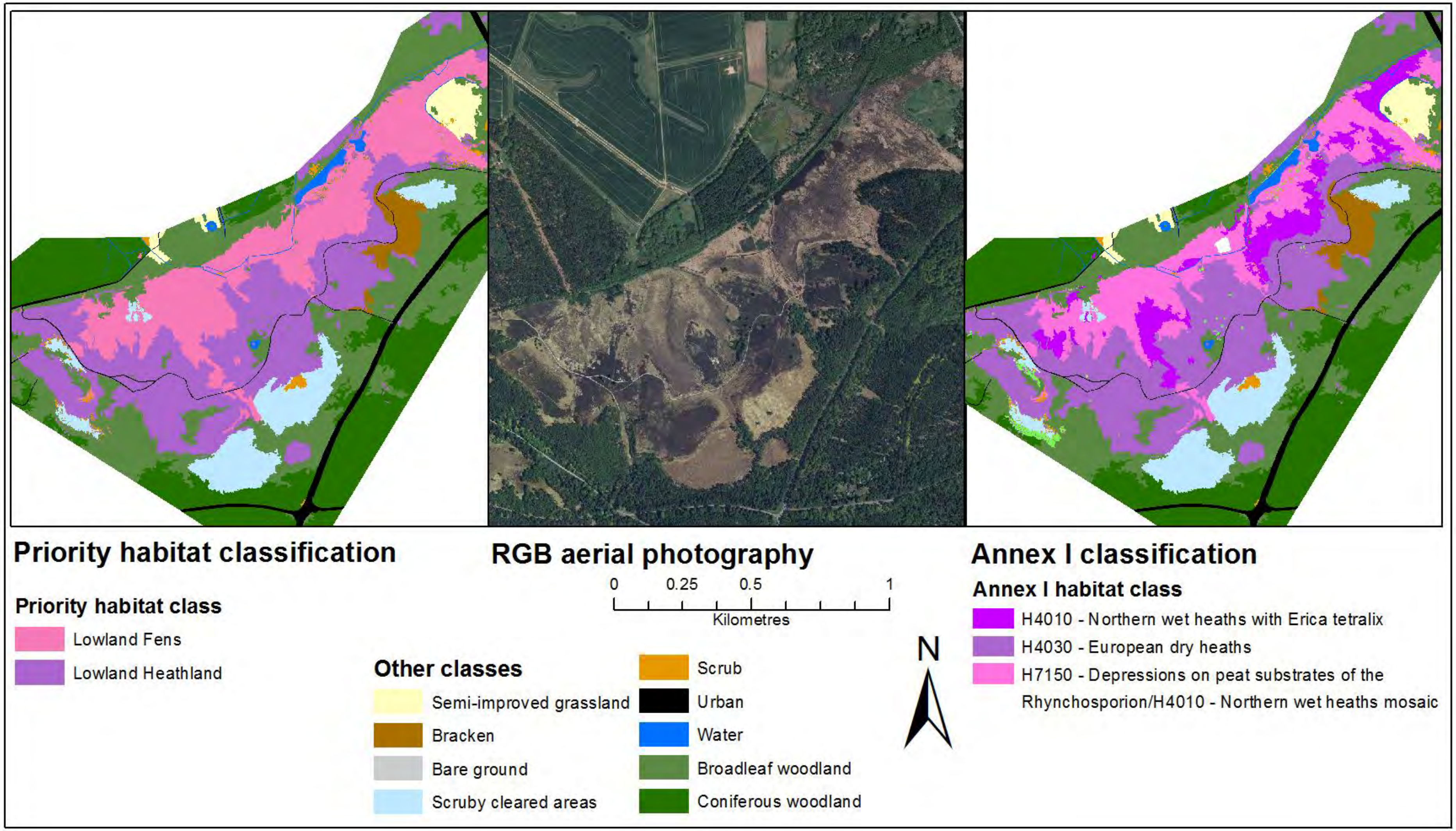

Figure 6:17: Resolving of earth observation categories into BAP priority habitats (left) and Annex I habitats (right)

The third approach used the UAS imagery which is shown in Figure 6:18, and provided a very high spatial scale of detail. The bog pools and the scrub can be seen in the RGB image on the left all in shades of green and brown. These features can be seen much more clearly in the MCA image on the right which includes several additional bands of information recorded in the NIR part of the EM spectrum such as the red-edge. The Digital Surface Model from the UAS in the centre of the image shows the row of trees at the northern edge of the imagery very clearly and also helps highlight some of the topographic undulation on the bog surface which give rise to wetter channels in the mire. These images have been used more extensively in mapping and modelling of the condition element of the report to show what is possible in terms of features pertaining to site management.

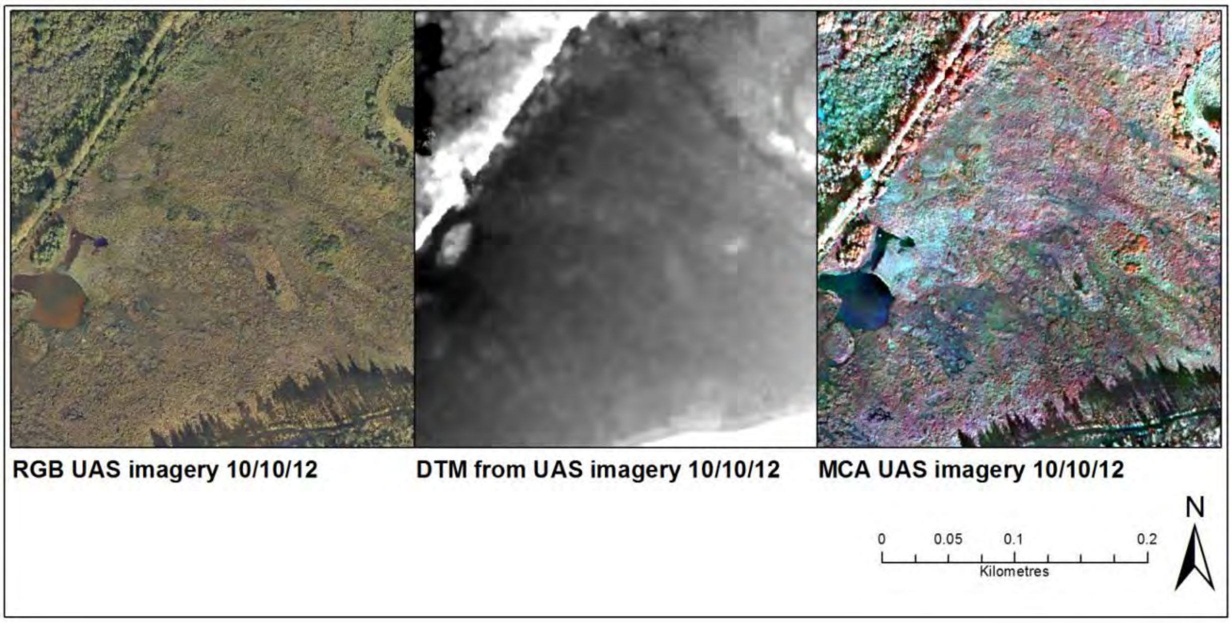

Figure 6:18: Data captured at Dersingham by the UAS

The main bog and heath habitat types can be distinguished from a combination of very high resolution Geo-eye imagery, CIR photography and LiDAR. The level of detail available within the UAS data gives a very accurate delineation of features such as ponds and areas of scrub. This type of detail is very useful to condition monitoring of the site and more features at this site are presented in section 6.5.

Transferability

Summary of what these findings for dwarf shrub vegetation mean for transferability

T7. Results from Wales and Norfolk demonstrate that the mapping of Lowland heathland and Upland heathland where there is a dominance of Calluna species is achievable at the landscape-scale. Upland and lowland heathland types can be split by using topographic data and biogeography.

T8. It is important take account of the component vegetation types of heathland mosaics so that additional information can be built into the rule-base to minimise confusion between spectrally similar vegetation types (e.g. wet and dry heath can be better discerned if detailed topographic data is included in the classification).

6.4 Habitats dominated by non-woody vegetation

This section of the report looks at the mapping of the extent of non-woody habitat types and considers three main types of non-woody habitat:

- dry grasslands
- wet grasslands dominated by brackish and saline water influence
- other wetlands and waterbodies.

Grassland swards need regular management to maintain their species diversity. The timing and extent of management activities such as grazing and cutting will determine the character of the sward and how valuable the grassland is as a habitat for small mammals, invertebrates and other wildlife. Grasslands that are sown or fertilised, tend to be dominated by productive grasses above a more varied mix of grassland species such as herbs and native graminoid species. Productive grassland generally provides more grazing for livestock but leads to a less diverse sward. If a grassland has been fertilised many years ago, the effect of rainfall will eventually wash the enhanced nitrogen and phosphorus burden from the soil leading to conditions that favour native species of grasses and herbs. Grasslands therefore, tend to exist in a state of flux. Some will be very diverse with a wide range of plant species and that support good numbers of invertebrates and birds, some that are intensively managed and fertilised every year or two and are dominated by rye grass and those that have not been fertilised in recent years and which may be becoming more species rich. Whilst this description is a simplification of the situation on the ground (where grazing and other factors will influence the species-mix) it is useful.

Species-rich grasslands are found across the whole of Norfolk but differ in their character depending on where they occur, for example in river valleys or on outcrops of chalk. Many areas of common land within the county contain interesting grasslands. It can be argued that species-rich grasslands are some of the most vulnerable habitats. In general, land managers are less aware of these habitats than the more obvious heathland and woodland habitats. The decline in the area covered by these special grasslands has become a serious threat to biodiversity in the county.

These habitats are distinguished in EO data analysis from woody vegetation by the difference in shade fraction and 'texture' consistent with the presence of a canopy and woody features.

6.4.1 Dry environments dominated by graminoid species

Summary of key findings and observations: <u>things that worked well:</u>
KF25. The Breckland heathland habitat contains a similar species assemblage as the Annex I class, 2330 Inland dunes with open *Corynephorus* and *Agrostis* grasslands. This was successfully identified using CIR aerial photography or other ultra-high resolution aerial imagery, such as UAS.
KF26. Where the arable field mask was good and the margins sufficiently wide, arable field margins could be successfully identified at the landscape level.

Summary of key findings and observations: <u>things that didn't work so well:</u>
KF27. It is possible to map semi-natural species-rich grassland at the landscape scale however, it is not possible to assign it to a priority habitat class as the geology and soils data available is not sufficiently detailed to inform the rules of the substrate and

individual herb species are not visible in a 10m pixel.

KF28. Identification of arable field margins is constrained by the quality of the arable mask. Further refinement of the arable mask will significantly increase the ability to identify arable field margins.

For the purpose of the report, the results for all dry grasslands are presented and discussed within this section, including traditional grassland habitats as well as Breckland heathland, as the predominant ground cover is often acid or calcareous grassland species.

Table 6:3: Annex I and BAP priority habitats within environments dominated by graminoid species

Type of feature	Priority habitat	Annex I Habitat
Arable landscape	Arable field margins	
Species rich grasslands	Lowland calcareous grassland	**6210.** Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*)
	Lowland dry acid grassland	
	Lowland meadows	
Open swards and habitats	Open mosaic habitats on previously developed land	**2330.** Inland dunes with open *Corynephorus* and *Agrostis* grasslands

Acid, calcareous and neutral lowland grassland types are found in the Norfolk study areas and there are areas of both wet and dry grassland, as well as the diverse habitat of open mosaic habitats on previously developed land most commonly found in urban environments and open grasslands found in coastal areas. This project has not addressed the open mosaic habitats on previously developed land, although recent Defra research looking at this priority habitat which has used EO is due to report soon (project WC0795). The images in Figure 6:19 show two different grassland habitats in Norfolk:

Figure 6:19: Two dry grassland habitats in Norfolk, a lowland hay meadow on the left and a lowland calcareous grassland on the right

The Lowland meadows priority habitat includes most forms of unimproved neutral grassland across the enclosed lowland landscapes of the UK. Meadows and pastures associated with low-input nutrient regimes contain a specialist group of scarce and declining plant species.

Lowland acid grassland typically occurs on nutrient-poor, generally free-draining soils with a pH ranging from 4 to 5.5 overlying acid rocks or superficial deposits such as sands and gravels.

Calcareous grasslands have a high pH and low nutrient status and occur where natural features such as steep slopes or patterned ground support chalk grassland or anthropogenic disturbance exposes the chalk. The main sites of calcareous grassland which survive are in north-west Norfolk and Breckland. The boulder clay grasslands of south-east Norfolk sometimes show a strong calcareous influence, but these are largely treated as lowland meadows unless there is a significant calcareous grassland interest.

Breckland heathland is a very important habitat within Norfolk. Here the thin nutrient poor soil gives rise to acid loving plants growing intermingled with species more commonly found on alkaline chalk soils. Grasses, lichens and wild flowers dominate the sward and heathers can be a very small component and are often considered an undesirable species. Frequent disturbance is necessary to maintain the thin soil containing a high proportion of inorganic material from the bedrock. The ground disturbance required to prevent a build-up of organic material in Breckland heath soil has historically been maintained by intensive rabbit grazing. The drastic decline in rabbit populations, following the introduction of myxomatosis in the 1950s, has contributed to a decline in the condition of many of these heathland habitats.

Figure 6:20: An area of Breckland heath at East Wretham LWS

Results: Landscape-scale mapping: identification of habitats in dry environments dominated by graminoid species.

Grassland occurs in a range of environments across the Norfolk landscape. This includes arable environments and less managed areas.

A key part of the process of mapping grasslands at a landscape scale is to accurately identify areas which are part of the arable cropping cycle. This includes a wide range of crop types, growth cycles and as a result, spectral cover values, which cause confusion with other cover types. This land must be accurately identified at an early stage so it can be either considered for the identification of field margins or excluded from the analysis of other habitats (thus simplifying the process of discriminating the remaining cover types with the imagery available). The remaining cover types include permanent and temporary grassland from improved through to semi-natural swards.

Species-rich grassland is generally characterised by a lower productivity and lower NIR signal in the spring than produced by grassland leys (i.e., temporary grasslands). This difference early on in the season is one of the main mechanisms for distinguishing grassland that is potentially more interesting and species rich. Confusions arise if arable crops (which have not already been identified as such) are growing at low intensity at this time or in a patchy way, because they mimic the heterogeneity of the reflectance characteristics of a semi-improved grassland sward.

The development and application of the rule base for splitting grasslands works in a very similar way for Norfolk as it did in Wales, but the complexity of the arable environment in Norfolk due to the extremely wide range of arable crops present and the variation in the timing of their cultivation meant there was a lot more scope for confusion between semi-natural grassland and arable in Norfolk and a more detailed rule base had to be developed as a consequence. The results of the grassland analysis can be seen in the image in Figure 6:21.

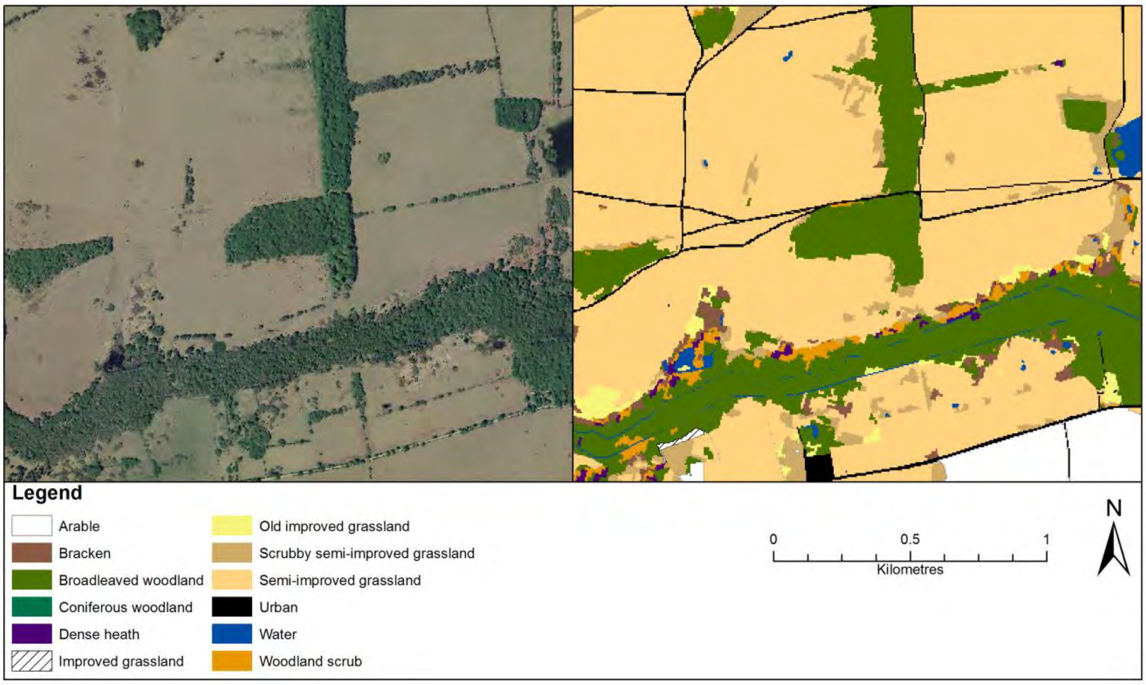

Figure 6:21: Neutral grassland habitat in Norfolk

Grasslands can be identified from imagery and split into overall types such as species-rich, improved and those that may be reverting back to a semi-improved state. However, at the landscape-scale it is not possible to extract from the reflectance values the information required to establish or indicate the specific grassland priority habitat types of Annex I habitat types present. This is because the identification of priority habitat types relies on assessment of the individual forbs and flower species that are present and these may occur in low frequency and be small in size. For example, the presence of heath bedstraw in the sward would indicate the presence of an acid grassland, while wild thyme would indicate that the grassland is calcareous. From space it is not possible to tell these small herbs apart. If fine resolution geology data is available so that calcareous outcrops or acid or calcareous soils can be accurately mapped then this could be used to give the contextual element to the rule-base for identifying dry grasslands and they could be inferred down to Annex I type. Therefore the grasslands largely remain as Crick Framework Tier 4 and 3c features.

Results: Case study Breckland heathland

Breckland heathland is dominated by native grasses with a very open sward and they were found not to be spectrally distinct form acid grassland. However, they can be identified from their landscape context because all open species rich sward grassland within the Brecklands landscape is considered to be Breckland heath. The landscape context, grassland spectral rules and low productivity scores can be used successfully at all scales of mapping to pull out these important heaths. As seen in Figure 6:22 highly detailed mapping can come from using very high spatial resolution aerial imagery, in this case CIR aerial photography.

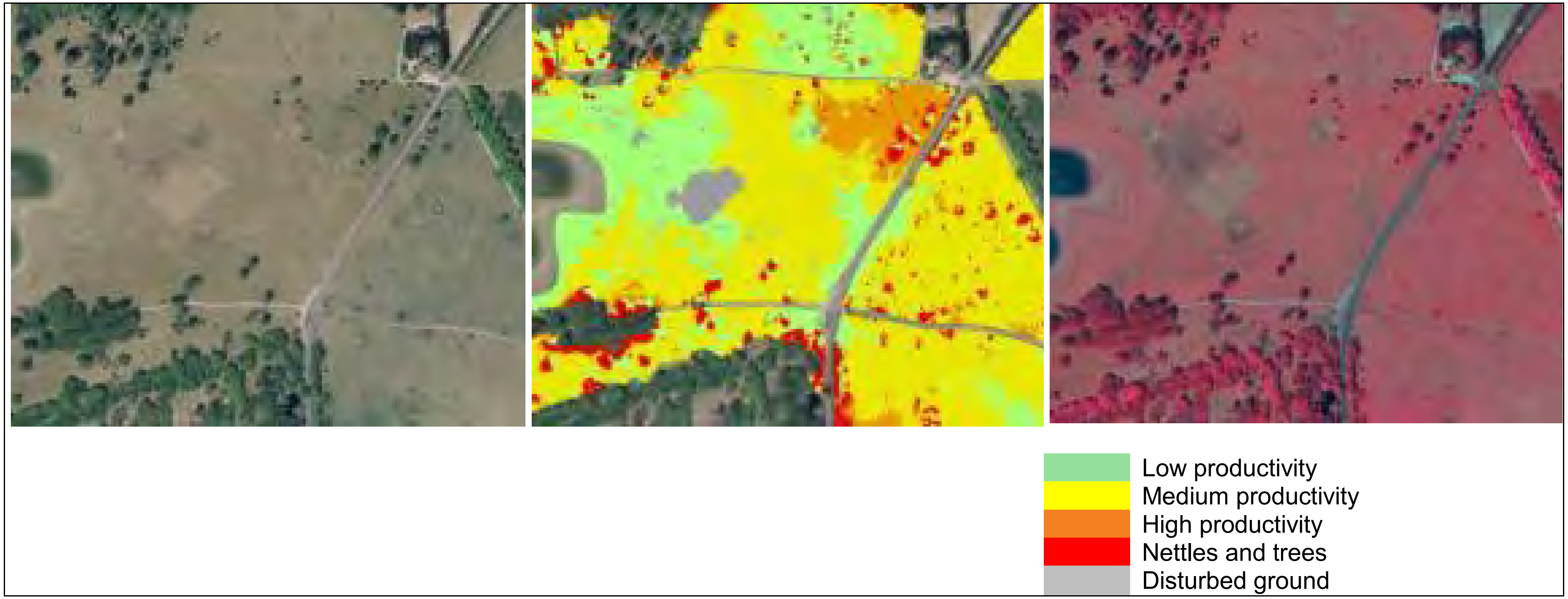

Figure 6:22: Classification and productivity for East Wretham Heath

Results: Case study field margins

The presence of arable field margins can be picked up with the broad level mapping in fields where the crop is significantly different from the species present in the margin, and the margin is wide enough to be picked up by the pixel size of the imagery. With an arable mask and a finer segmentation, even better field margin separability can be attained. Two images from different points in the year allow for the crop to be at very different growth states, while the margin will be more similar. The broad scale mapping of field margins is shown in Figure 6:23. The imagery used to classify the margins is a later date than the air photography and the margins have changed slightly. These features are annually or bi-annually mobile within the agricultural landscape, depending on the agricultural practice for the year. EO would offer a good way of monitoring where they are and what type of margin they are.

Figure 6:23: Identification of arable field margins with broad scale mapping

Transferability

Summary of what these findings on dry grassland vegetation mean for transferability	
T9.	Results suggest that areas of potentially species-rich grassland should be identifiable at the landscape scale throughout the UK.
T10.	Without detailed geology and soils data the particular type of grassland cannot be discerned. A lack of such data nationally suggests that there are few parts of the UK that will have the information necessary to identify grassland priority habitats and Annex I habitats.
T11.	Farming regimes can result in a very complex mix of spectral characteristics in warmer, drier parts of the UK. Thorough understanding of the crop calendar and the way the crops behave spectrally is required to build an arable mask that is comprehensive enough to allow areas of potential semi-natural habitat to be identified in the wider countryside by the classification process.
T12.	If the arable spectral signatures are well understood the mapping of field margins is possible; it is necessary to know the range of the forms these take locally (e.g., grassland field margins, uncropped field margins etc).

6.4.2 Environments dominated by a saline and brackish water influence

For the purpose of the report, results for all habitats dominated by a saline and brackish water influence are included in this section. Grazing marsh can have a freshwater or brackish influence and is considered in this section. Reedbeds again occur in both brackish and freshwater but because they are a particular part of the case study on the saltmarsh they are considered within this section. This project does not consider the identification of the landscape scale marine features or the intertidal and marine habitats. There are high numbers of both Annex I and priority habitat types in saline and brackish water environments in Norfolk (Table 6:4).

Table 6:4: Annex I and priority habitat types found in saline and brackish water environments in Norfolk

Type of feature	Priority habitat	Annex I Habitat
Landscape scale marine features		**1130** Estuaries **1160** Large shallow inlets and bays
Intertidal and marine habitats	Mud habitats in deep water	**1170** Reefs
	Sabellaria spinulosa reefs	**1110** Sandbanks which are slightly covered by seawater all the time
	Seagrass beds	
	Sheltered muddy gravels	
	Blue mussel beds	
	Intertidal chalk	
	Subtidal sands and gravels	
	Subtidal chalk	
Saline lagoons	Saline lagoons	1150 Coastal lagoons
Mudflats and saltmarsh	Coastal saltmarsh	1140 Mudflats and sandflats not covered by seawater at low tide
	Intertidal mudflats	**1310** *Salicornia* and other annuals colonising mud and sand
	Reedbeds	**1330** Atlantic salt meadows
		1420 Mediterranean and thermo-Atlantic halophilous scrubs
Sand dunes and maritime cliffs	Coastal sand dunes	**1210** Annual vegetation of drift lines
	Coastal vegetated shingle	**1220** Perennial vegetation of stony banks
	Maritime cliff and slopes	**2110** Embryonic shifting dunes
		2110 Shifting dunes along the shoreline with *Ammophila arenaria*
		2150 Atlantic decalcified fixed dunes (*Calluno-Ulicetea*).
		2160 Dunes with *Hippophae rhamnoides*
		2170 Dunes with *Salix repens* ssp. *Argentea* (*Salicion arenariae*).
		2190 Humid slack dunes
		2130 fixed dunes with herbaceous vegetation
Grazing marsh	Coastal and floodplain grazing marsh	

At a landscape-scale the research sought to map the main types of saltmarsh and sand dune features together with saline lagoons and maritime cliff and Atlantic meadow communities.

Summary of key findings and observations: <u>things that worked well:</u>

KF29. The Landscape scale work using SPOT and IRS was able to pull out the broad saltmarsh communities (water, sediment, vegetated saltmarsh).

KF30. Even at the landscape scale it is possible to split between 1310 *Salicornia* and other annuals colonising mud and sand communities and other marsh however, the boundaries are somewhat 'fuzzy' and indistinct at the 10m pixel resolution.

KF31. Sediment can also be identified successfully at low tide, sand and mud are harder to split definitively at the landscape scale because of the resolution issues where they grade into each other.

KF32. Atlantic salt meadows and 1420 Mediterranean and thermo-Atlantic halophilous scrubs are being considered at the case study level, initial results are promising for their identification and classification.

KF33. The priority habitat class of sand dunes can be successfully identified at the Landscape scale level.

KF34. The Annex I sand dune classes can be successfully identified with finer resolution data such as GeoEye and or CIR photography as part of the image stack to give a suitable scale of segmentation.

KF35. The use of 1m resolution LiDAR in the image stack dramatically increased the ease of identification of all coastal classes.

KF36. Reedbeds are classifiable when LiDAR first and last return data is available within the image stack.

KF37. Coastal vegetated shingle and 1210 Annual vegetation of drift lines can be identified with GeoEye or CIR resolution data.

KF38. The hybrid-pixel object-based approach identified a range of measures of within-field variation of the grassland vegetation in an area of grazing marsh in the Broads (arising from the vegetation and its management).

Summary of key findings and observations: <u>things that didn't work so well:</u>

KF39. Saline lagoons were difficult to split from other water features, as the saline influence is not possible to detect from optical imagery.

KF40. It was not possible to identify the species which create Annex I sand-dune components at the landscape level using (SPOT 10m and IRS 23m) data. (However see KF34 for the case study results)

KF41. LiDAR at 2m resolution was found to be insufficiently detailed to assist in making the identification of any of the habitats more achievable.

KF42. The very small patches of vegetation that comprise Coastal vegetated shingle and 1210 Annual vegetation of drift lines cannot be identified with 10m SPOT data.

Results: Saline Lagoons

Saline Lagoons are important water features because of the specialist flora and fauna they support. Their ecology is driven by the saline influence due to proximity to the sea. The presence of salt water can differ from lagoon to lagoon giving each a unique ecology. However all are characterized to some extent by the fluctuating water level. The rule-base for identification of these features hoped to use the landscape splitting giving the water class from MasterMap and different time of imagery to provide a fluctuating water table. The two images in Figure 6:24 show the water level differences present within the same year. However, the image stack available did not provide sufficient difference in tidal influence and this class has not been separated from the general water class in this project.

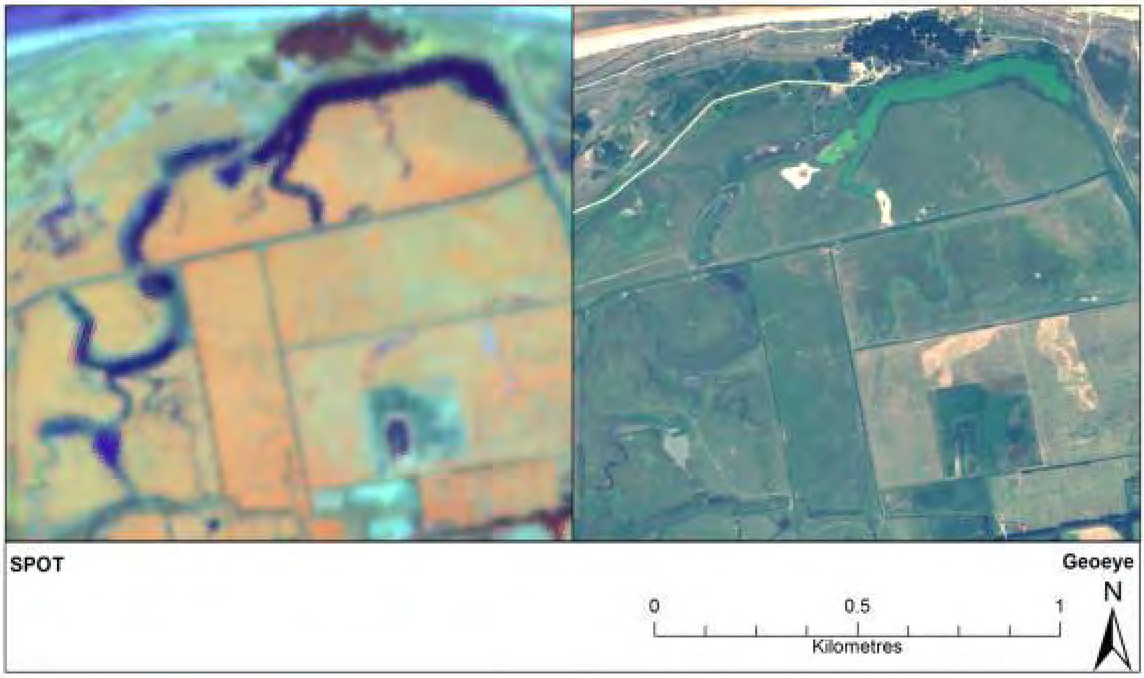

Figure 6:24: Saline Lagoons within the SPOT imagery and GeoEye showing very little tidal differences between the two images

Results: Mudflats and Sandflats

Intertidal mudflats and 1140 Mudflats and sandflats not covered by seawater at low tide are extremely important communities because they are highly productive areas which support large numbers of predatory birds and fish and are also important nursery areas for flatfish. They provide feeding and resting areas for internationally important populations of migrant and wintering waterfowl.

Mudflats and Sandflats are visible in the imagery as can be seen in Figure 6:25. They were classified spectrally using imagery captured at low tide, based on bare ground (unvegetated) and wetness characteristics. One of the issues with mapping them however, is that the boundary between mudflats and sandflats can be very indistinct, as part of a sediment continuum. The sediments are highly mobile and the patterns between them will change over time, even one storm event can affect them. Therefore, between images there is likely to have been some change in the spatial extent and distribution that can also confuse the boundary between the two habitat types, the state of the tide can also vary their extent between images as well.

Classification of mudflats and sandflats was possible at the broad scale (SPOT + IRS) however, the spatial resolution provided by these sensors was considered too coarse to adequately map this habitat; GeoEye and CIR imagery facilitated sharper definition. The results of this mapping show that it is possible to use imagery to map the habitats and if regular high resolution imagery was available over intertidal areas such as this it would provide useful data on the sediment moving and mixing.

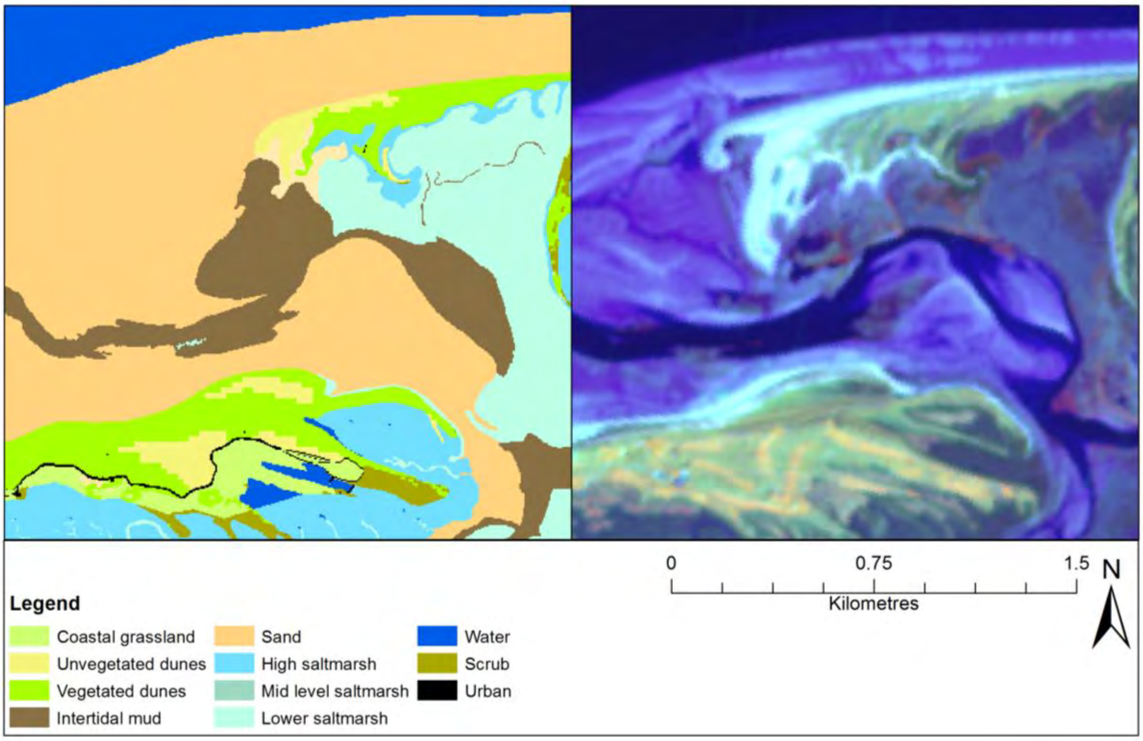

Figure 6:25: Landscape classification of mud and sand flats in comparison with the SPOT imagery

Results: Saltmarsh

Saltmarsh vegetation is composed of halophytic (salt tolerant) species adapted to regular immersion by the tides. A natural saltmarsh system with many of the Annex I and Priority habitats occurring within it shows a clear zonation according to the frequency of inundation. At the lowest level the pioneer glassworts *Salicornia* spp can withstand immersion at nearly every tide, while transitional species of the upper marsh can only withstand occasional inundation of storm events.

The results of saltmarsh identification are shown in Figure 6:26. Saltmarshes as an overall priority habitat were successfully mapped at the coarse (SPOT and IRS) scale; at this scale it was also possible to distinguish between *Salicornia*-dominated saltmarsh, and higher-successional saltmarsh. However, the Annex I habitats were not identifiable using this scale imagery as they occur at too fine a scale or are reliant on plant species assemblages which occur at too fine a spatial scale.

A further study was undertaken using GeoEye imagery with a 2m pixel size. Using the GeoEye image, the saltmarsh category could be divided into three classes; "low saltmarsh" (*Salicornia*-*Spartina* dominated), "mid saltmarsh" (mid-successional) and "high saltmarsh" (least tidal influence). Low saltmarsh (*Salicornia*-dominated) was classified spectrally using the bare mud signal in addition to seasonal vegetation characteristics; this vegetation type was defined by very low productivity in May (IRS scene), and higher (but still relatively low) productivity in September (Landsat scene).

The creek system is also an important component of the saltmarsh environment. It was found that it was possible to map saltmarsh creeks within the saltmarsh environment in detail using one or more of the following datasets: medium resolution image (GeoEye), high resolution image (CIR), or 1m resolution LiDAR.

Results: Atlantic Salt meadows

The highest level of the saltmarsh above sea level forms Annex I class 1330 Atlantic salt meadows which can be seen in the photo in **Error! Reference source not found.**. Atlantic salt meadow vegetation was classified in the high saltmarsh class, which displayed more spectral similarity to grassland habitats. This saltmarsh type was characterised by higher productivity in May, and overall greater seasonal stability. In addition to spectral characteristics, elevation was used to differentiate this class. Figure 6:26 shows the classification.

Error! Reference source not found.. Atlantic salt meadow

Results: Reedbeds

Reedbeds occur alongside the saltmarsh and saline lagoons, they form a part of the case study which will be reported in detail in the final report however, initial results show that with the inclusion of 1m LiDAR within the image stack they can be identified as a separate habitat.

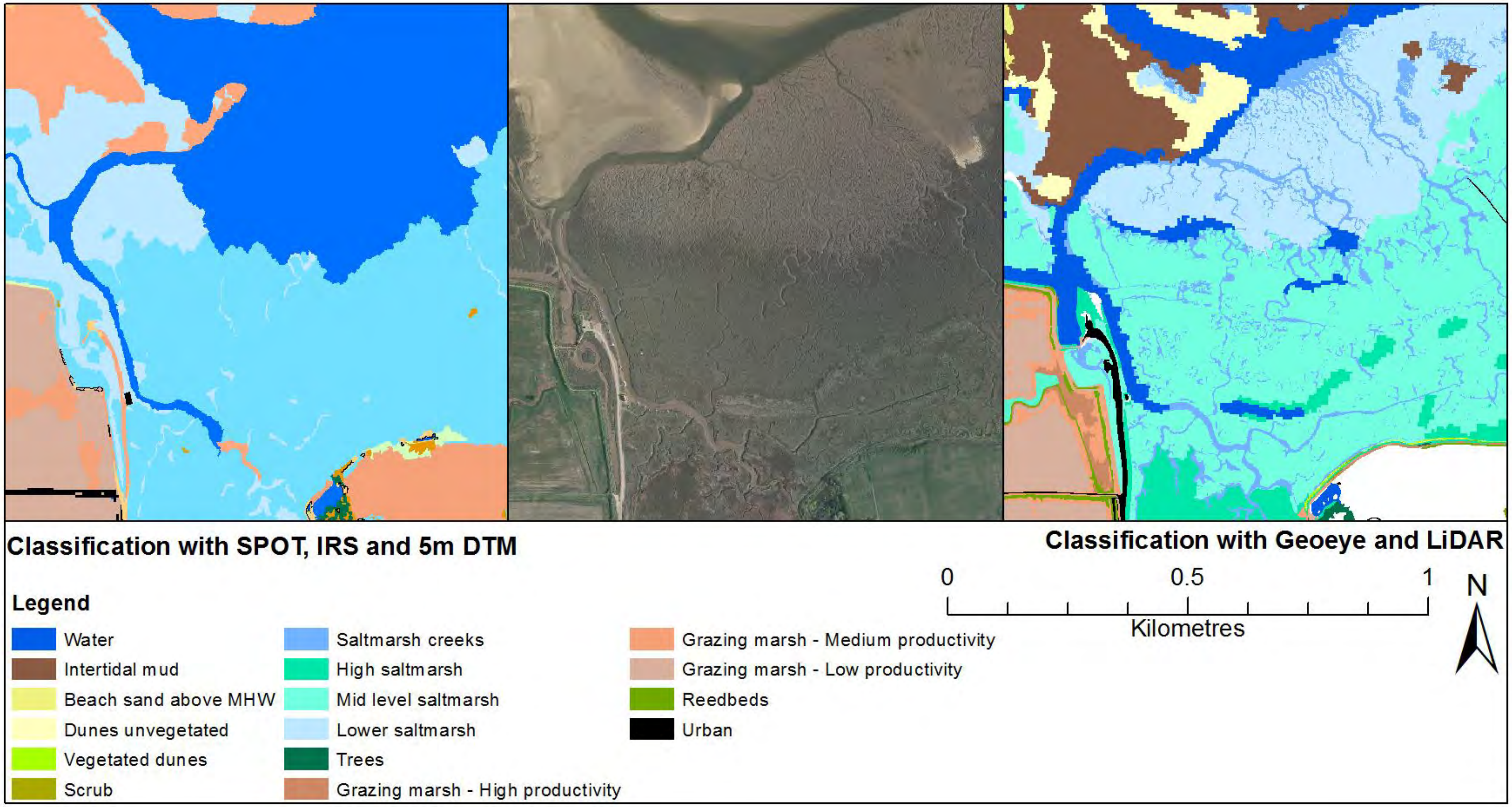

Figure 6:26: Saltmarsh classification showing the difference in spatial scale and classification detail achievable using Landscape Level data (left hand image) and ultra-high resolution imagery (right hand image) The water level varies with the imagery captured at different states of the tide.

Results: Sand dunes

Coastal sand dune vegetation forms an active marine environment and contains a number of zones, which are related to the time elapsed since the sand was deposited and the degree of stability which it has attained together with influence from the local hydrological conditions. Within Priority habitat terms the whole of the sand dune system is one class and this can be identified at a landscape scale of data using SPOT and IRS imagery (see Figure 6:28).

The Annex I definitions identify the different components of the sand dune system. 2110 Embryonic shifting dunes occur mainly on the seaward side of a dune system where sand deposition is occurring and occasionally further inland in blow-outs. These areas support very few plant species with marram grass *Ammophila arenaria* forming the dominant cover. The transition from this to 2110 Shifting dunes along the shoreline with *Ammophila arenaria* can be considered to be found with a certain density of grass cover.

2150 Atlantic decalcified fixed dunes with *Calluno-Ulicetea* forms closed swards on dunes which have become acidified by leaching, as a result acid dune grassland or dune heaths develop. Dune heaths are usually dominated by heather *Calluna vulgaris*. Acidic dunes which are heavily grazed by rabbits may support lichen communities. 2190 Humid slack dune vegetation occurs in wet depressions between dune ridges (see Figure 6:27); it is often characterised by creeping willow *Salix repens*.

Figure 6:27: Sand dune complex with dune slack vegetation

In the absence of grazing, dune grasslands become invaded by scrub species such as sea buckthorn *Hippophaë rhamnoides*. The dune complex is the subject of a more detailed case study. Initial results show that with Geo-Eye it is possible to identify many of the Annex I components of the dune system and this can be seen in Figure 6:28.

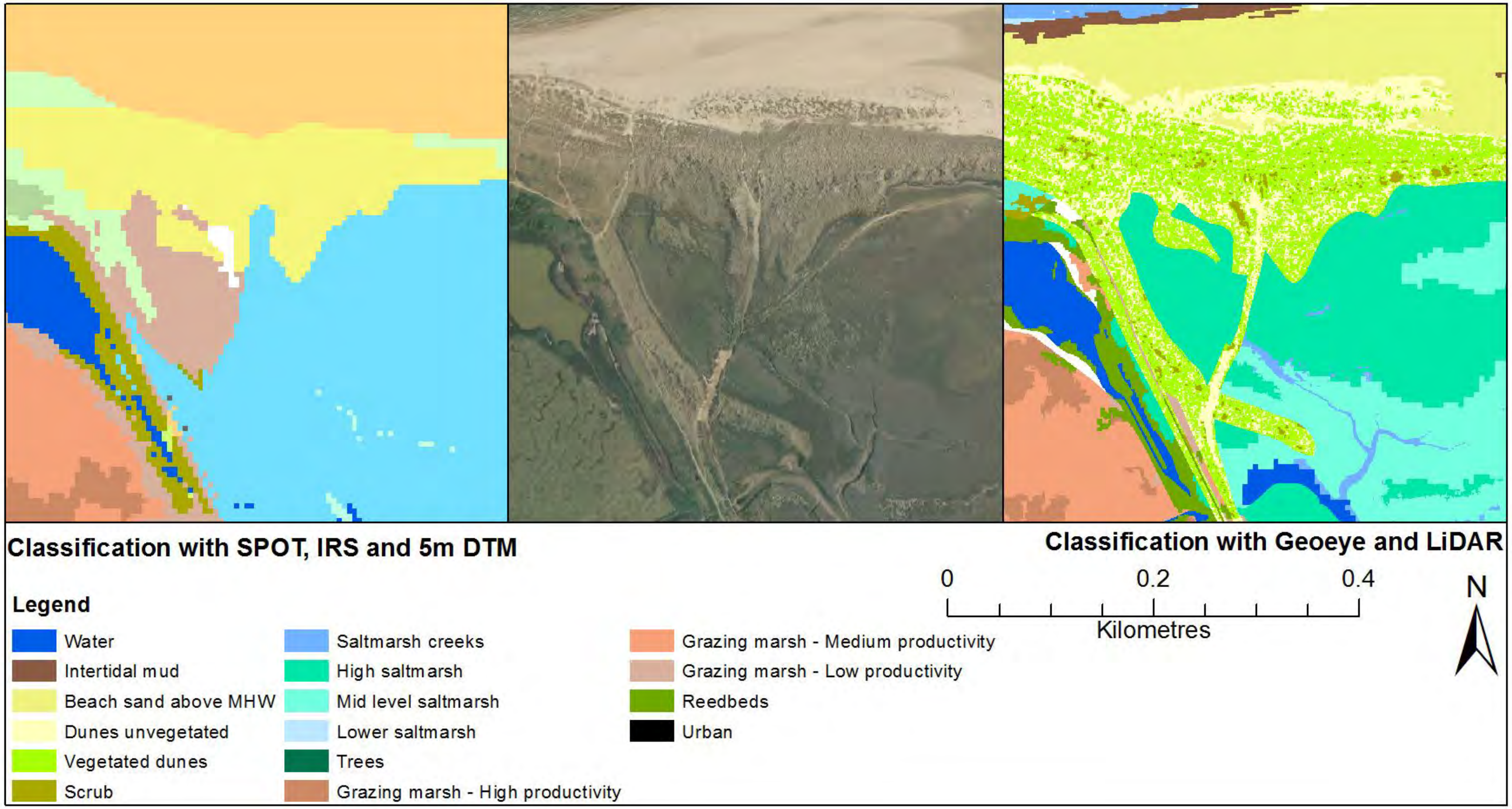

Figure 6:28: Sand dune classification, showing the landscape level on the left and the case study detail on the right

Results: Coastal areas - sparsely vegetated habitats

As part of the examination of the role of UAS imagery and CIR air photography an analysis was undertaken to see if it was possible to pull out the sparsely vegetated Annex I classes:

1210 Annual vegetation of drift lines
1220 Perennial vegetation of stony banks
2110 Embryonic shifting dunes

This type of vegetation can be identified using ultra –high resolution imagery such as CIR photography. It is not possible to identify species, but the presence of sparse vegetation gives a characteristic high NIR signal amongst the shingle. Within the area of the case study all the sediment was fine to very fine sediment size (sand to mud) so it was only possible to evaluate where it is possible to pick out 2110 Embryonic shifting dunes. From a visual inspection the CIR photography did not contain enough detail to differentiate areas of shingle from sand.

Figure 6:29 shows the data from the UAS flight, the 10cm resolution not only picks out the shifting dune vegetation in the RGB, but also shows where children have been making sand castles on the beach (northern edge). The CIR photography from 2010 also shows the marram grass as bright red. The NIR band from the UAS shows vegetation as bright white, there seems to have been a large spread in the dunes over the three years between the imagery.

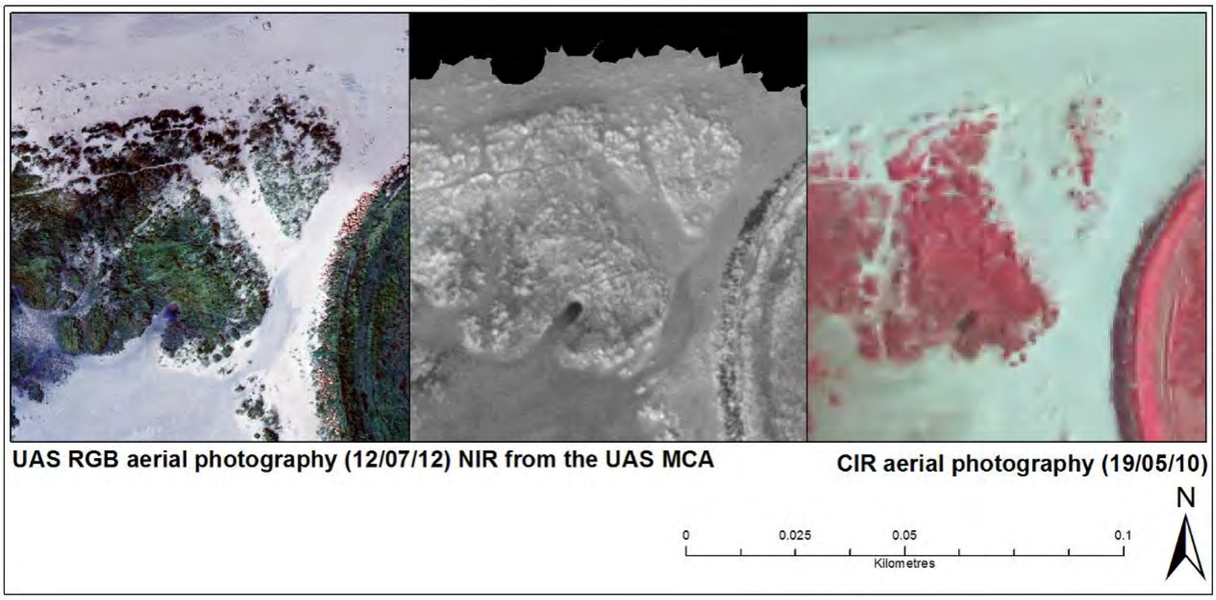

Figure 6:29: Comparison of the UAS imagery and the CIR aerial photography

The level of detail available within the CIR and especially the UAS imagery is sufficient to show up where vegetation occurs on the strand line. However, it is not possible to identify individual species. For embryonic dunes this is not an issue as within this environment all species would be counted as part of the Annex I habitat. It is more difficult to differentiate between gravel, sand and silt from the imagery as their appearance varies with the parent material and the mix of particle sizes present. An interesting further analysis would be to run the comparison again over areas with known proportions of sand and shingle and see if they could be identified at this spatial scale.

Identification of the extent and movement of embryo dunes would be a very valuable tool in determining the extent and health of the system. From the comparison in Figure 6:29 it does appear that much real change has happened in three years. We were able to separate isolated and more dense vegetation from the substrate, but did not have high enough resolution imagery for areas of shingle, to assess if shingle had a different appearance to sand.

Results: Grazing Marsh

Grazing Marsh was historically created by building sea walls and draining the land using ditches and gravity. Where the marshes are managed as low intensity agricultural systems with traditionally managed ditches, they contain a wealth of biodiversity. Some of this biodiversity is habitat related but also supports invertebrates which in turn support winter wildfowl. The photo in Figure 6:30 shows a low intensity grazing marsh with a diverse network of ditches.

Figure 6:30: Photo of Grazing Marsh at Claxton Broad

In many cases the grazing marshes have been very heavily drained and fertilized and these provide much less biodiversity. The productivity of the marsh is therefore indicative of its biodiversity and whether it is considered as part of the BAP priority habitat. Using the high to medium resolution satellite imagery it was possible to identify grazing marsh from within the grazing marsh mask and to type it. This mask was created using the proximity to the Broads or coast and the height of the land above sea level, which are the two controlling factors of winter flooding from a high level in the aquifer. This classification within the East Norfolk Study area can be seen in Figure 6:31. It shows the variation in the productivity of the grazing marsh, allowing both the high quality low productivity grazing marsh to be identified and that of medium productivity which could be restored with active conservation management.

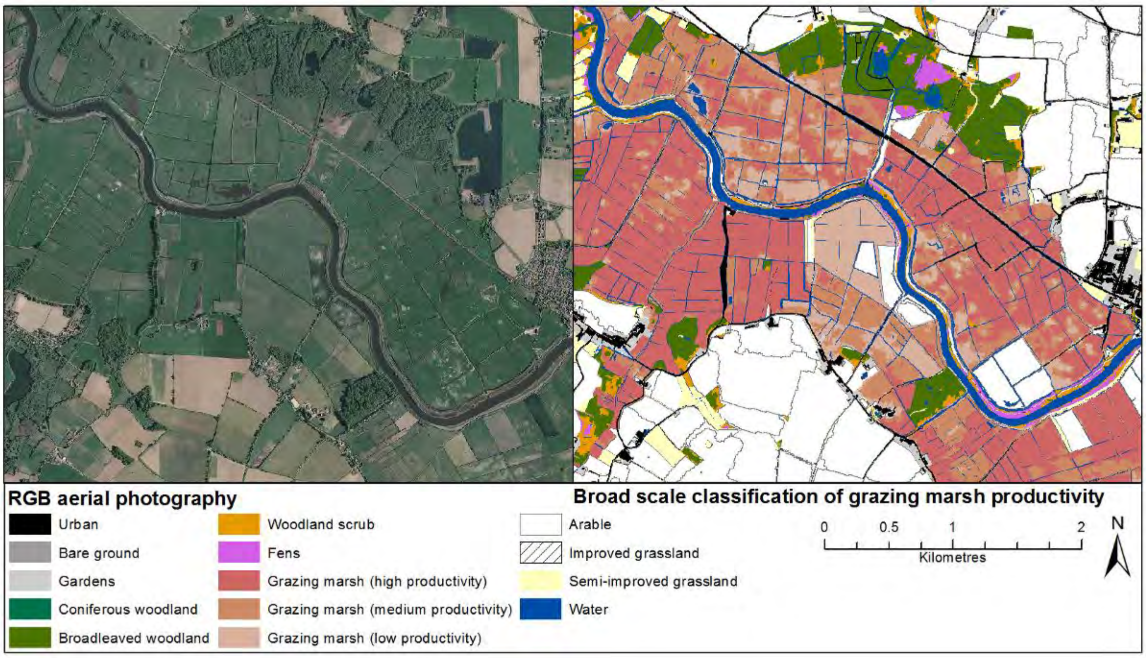

Figure 6:31: Grazing Marsh classification in an area of the Broads, within the East Norfolk study area

Results: application of a hybrid pixel and object based approach in the Broads

A hybrid pixel and object-based approach to landscape splitting as an alternative OBIA classification method was tested for an area of coastal floodplain and grazing marsh, around Halvergate marshes in the Broads. The approach is described in section 4.8.5.

Species rich grasslands are often formed of patch forming grasses, herbs and sedges which have differing heights and phenotypic manifestations. This aspect can therefore be used to separate very species rich grassland from grassland which has been improved at some point in its lifetime. Monitoring the change in land parcel heterogeneity can give an indication of whether one species is becoming dominant or whether the grassland is becoming more species rich, with more habitat patches forming. In addition, grazing marshes have a strong wetland influence which is an important component of the diversity of the field parcel.

The heterogeneity of grassland can be a useful indicator of management practices or site condition. Spectrally homogeneous grassland fields tend to be indicative of more intensive agricultural management. Spectrally heterogeneous fields are often indicative of more extensive management or they may be unmanaged; as a result, they may have higher biodiversity value. Figure 6:34 shows the heterogeneity of field parcels measured as relative entropy (SCENT) calculated on the proportions of the subclasses within the objects. A value of 0 is recorded for an object which contains a single subclass (green) and increases to a value of 1 when an object has equal amounts of each of the subclasses present in the data and is thus the most heterogeneous (dark blue). As this approach only considers the summary statistics it does not include the internal pattern of the subclasses which can be further examined by sub-segmentation or patch statistics.

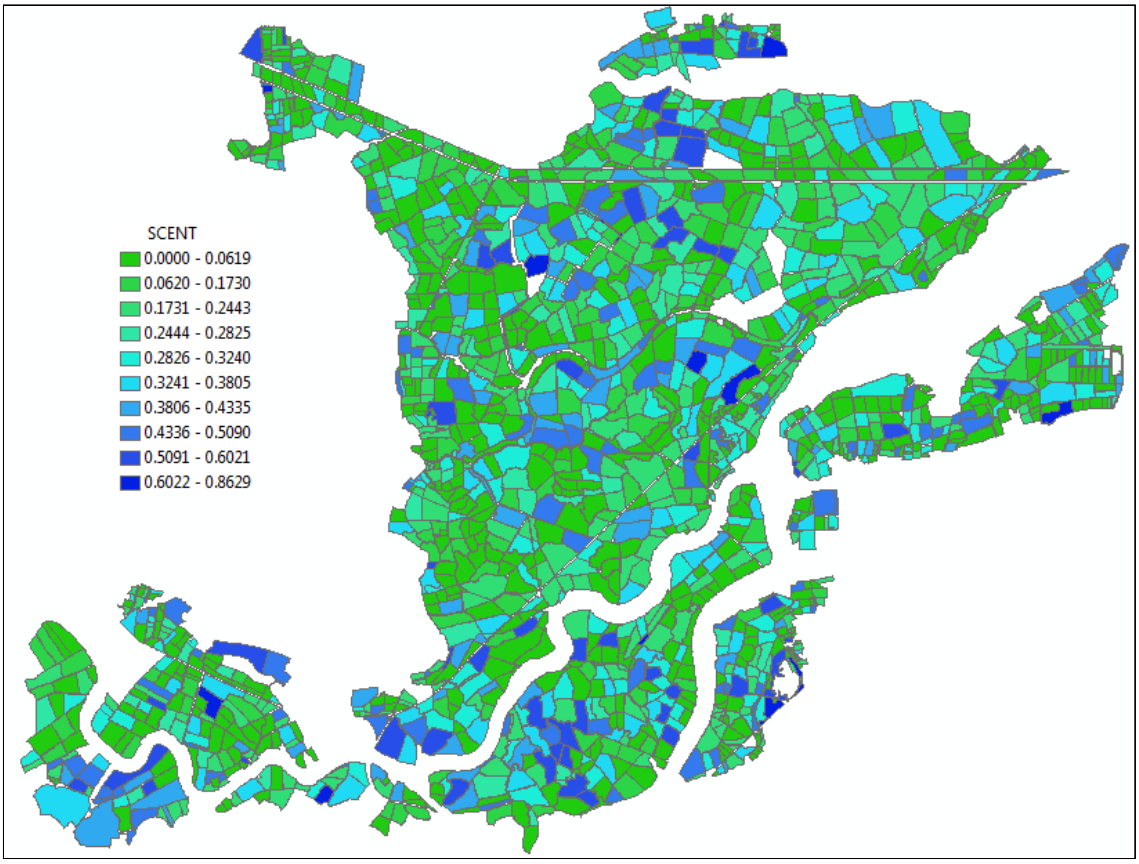

Figure 6:32: Field parcels classified by measures of heterogeneity (relative entropy). The higher the SCENT value, the higher the heterogeneity

Fields with similar levels of heterogeneity appear to be clustered in small groups, which might be expected as their similar conditions may be related to ownership, management or location.

To gain an overview of spectral variation within the grassland objects, both the number of subclasses within a parcel and the relative heterogeneity of fields identified as BAP priority habitat grazing marsh on the ground were examined. The majority of grazing marsh fields are represented by the presence of more than one subclass within them (Figure 6:33) and had a heterogeneity modal value of around 0.3. One fifth of grazing marsh fields comprise a single component and heterogeneity value of 0 suggesting these may be the more intensively managed areas of grazing marsh leading to a more uniform parcel of land.

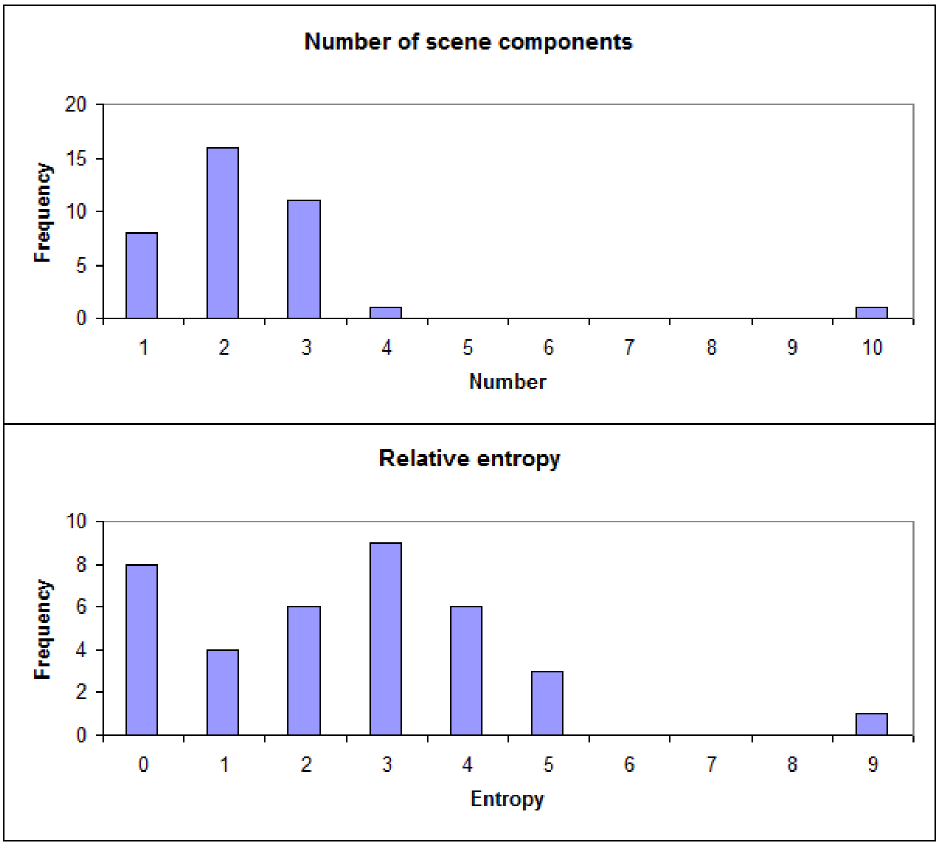

Figure 6:33: Frequency of grazing marsh parcels which contained different numbers of scene components within them and how heterogeneous they were (SCENT relative entropy value)

The approach required ecological knowledge of the grassland types as well as the remote sensing knowledge to interpret the grassland variation into meaningful classes. To identify the "scene components", or classes and subclasses within the landscape and gain an understanding of the amount of spectral information in the data, the dual date image was analysed with an unsupervised per-pixel classification. The resulting clusters of pixels were then identified as 11 land cover classes including grazing marsh, crop, coniferous woodland and a range of subclasses based on visual interpretation of the input Landsat images. There was excessive noise (very small patches of classified land cover) in the data so a majority filter was applied to minimise these. The result provided a good representation of the area, with the grazing marshes of the Broads clearly distinguishable from surrounding cropped areas.

This creates one possible representation of a land cover / broad habitat product and appears to provide a reasonably good correspondence to the known distributions of land cover types within the area. As there is a particular interest in grassland, the full range of grassland subclasses are shown for Grazing Marsh and Rough Grassland classes (Figure 6:34). These have been split based on the mix of their component parts. These sub-classes have not yet been interpreted to attribute them to management type.

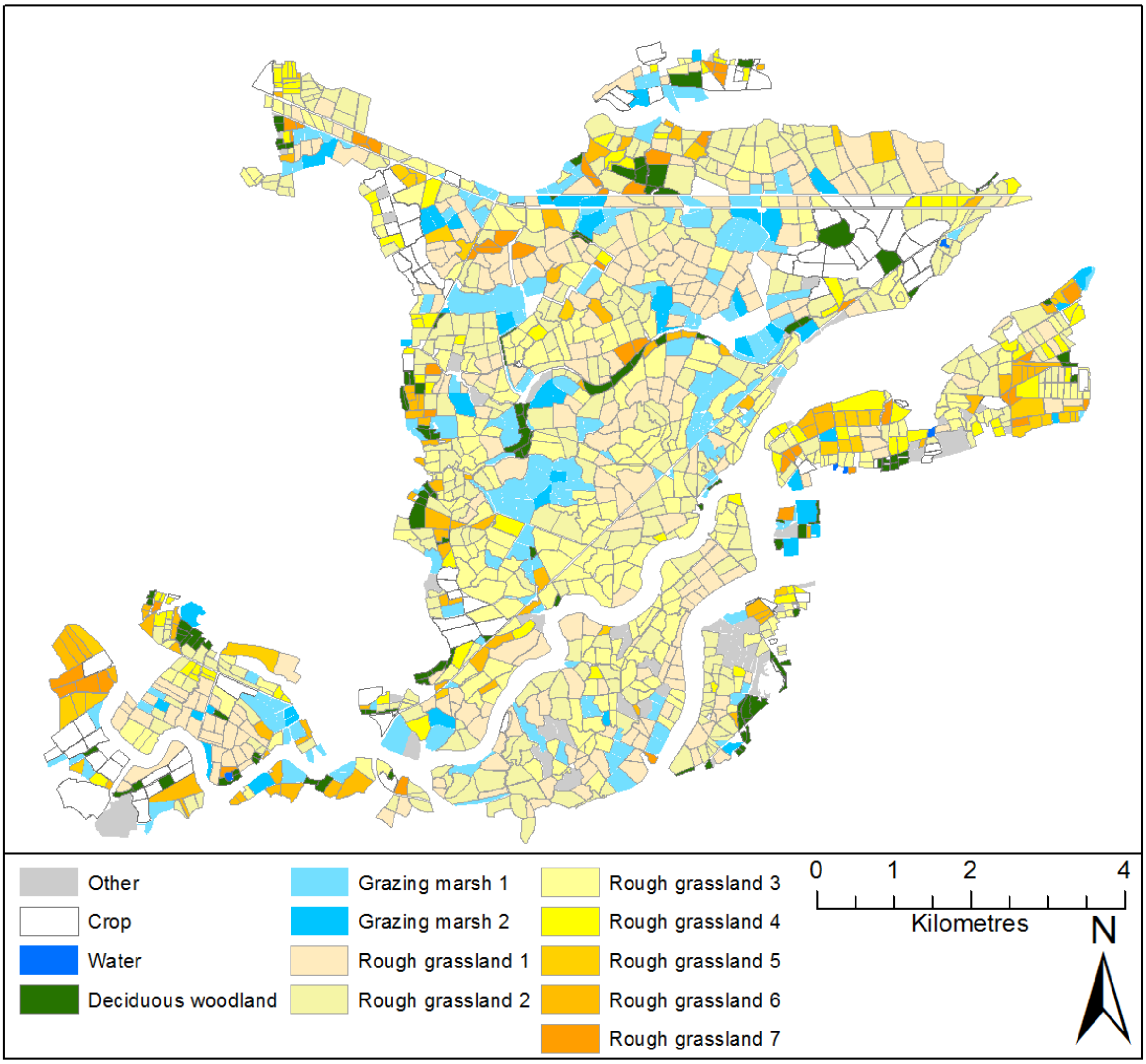

Figure 6:34: Classification of objects by the dominant scene components for an area of grazing marsh in the Broads.

Transferability

Summary of what these findings on environments with a saline and brackish water influence mean for transferability

T13. The general features of these environments (sand dunes, saltmarsh etc.) can be discerned at the landscape scale using medium resolution satellite imagery such as SPOT. However, very high resolution imagery such as GeoEye (1.65m) is a minimum requirement for mapping the habitats in a way that creates boundaries that accord with those found on the ground. This is likely to be the case nationally.

T14. The hybrid pixel and object based approach is based on relatively straightforward and established image analysis and GIS technology and so can easily be adopted by end user organisations. It requires local expert knowledge of habitats and land management to evaluate the usefulness of some of the attributes generated and to interpret classes.

T15. The hybrid pixel and object based approach could be supported by many current sensors such as DMC and future sensors such as Sentinel 2.

6.4.3 Environments dominated by a fresh water influence

For the purpose of the report, results for all wetlands dominated by freshwater are included in this section. Grazing marsh can have a freshwater or brackish influence and is considered under the section on environments dominated by a saline and brackish water influence in this report. Reedbeds also occur in both brackish and freshwater settings and are again are considered within the saline and brackish water section. Wet woodland is considered under the section relating to habitats dominated by woody species, as its main characteristic from the air is from its tree species.

There are high numbers of both Annex I and priority habitat types in fresh water environments in Norfolk (Table 6:5).

Table 6:5: Annex I and priority habitat types found in environments dominated by a freshwater influence in Norfolk

Type of feature	Priority habitat	Annex I Habitat
Wet grass and forb dominated	Purple moor grass & rush pasture Aquifer-fed naturally fluctuating water bodies	**H6410.** Molinia meadows on calcareous, peaty or clayey-silt-laden soils
Fens and Bogs	Lowland fens	**H7140.** Transition mires and quaking bogs **H7150.** Depressions on peat substrates **H7210.** Calcareous fens **H7230.** Alkaline fens
Permanent Freshwater	Eutrophic standing waters	**H3110.** Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*).
	Mesotrophic lakes	**H3130.** Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*.
	Oligotrophic and dystrophic lakes	**H3140.** Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp..
	Rivers	**H3150.** Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation.
	Ponds	**H3260.** Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation.

Summary of key findings and observations: <u>things that worked well:</u>

KF43. It is possible to find wetland habitat types dominated by Purple Moor grass *Molinia carulea* at the landscape scale using SPOT and IRS data.

KF44. Fen vegetation shows as a mixture of marshy grassland, wet heath and scrub vegetation at the landscape scale. It is possible with ultra-high resolution data to separate out the various components of fen vegetation to identify more of the Annex I habitat types.

Summary of key findings and observations: <u>things that didn't work so well:</u>

KF45. Mapping wetland features where they have a tree over-story which is not an important part of the sward, is more difficult with EO, as the signature from the tree canopy dominates the signal, masking the wetland vegetation below.

KF46. Ultra-high resolution data is necessary to identify individual wetland components

KF47. Pingos are so diverse in their ecology, that it is not possible to identify them spectrally.

Results: Landscape-scale mapping

Within the Crick framework the permanent freshwater habitats are generally regarded as Tier 4 features. The attributes that make the specific rivers, lakes and ponds the priority / Annex I habitats rather than the general habitats are normally the occurrence of specific species or specific water chemistry. Individual species, particularly if they are submerged and very small in size are not generally identifiable at the level of spatial detail available for the broad scale mapping. There may be some spectral effect of certain aspects of water chemistry and temperature effects but these are at the stage of active research projects rather than implementation schemes at present. Therefore these aspects are not considered further in this phase.

Mapping the extent of freshwater habitats also suffers from the fact that many rivers and lakes are lined with trees or scrubs. These features dominate the signal from the remotely sensed imagery as it is viewed form above and obscure the outline of the features to a greater or lesser extent. For this reason the water features within Norfolk are taken directly from OS MasterMap.

Results: Fens and Bogs

Bog species in Norfolk are found in mires and fens located in north and mid Norfolk as well as the Broads and form an important part of Norfolk's wildlife heritage. Fens are dynamic, semi-natural systems; water supply together with grazing management is generally needed to maintain species rich communities. Without appropriate management, scrub and woodland species invade the site, changing it to woodland. Norfolk is considered to have the best representation of fen types in England, particularly valley head and floodplain fens. Fen vegetation has declined significantly in the last century, both nationally and across Europe.

Fens fall into two classes 'poor-fen' or 'rich-fen'. Poor-fen describes fens where the water is derived from base-poor rocks and this habitat occurs in the lowlands with heathland. Rich-fens are fed by mineral-enriched calcareous waters. Fen habitats support a particularly diverse array of plants and animals. Norfolk is especially rich in fen habitats, supporting a large proportion of the UK total for certain types. The Broads natural area possesses some 5,000 ha of rich-fen habitat, mostly of the floodplain type, with some examples of valley fen. Rich-fen is also associated with fossil pingo sites such as Thompson Common, East Walton and Adcock's Common and Foulden Common. Elsewhere, numerous rich-fens of the valley head type are found associated with the county's rivers. In north-west Norfolk, about 350 ha of poor-fen is found primarily associated with Roydon Common and Dersingham Bog.

Broad Scale Identification of Fen vegetation

Fens form in a complex of mosaics with areas of sedge rich lawn, reeds, heather species, wet woodland and marshy grasslands, shown in Figure 6:35.

Figure 6:35: Wheat Fen and the complexity of vegetation types

An example of mapped output for one such area is shown in Figure 6:36 from the broad scale mapping. Most of the species are graminoid in nature, and occur on wet soil types. At the broad scale level therefore the general pattern of the fen can be picked up but the detail within it is lost due to the signal being dominated by grassland species. Using just SPOT and IRS, the fen areas are all part of the marshy grassland continuum and are not easily separable. A case study is being undertaken on the Broads to look at using finer spatial resolution data. This is showing initially positive results at separating the different components of the fens and will be reported in the final report.

Poor fens are described in detail at Dersingham in section 6.3.3. Similar findings were made in that where a fine scale of imagery was used, for example GeoEye data, the mosaics of the components of the fen could be easily identified. Within Dersingham Bog there is also an example of a quaking mire. These small features are formed in depressions within the surface and fill with sphagnum to form a floating mat. As an experiment, the UAS was flown with a thermal imaging camera to see if this sort of technology could be used with further development in the future. The results of this case study aspect are described with the condition features in section 6.5.

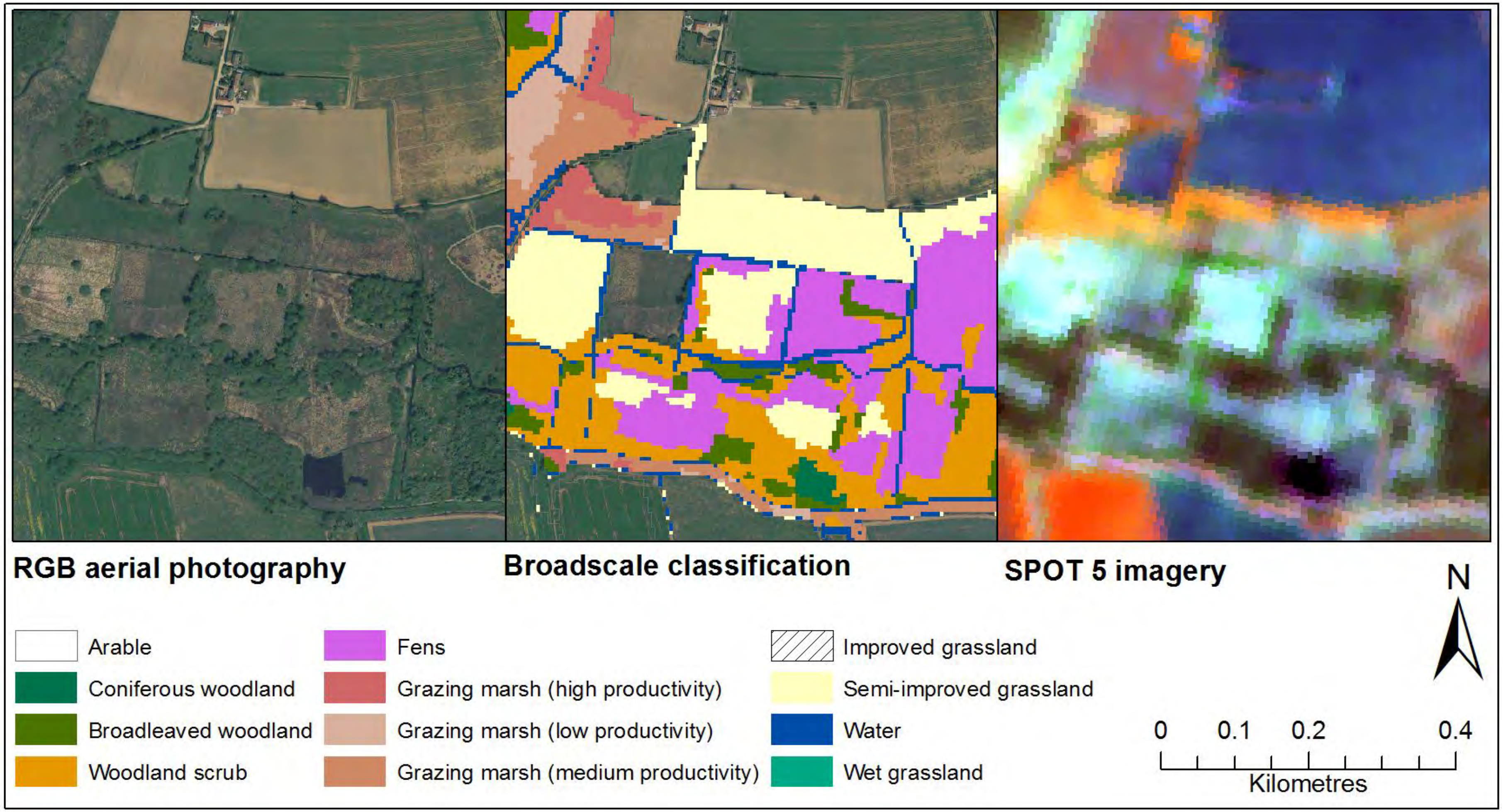

Figure 6:36: An area of the Broads showing the woodland, fen, grazing marsh, arable transitions and the landscape scale mapping compared with the aerial photography on the left and the SPOT imagery on the right

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Pingos

Fossil pingos are peri-glacial features which often support Annex I or BAP habitats including H7140 Transition mires and quaking bogs or H91D0 Bog woodland features, and many are included in the Ponds BAP priority habitat, they therefore have both local and national significance. Pingos were formed by conical ice-cored mounds, which formed in permafrost regions as a result of frozen ground being forced upwards by the growth of a large ice mass as water under pressure froze below the surface. Disturbance of the vegetation and soil as the pingo increased in size caused exposure of the underlying core of ice. When the ice melted, the pingo collapsed, leaving behind a central depression or crater, with a rampart of displaced sediment around the rim. These landforms occurred in clusters, sometimes at a density of one hundred per km^2. Many of these features have an associated fen habitat, but a great many sites have been cultivated or destroyed and a large number have become overgrown and located in woodland. We had little success at identifying pingo features from the air. They either gave a woodland, wet woodland or fen signal and this was not distinguishable from these habitats formed on less important peri-glacial features. Many of the pingos visited for 'training' of the rule base were filled with nettles and consequently had a ruderal signal. The variation of vegetation types within the pingos means these features are not an ideal candidate for spectral separation.

Figure 6:37: Pingo with Nettles *Urtica dioica*

Figure 6:38: Pingo with tree cover

Marshy grasslands and fluctuating water body meres

Marshy grassland dominated by *Molinea carulea* has a very clear spectral signal if early and late season imagery is used. The rules were fairly transferable from those in Wales. In order to understand the priority habitat type, other plant components must be present. This is not possible to ascertain with 10 or 23m imagery. But in the Dersingham Bog case study more information could be extracted from the UAS, this will be reported within the final project report.

The Meres were studied in detail at East Wretham and within the UAS case study the zonation of vegetation around the water body could be clearly seen. With the more detailed imagery such as RapidEye the spatial scale is sufficient to pick up the fact that a mere is present. Tree presence round the edge of some may make mapping of the exact extent difficult without the use of high resolution airborne data.

Transferability

Summary of what these findings on environments with a freshwater influence mean for transferability
T16. At the landscape scale the general pattern of the wetland vegetation can be picked up but high resolution imagery such as GeoEye (1.65m) and a good DTM (1m or better) is required to pick out particular components of vegetation that are relevant to habitat definitions in wetlands.

6.5 Condition measures

This section presents the findings of the part of the pilot that investigated how well EO can measure aspects of sites and vegetation that could be useful in determining site condition. The main routes of enquiry which are presented in this section are:

- Vegetation productivity
    - Normalised Difference Vegetation Index (NDVI)
- Single species stands of negative and positive indicators
    - Purple moor-grass *Molinia caerula*
    - Nettles *Urtica dioica*
    - Gorse scrub *Ullex sp*
    - Birch scrub *Betula sp*
    - Himalayan balsam *Impatiens glandulifera*
- Wetness/dryness
    - Normalised Difference Wetness Index (NDWI)
    - Modified Normalised Difference Wetness Index (MNDWI)
- Freshwater metrics
    - Chlorophyll-*A* concentrations
    - Total Suspended Solids (TSS)

Summary of key findings and observations: <u>things that worked well:</u>

KF48. The use of NDVI measures enabled productivity maps to be produced at a range of scales that allowed visualisation and quantification of the nutrient balance within and around sites. Sources of nutrient risk and mitigation features could be identified at the scales at which they occur.

KF49. The extent of a range of competitive and invasive plant species that can be damaging to sites (such as nettles, Himalayan balsam, gorse and birch scrub and purple moor grass) was classified successfully with a range of types of EO.

KF50. Use of a NDWI allowed mires to be classified into a number of wetness categories.

KF51. Use of a modified NDWI (MNDWI) was found to have the potential to identify wet and dry woodlands.

KF52. The addition of finer resolution imagery "sharpened" and improved the detail of maps of condition measures although care must be taken with interpreting mixed pixel values created this way.

KF53. Producing condition measures and indices from medium scale to very high resolution data allowed condition features to be assessed at the range of scales at which they occur.

Summary of key findings and observations: <u>things that didn't work so well:</u>

KF54. These findings are an initial analysis into potential monitoring tools. More work will be necessary to develop these into robust techniques including:

- Understanding the normal seasonal, daily and meteorological effect on the indices values
- Investigation into calibration for the indices such as using features on the site unlikely to change which can be used as a standard against with which to

normalise image values
- Developing methods to track “out of site” and “within site” condition risk factors by establishing thresholds above which to trigger action

This section examines and provides the results of case-studies to demonstrate how remote sensing metrics can be used to help monitor and manage semi-natural habitats, including those found within the designated sites network within the UK. It focusses on three condition aspects: productivity, single species stands and wetness/dryness of the site and provides the rationale for their use.

These case studies examine how EO can be used to analyse and monitor these site aspects and how these features could be incorporated into standard analysis tools to aid the monitoring of sites especially in large or very vulnerable areas where extensive field survey is impractical or undesirable.

The tools presented allow the identification of external issues which are adversely impacting on the site, and how they could be used to highlight sites which are at high risk and therefore require more immediate attention.

Four condition monitoring case studies involved the use of high and ultra-high spatial resolution data including UAS flights using multi-spectral imaging at 0.1m resolution and satellite imagery, including SPOT 5 at 10m and RapidEye at 6.5m.

6.5.1 Context

Maintaining and enhancing the ecological condition of semi-natural habitats and avoiding their loss or deterioration, is vital to maintaining ecosystems services. Country biodiversity strategies set out the activities in place to achieve this. Habitat surveillance and monitoring provides evidence to support the delivery of outcomes required by these biodiversity strategies. There are legislative requirements to assess the ecological condition of habitats of particular importance. Norfolk, for example, contains 124,654 ha of Special Areas of Conservation (SAC) which have to be assessed regularly for Article 17 reporting of the Habitats Directive. In many cases, the same area of land is protected by more than one designation; the basic building block is the SSSI, which underpins the vast majority of the international site designations. Country conservation agencies provide regular surveillance of protected sites, using techniques such as common standards monitoring (JNCC, 1998).

Surveillance and monitoring of the condition of non-statutory sites of conservation importance is also carried out, being the responsibility of both national and local government organisations (for example Local Sites and habitats under agri-environment agreements).

Monitoring the ecological condition of semi-natural habitats is a time consuming process using standard field techniques. EO provides several useful techniques which in turn will produce evidence layers that could assist the condition monitoring process within the UK.

Designated sites and other patches of semi-natural habitat in the wider countryside contain semi-natural vegetation as associated habitats. These habitats rely on the integrity of natural systems such as nutrients and water cycling. They are at risk from pressures from the surrounding land use, such as intensive management and development.

6.5.2 Rationale for the condition measures selected

Previous research has established that remote sensing is particularly useful for measuring some aspects of sites and vegetation that have been found to be useful in determining site condition. These include:

- Vegetation productivity
- Single species stands of negative and positive indicators
- Wetness/dryness

Research also suggests that EO data can be used to quantify vegetation aspects such as the “woodiness / leaf shape” and “living / dead” material present within the sward. When applied to habitats, these features are useful for assessing condition as they assist in identifying species assemblages. As such they form an important part of the classification of single species stands and are included within section 6.5.4.

Vegetation Productivity

Vegetation productivity can be used as an indicator of the nutrient status of sites. Sites with important semi-natural vegetation generally have low productivity as the soils contain low levels of nutrients, especially phosphorus and nitrogen.

Vegetation in species rich habitats are generally characterised by stress tolerant species which occur in abundance and add significantly to the biodiversity. They tend to have less vigorous growth cycles than areas with a higher nutrient status, where one or two competitive species become dominant.

Therefore measures of productivity within the site can be used to describe a range of different aspects all of which pertain to the good condition of the site including:

- distribution of low productivity vegetation consistent with the habitat under study;
- any more vigorously growing plant species,
- patches of bare ground,
- single species stands of highly competitive invasive plant species,
- the productivity of the site as a whole, which can identify habitat or site system nutrient budget issues,
- productivity hot spots in the area surrounding the site, which can identify risks to the site from nutrient enrichment.

The nutrient balance can be disturbed within a site containing semi-natural vegetation in a number of ways and from a number of different sources:

- active intervention, such as fertilizer application,
- heavy grazing and dunging,
- through leaching from a site via the water table,
- surface runoff from neighbouring heavily fertilised areas,
- through atmospheric processes (e.g. nitrogen deposition).

Productivity can also be related to the presence of invasive species which form large single species stands, which can be considered indicators of the site being in poor ecological condition. As these species form in stands large enough to occupy several pixels within the imagery and have distinct spectral signature they can be readily mapped and monitored using EO. Many sites have single species stands of desirable species such as common heather *Calluna vulgaris*, and again EO provides an ideal tool to monitor the extent of these stands.

Single species stands of negative and positive indicators

Single species stands of vegetation can be classified well by EO. For habitats which are dominated by one main cover forming component, such as heather on heathland sites EO is already established as a very useful tool for classifying the habitat and mapping its extent (Sections 6.3 and 6.4). This section focuses more on single species stands of vegetation which are considered to be negative indicators of ecological condition.

Wetness / dryness

Wetness and dryness of a site may also be a major factor maintaining ecology and controlling the development of the interesting ecology. Spring lines, flushes and mires forming in wet hollows alongside slightly dryer ground, lying only a few centimetres higher, mean that the water regime can lead to many different conditions within a quite limited geographic area. Any change in wetting or drying of these sites affects the balance of the ecology and can lead to loss of diversity. Drying occurs through drainage, or through general climatic changes, which can directly or indirectly affect the water table of the site. Wetting can be associated with occasional flooding events, changes in the water table or as the result of water movement changes higher up in the catchment.

Scale at which processes occur

Each of these three features can be important in describing protected sites and they can therefore be used as indicators of the ecological condition. These aspects can be seen to interact with sites at three scales; features within the site, the condition of a site as a whole and the condition of the area surrounding the site that impacts upon it (Figure 6:39).

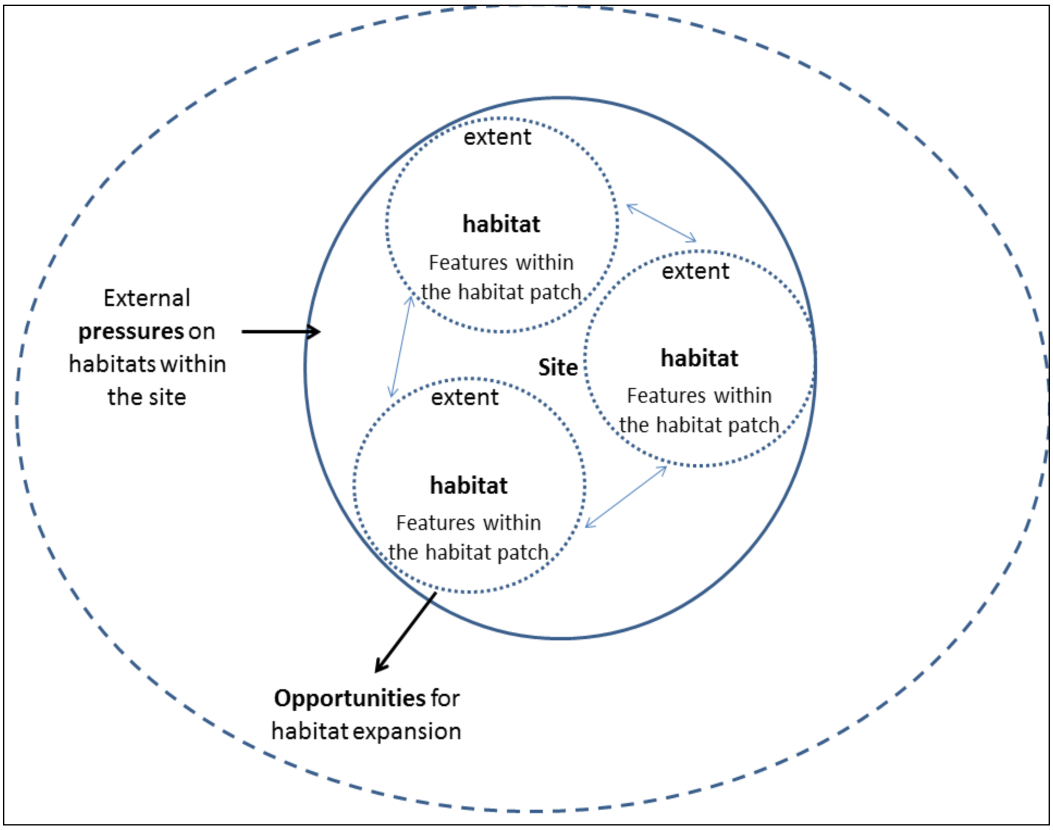


Figure 6:39: Processes present around and within a site

6.5.3 Results: Site-based Case studies of productivity

Vegetation productivity is one of the key indices used in EO analysis. It is easy to describe with EO data due to the relationship that exists between the reflectance of NIR light (which passes through the leaf and is reflected off the lower surface) and red light (which is absorbed by the chlorophyll in the leaf and used in photosynthesis). This is illustrated in Figure 3:2 in section 3.5 which summarises key EO theory.

Box 6:1 describes the Normalised Difference Vegetation Index (NDVI), which is the main technique used for quantifying productivity from EO data. Measures of vegetation productivity derived in this way can be used to quantify how productive the vegetation is, allowing un-vegetated surfaces to be easily separated from vegetated ones and differences in stands of vegetation within habitat patches to be separated. A time series of data showing when species are in full growth and when they are senescent allows different types of vegetation to be separated from one another based on phenotypic variation.

Box 6:1: Productivity technique 1 - NDVI

Normalised Difference Vegetation Index (NDVI)

What it is

The Normalised Difference Vegetation Index (NDVI) is a well-established spectral index, it summarises the relative red and NIR reflectance values.

$$NDVI = (NIR - Red)/(NIR + Red)$$

Why we think it's useful

The NDVI is related to vegetation productivity and has been in use for many years to measure and monitor plant growth (vigour), vegetation cover, and biomass production from multispectral satellite data. Chlorophyll in plants absorbs red light from sunlight, whereas the mesophyll leaf structure creates considerable reflectance in the NIR band (Tucker, 1979). As a result, vigorously growing healthy vegetation has low red-light reflectance and high NIR reflectance, and therefore a high NDVI value.

Using NDVI as a condition monitoring measure

NDVI can be used as a tool to record relative changes in productivity on sites, which could be of benefit to site managers to identify and quantify the extent of change as part of their monitoring. Further work is required in calibration steps to allow the NDVI of different images to be directly compared.

Figure 6:40 shows the surface of the fen at Dersingham Bog as it appears in the NDVI and in the RGB imagery that was captured by the UAS in mid-summer 2012. Much more variation in the vegetation can be seen in the NDVI layer than in the RGB, the brighter the area, the higher the NDVI value. The brighter and therefore more productive areas that can be seen on the fen surface will contain more graminoid species. Trees at the waters edge (in the north west of the image) also have a very high productivity in mid-summer. Repeating the flight at a similar time of year in future will show any patterns of change in the productivity for the area. If nutrient rich water begins to affect the site then productive species such as purple moor grass *Molinea caerulea* will be favoured. These changes will be clear from a visual comparison of images however, the NDVI values within the images can be used to measure the direction and extent of any change. Objects within the site can be tagged with their NDVI value, and relative values can be compared. NDVI values from repeat flights can potentially be calibrated against features unlikely to change (such as mature trees), to provide meaningful comparisons of productivity change year on year, however, further work is required to assess the robustness of such calibration and therefore its use as a monitoring tool.

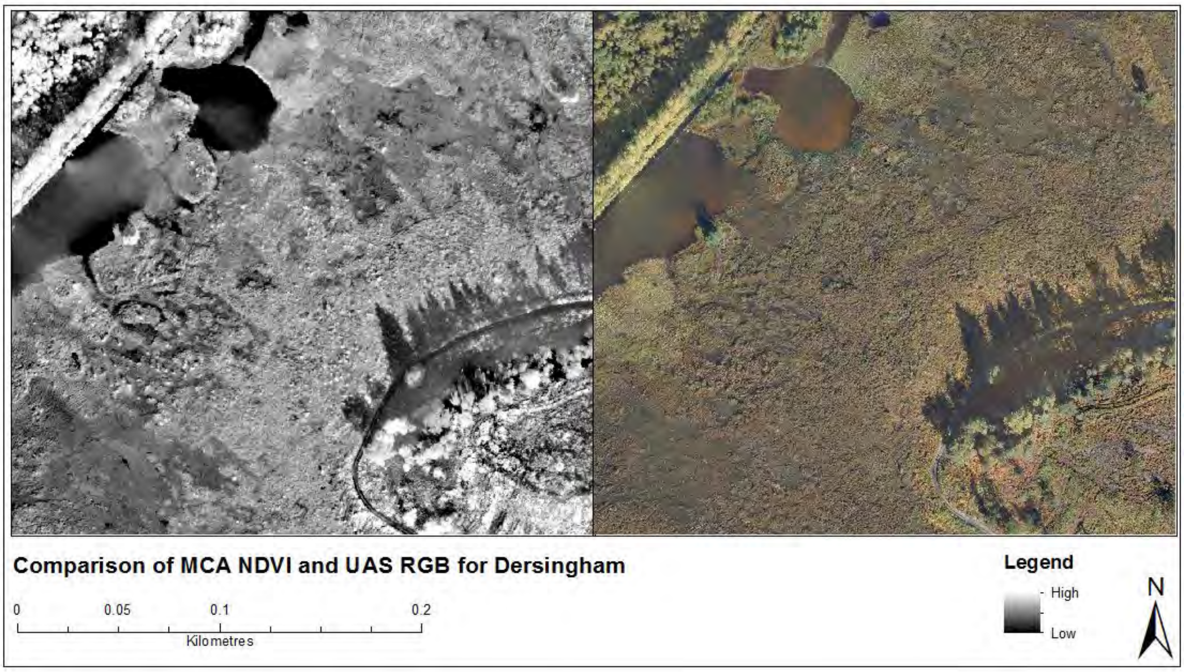


Figure 6:40: Detailed comparison of the fen surface at Dersingham Bog captured by the UAS showing areas of higher and lower productivity

Figure 6:41 shows the NDVI at Dersingham Bog at three different scales, the UAS on the left at the finest spatial scale, GeoEye in the middle and SPOT 5 on the right at a broader scale. These images demonstrate how EO indices can help identify both risk and mitigation features which may not be as easily seen in a RGB photograph or vegetation map. The SPOT 5 image taken in March is the broadest scale and shows the NDVI of the surrounding vegetation as well as of the site. In this March image the fen appears very dark compared to the arable fields to the North West; these surrounding fields could represent a risk of nutrient input to the fen system either from the water or air. This shows that 10m scale data is useful for looking at the land surrounding the site to identify possible risk areas. Comparing spring and/or autumn imagery can be very useful in this landscape context, as the managed arable systems with fertilizer application are much more productive than native vegetation at this time. At Dersingham, the bank of trees between the improved fields and the fen site is probably playing an extremely important role in regulating nutrient input to the site.

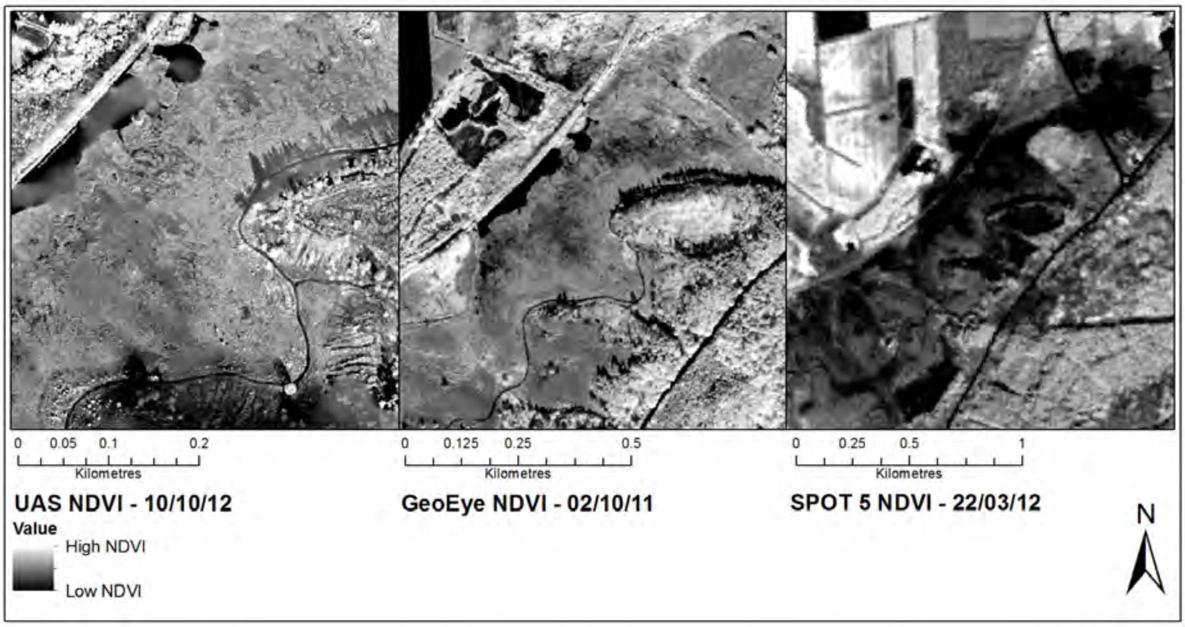


Figure 6:41: NDVI from different scales of imagery at Dersingham Bog which contains fen vegetation

Productivity is significant within a wetland / heathland site such as Dersingham Bog. It is even more important as the major defining aspect of grassland systems such as those found within Breckland heaths, which are characterised by a very open grassy sward, rich in forbs, maintained by the nutrient poor dry sandy soils. Within grassland sites such as these, NDVI becomes an even more significant management tool.

The images in Figure 6:42 show NDVI layers for East Wretham Heath at three different scales, the UAS on the left at the finest scale, RapidEye in the middle and SPOT 5 on the right at a broader scale. The images have been captured at different times of year, grassland system growth cycles must be taken into account when comparing and interpreting them. The UAS NDVI image highlights within-site variation, the dark areas have a very low NDVI values and are bare or have very sparse vegetation. They include the recently mown area in the middle of the fluctuating mere to the left of the image and the small patches of bare ground caused by rabbit disturbance. The RapidEye image shows variation over the whole site, the mere can still be seen and the Heath appears darker with a much lower NDVI value than the surrounding farmland to the north and south of the site. The SPOT 5 image shows variation in the surrounding landscape, with the fields to the north very dark as they have just been ploughed. The woodland to the North West and South East of the mere is appearing darker than the grassland of the Heath; this is because in March the grassland is growing more vigorously than the woodland.

The pattern of bare and disturbed ground formed by rabbit grazing is critical to maintaining the condition and species distribution of these Breckland heath grasslands, drawing sub-soil to the surface and preventing organic matter from developing. The NDVI images show bare ground as very dark and can therefore be used to evaluate of the current extent of soil disturbance.

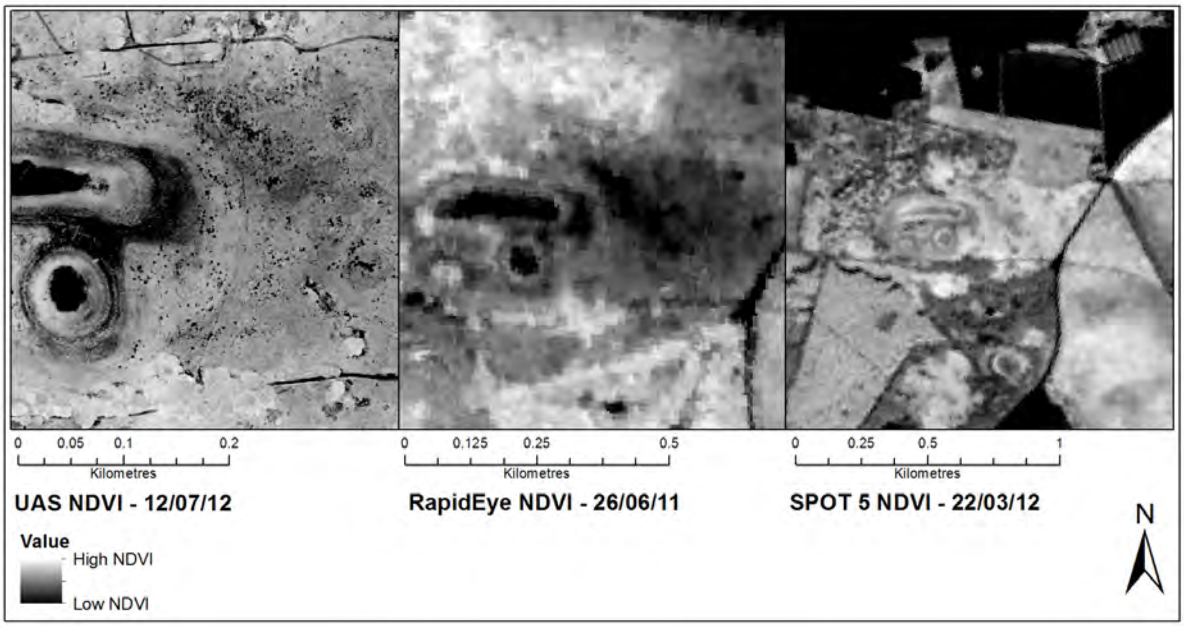


Figure 6:42: NDVI images derived from different scales of imagery at East Wretham SSSI

The grassland at East Wretham has been divided into three categories of productivity based on the range of NDVI values which can be seen in Figure 6:43. These categories relate to the proportion of grassland to bare soil present on the ground and as such present a potentially useful monitoring tool as they would allow areas with high productivity grassland to be identified. Such grassland areas within the site may have become rank or nutrient enriched and would require vigorous active management to recreate open swards.

Analysing the NDVI also enables monitoring of the extent of bare ground. In this context extensive rabbit grazing keeps bare ground present which allows seeds to germinate that would not grow through a closed sward. In other grassland settings it can allow for the identification of areas of overgrazing.

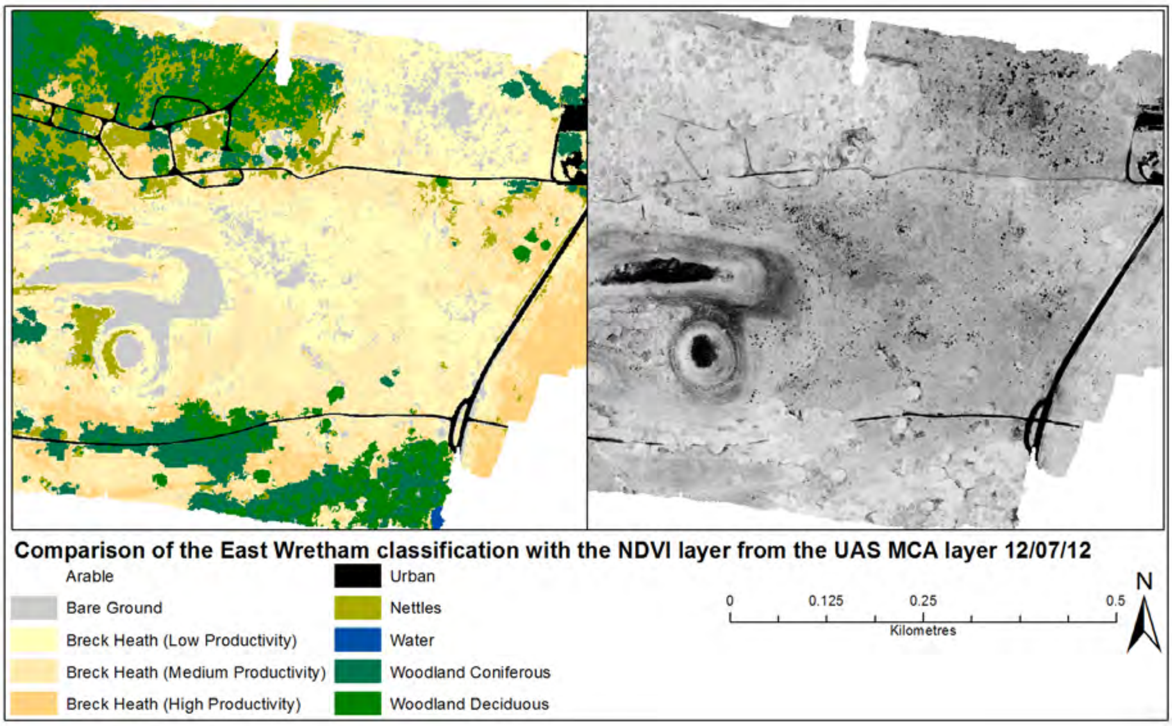


Figure 6:43: East Wretham classification derived from NDVI values of the MCA UAS imagery

The third case study area around Surlingham Broad covers a much larger area than the previous two study sites. The NDVI images in Figure 6:44 show the NDVI at three different spatial scales and show differences in seasonal productivity between arable and semi-natural grasslands. These images highlight the importance of timing of image acquisition if NDVI is to be used as a condition measure for a mainly grassland dominated system.

The spring image (SPOT 5 image on the right) highlights the difference in productivity between the semi-natural vegetated area and the arable land. At this time of year, productivity is much higher for arable areas where fertilised crops are growing vigorously (much more quickly than the semi-natural grassland), while some of the arable fields are still bare, with very low NDVI, having just been ploughed for new planting. By mid-summer (RapidEye image in the middle) all the vegetation is at full growth and differences between the grasslands, swamp and arable fields are much less distinct. The images show a fringe of higher productivity, alongside the edge of the Broad itself as a brighter band, this is more noticeable in the March SPOT image as the surrounding arable land is less productive. This may be due to the occurrence of nettles, which are particularly a problem where the dumping of dredgings might have occurred. Within the UAS image macrophytes in the water can be seen as pale areas within the Broad itself. The NDVI is usefully demonstrating risk factors and additional features not immediately apparent from the RGB photography alone.

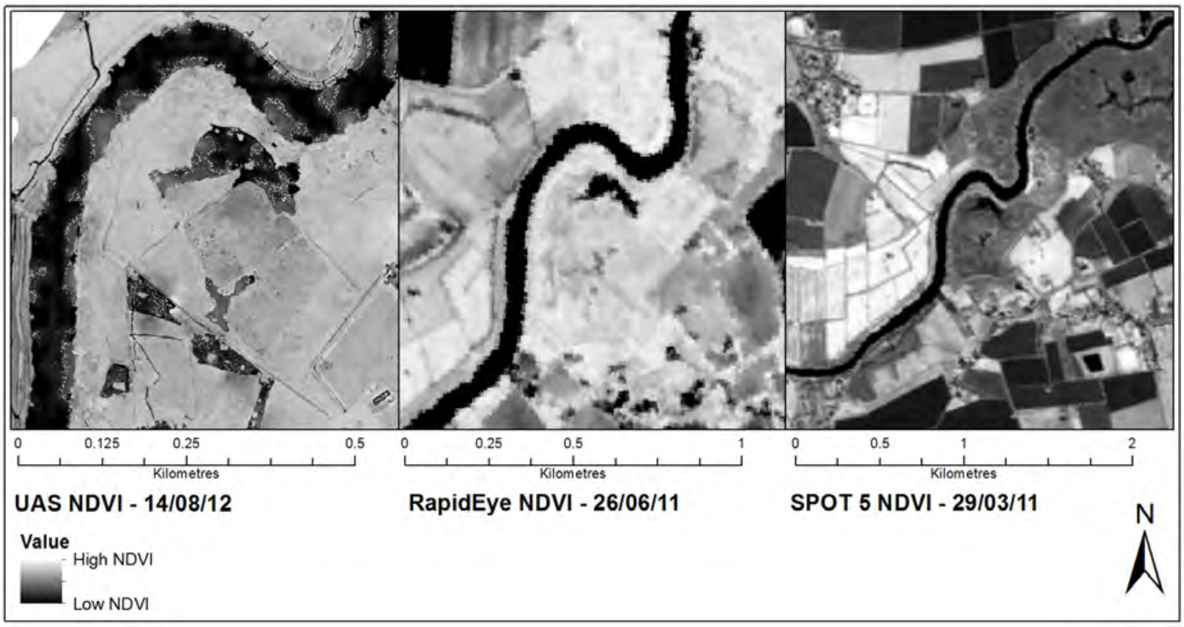


Figure 6:44: NDVI from different scale imagery at Surlingham Broad

6.5.4 Case study: Single species stands

Negative "ecological indicator" plant species tend to have very specific phenological characteristics which can be used to separate them from the surrounding vegetation in EO analysis. These species tend to be highly competitive ruderal species that have a rapid growth cycle, produce large quantities of dead plant material and they occur in stands large enough to be picked up using EO imagery.

The extent of these species can be difficult to quantify from the ground as they can form dense mats of vegetation and are often too high to see over and too dense or prickly to walk through. Mapping them from above using EO analysis therefore offers potential for what is a recognised mapping issue in techniques such as common standards monitoring (Parker *et al.* 2010).

Although these species have a specific character which can be used to separate them from the surrounding vegetation, a specific rule or an "out-the-box" metric approach is not as suitable as it is for assessing wetness and productivity. The context of the stands must be considered and the classification system must account for features with a similar spectral characteristic that are not relevant; these are often referred to as "anti-confusion" rules. The stages for developing such rules are set out in Figure 6:45.

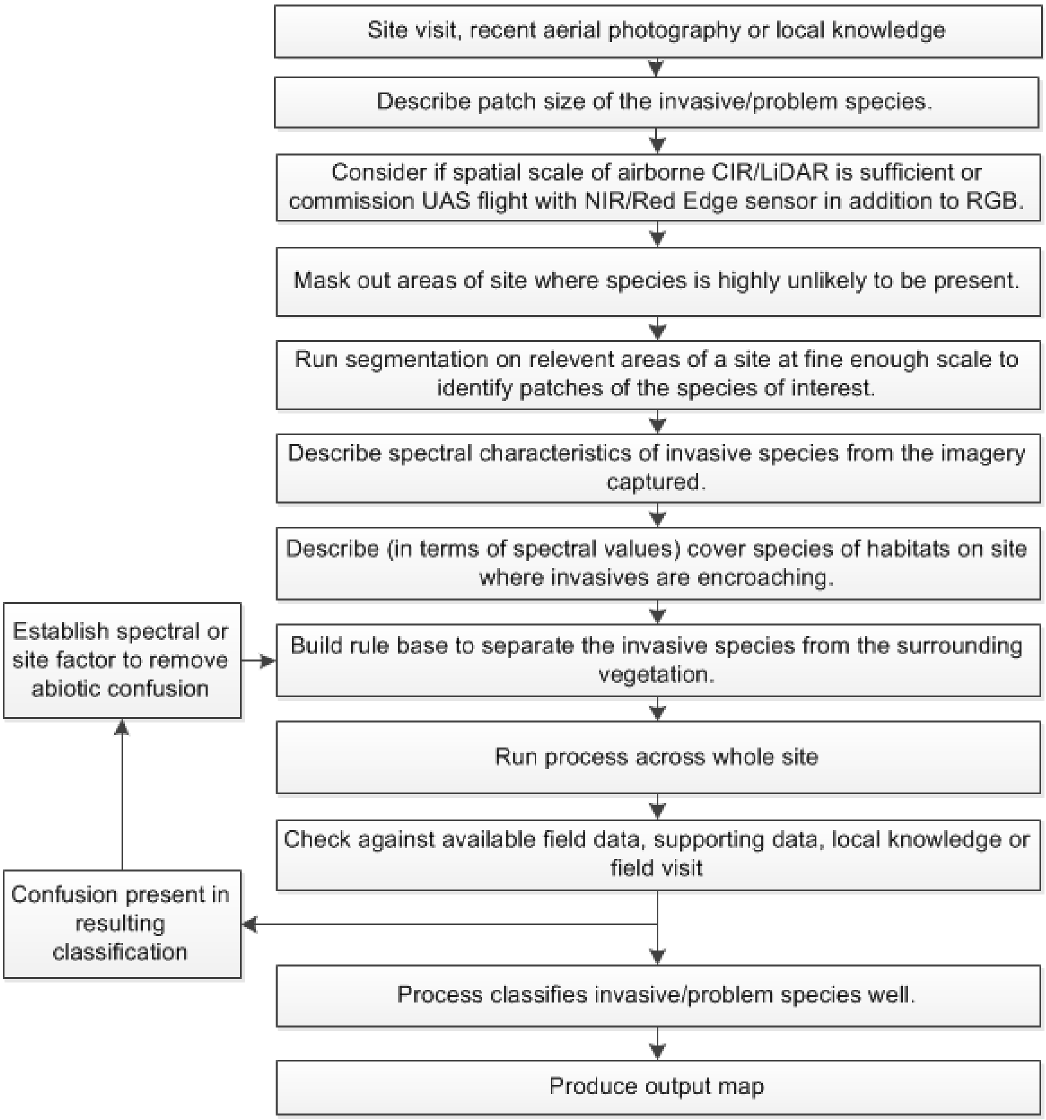


Figure 6:45: Process for creating rules for specific single species stands

As a tool for monitoring these species provide useful indicators for seeing if the competitive plants on a site are extending within the site area, outcompeting more interesting species over time. A baseline extent is therefore useful for comparison to be made in the future.

Molinia

Molinia caerula (purple moor grass) is a graminoid species that grows in wet conditions such as bog surfaces. Although it is a normal component of many mire systems, it can in some situations act as an indicator of nutrient enrichment and changes in the hydrological regime in the bog surface. *Molinia* is more competitive than sedges and other desirable bog species. It also flourishes where the water moves through the system and fluctuates slightly. It can therefore compete well when the hydrological regime of the wetland is changing and drying out. It also has been found to become more prevalent under heavy grazing regimes as the surrounding plants are grazed out in preference, leaving this unpalatable species to spread. Generally if the *Molinia* is scattered throughout the site as part of the mosaic it is a positive component, whereas when it occurs in dense tussocks it might be more of a negative indicator, although ideally this should be interpreted by the site manager. Figure 6:46 shows a fieldwork photo of an area dominated by *Molinia* at Dersingham. The *Molinia* has colonised an area which is slightly higher than the fen surface, and is therefore drier.

Figure 6:46: An area of *Molinia caerula* on a drier area of Dersingham bog (photo taken May 2012)

Molinia can be classified using EO data as it is more productive than the other wetland vegetation in mid-summer and leaves pale dead vegetation with a distinctive signature for much of the rest of the year. This growth cycle can be used to separate the *Molinia* from other vegetation as can be seen in Figure 6:47.

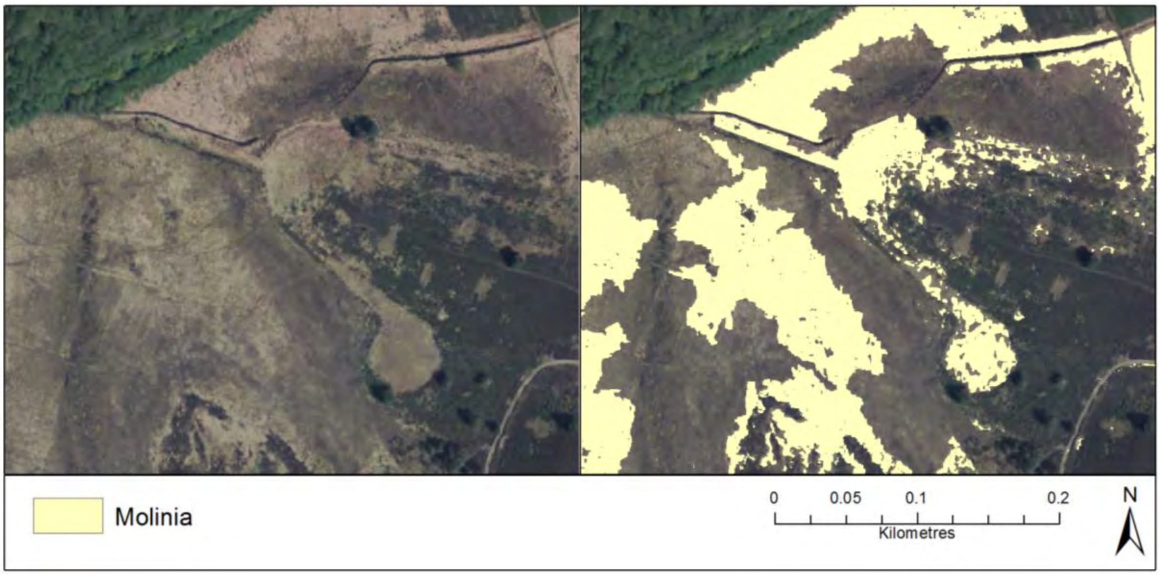


Figure 6:47: Classification of *Molinia* on the bog surface at Dersingham compared with the RGB aerial photography

Nettles

Common nettle *Urtica dioica* is another indicator of poor site condition. They occur in disturbed areas which have a high nutrient burden and grow vigorously in areas rich in phosphorus and nitrogen. The photos in Figure 6:48 show nettle growth at East Wretham.

Figure 6:48: Nettles at East Wretham Heath

Nettles are strongly linked with enhanced nutrient burdens to the site, which are often associated with unsuitable animal grazing regimes and associated dunging areas as well as from aerial or water deposition from adjacent land. The pattern of nettle distribution and change in the extent of this is therefore a good indicator of site condition. At East Wretham Heath, many areas of nettles surround fallen trees or are found in the base of the meres themselves, which are often under water. During the few years leading up to 2012 these meres have been dry all year and the bare soil and readily available nutrients from the aquifer-fed water provided ideal conditions for nettle growth. Figure 6:49 shows the results of classification of ultra-fine UAS imagery to identify areas of nettles in the East Wretham heath case study site. The UAS RGB image is provided for comparison. Many of the nettle patches have been manually cut within the reserve to control their spread and these are shown as large patches of bare ground.

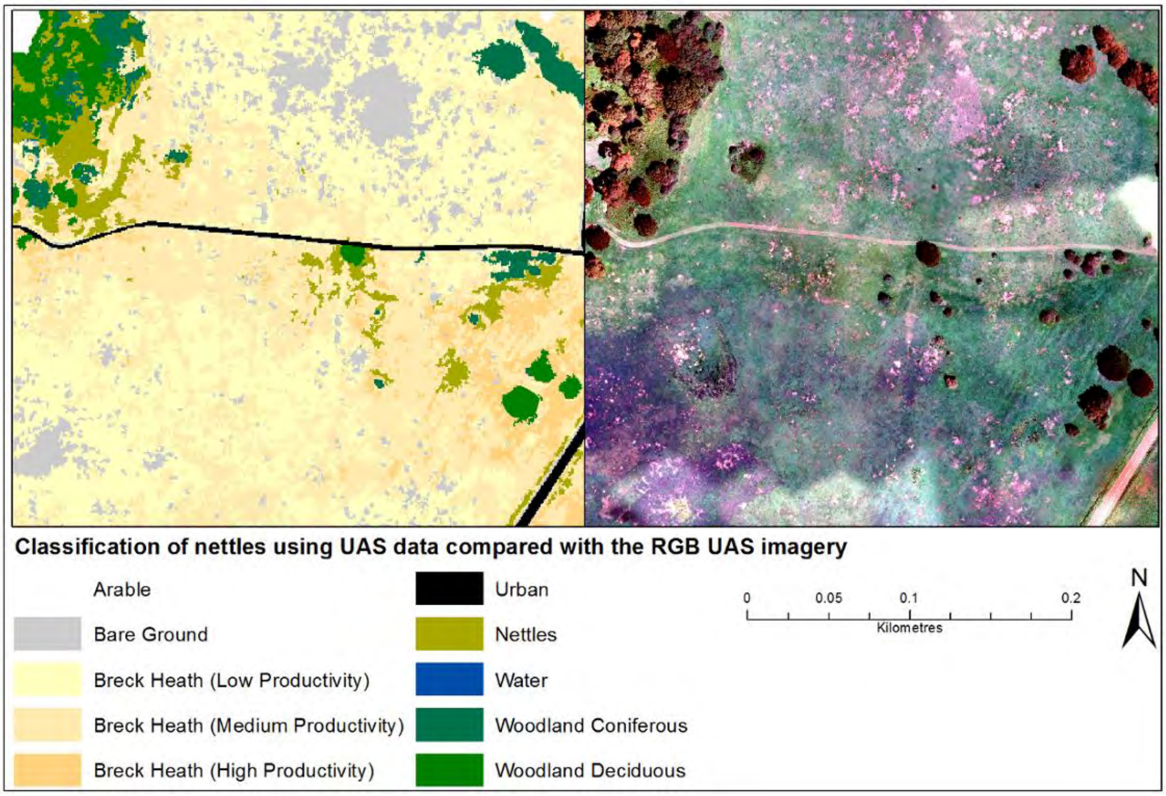


Figure 6:49: Example of classification of nettles at East Wretham Heath

Gorse scrub

Native gorse scrub species, western gorse *Ulex gallii* and dwarf gorse *Ulex minor* are a natural component of many habitat mosaics, in particular of heathland habitats, where small quantities of gorse add to the structural diversity of the habitats. However, common gorse *Ulex europaeus* is a competitive species and under management regimes where less vigorous plants are preferentially grazed, it can spread to make dense impenetrable stands of little conservation value. Once gorse has colonised a site it is extremely difficult to remove it completely and therefore active management is needed to keep it under control. Figure 6:50 shows gorse on the fringe of Wheat fen.

Figure 6:50: Gorse scrub on the fringe of Wheat Fen

The distribution of gorse scrub derived from EO has the potential to become an important monitoring tool. A dense stand of gorse can be over two metres tall and on flat sites where its distribution is a problem it is extremely difficult to map its distribution from the ground. Using multi-spectral EO data it is possible to develop rules to pull out the very dense large gorse stands from their spectral and textural characteristics at any time of year while in RGB imagery many species are only visible while in flower (shown in Figure 6:51). Individual gorse bushes that may become a problem in the future can be classified using high resolution data from the UAS. Separating out the native species of gorse and the more competitive species can be difficult but the flowering times of the species vary, with common gorse flowering earlier in the year and for a much longer period of time. When they are in bloom the distinctive yellow flowers can be clearly seen in aerial photography, as shown in Figure 6:51 therefore, if suitable imagery were available this separation can occur.

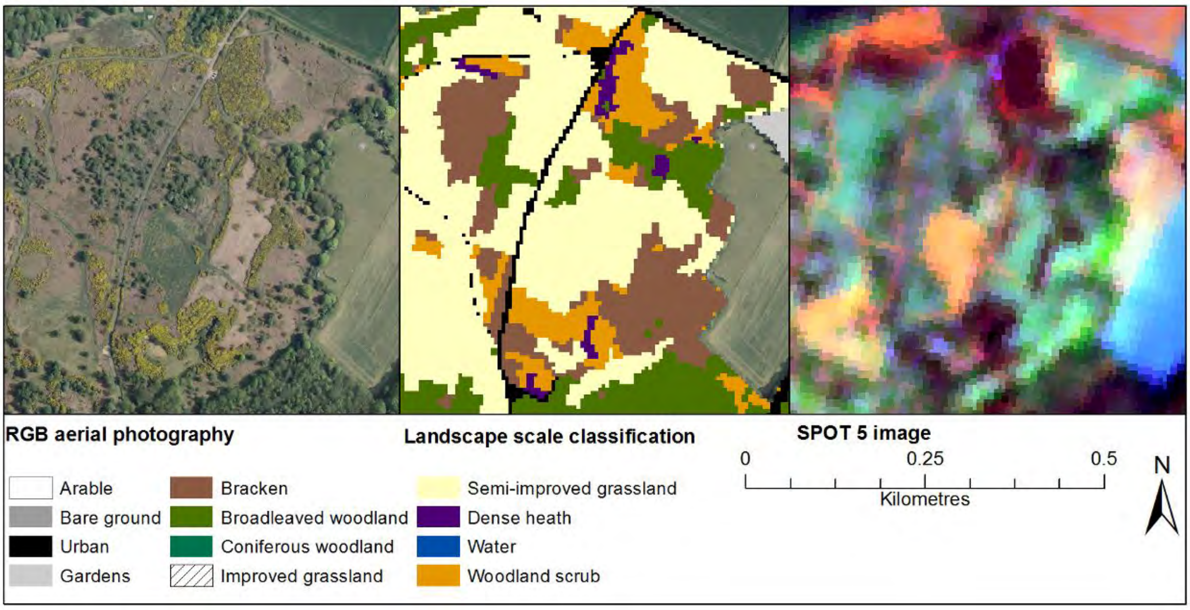


Figure 6:51: Gorse scrub classified within the woodland scrub category on a site in North Norfolk

Birch scrub

Figure 6:52 shows the emergence of young birch trees within the heathland plant communities at Dersingham Bog. Where there is insufficient grazing, lowland heath will revert to woodland over time and birch colonisation is the first sign of this succession. Figure 6:53 shows that using the finest spatial scale data from the UAS it is possible to map even very small birch trees. This can act as an additional management tool to monitor the extent and potentially target active management intervention, although again this is a specific site issue and any management would have to be taken by the site manager. The RGB image of the heathland surface, shown in the right of the figure shows that it is extremely difficult to separate the trees from the heath using just the visible bands. The MCA instrument mounted on the UAS records information in several bands within the NIR region of the EM spectrum this makes separation possible as it picks up the distinct differences in leaf physiology.

Figure 6:52: Young birch trees trying to colonise the bog surface at Dersingham Bog

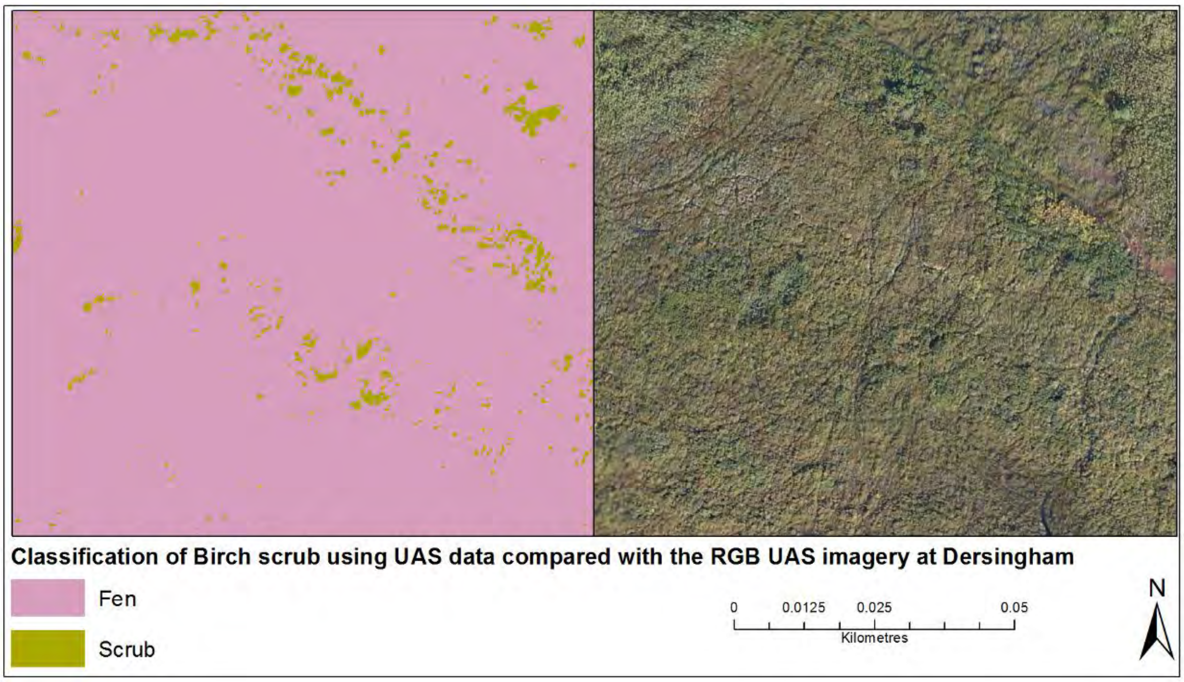


Figure 6:53: Classification of birch scrub on the wetland surface of Dersingham Bog

Himalayan balsam

Invasive non-native species such as Himalayan balsam *Impatiens glandulifera* are very vigorously growing species which out-compete and choke out the native species. It is normally difficult to map Himalayan balsam on the ground as it occurs alongside water courses and in areas where access is difficult. Most of the management of this species is by spraying. These sprays are expensive and maps of the distribution of this species will not only help target the management action but allow an accurate estimate of the cost of the spray to be calculated.

Figure 6:54 shows the classified extent of Himalayan balsam for an area of the Broads where it is a particular problem. The classification is shown over the UAS RGB imagery with the same image on the right hand side of the figure without the classified polygons for comparison. The large pink flowers of the Himalayan balsam can be seen in this image as it was captured in mid-August while the species was in flower.

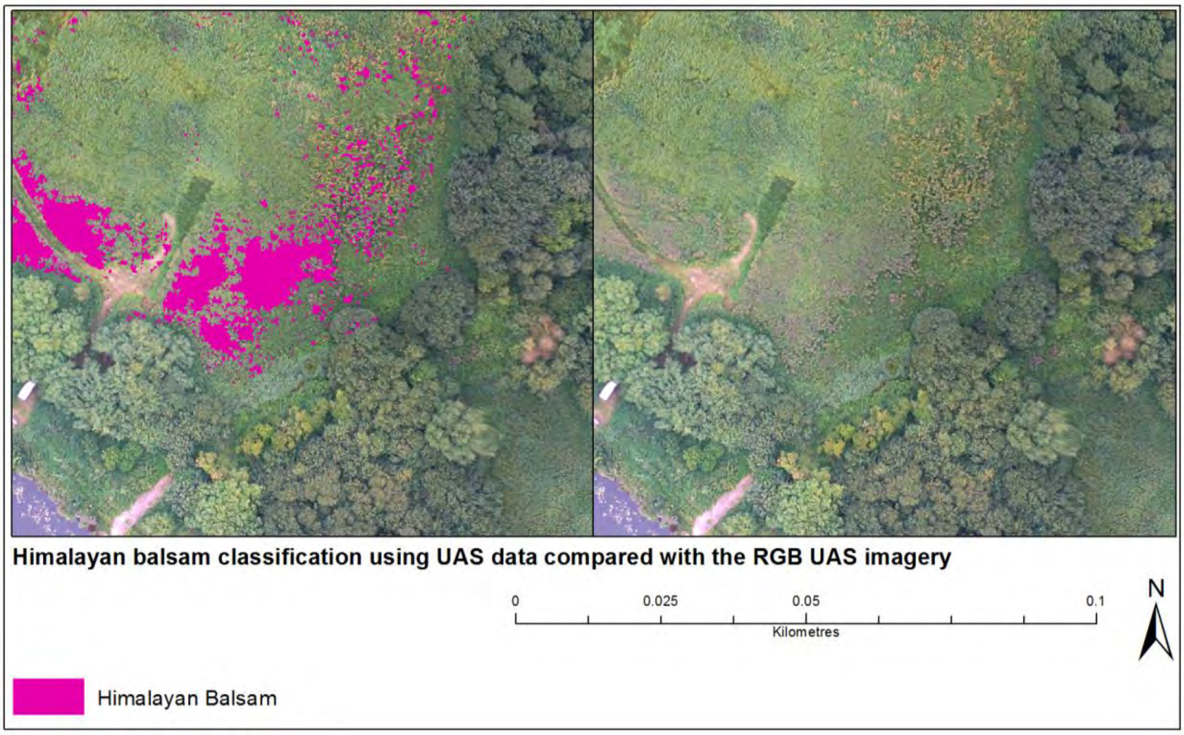


Figure 6:54: Classification of Himalayan balsam from UAS imagery in the Broads

Figure 6:55 shows a comparison of the Himalayan balsam classification with the RGB and MCA UAS imagery captured on the 14/8/12. The large pink flowers can again be seen in the RBG image, while in the MCA image the plant as a whole can be seen in the additional spectral bands of the sensor from its leaf structure. Therefore the plant could be identified in imagery captured earlier in the year, before it flowered and set seed, making treatment possible at other times of year.

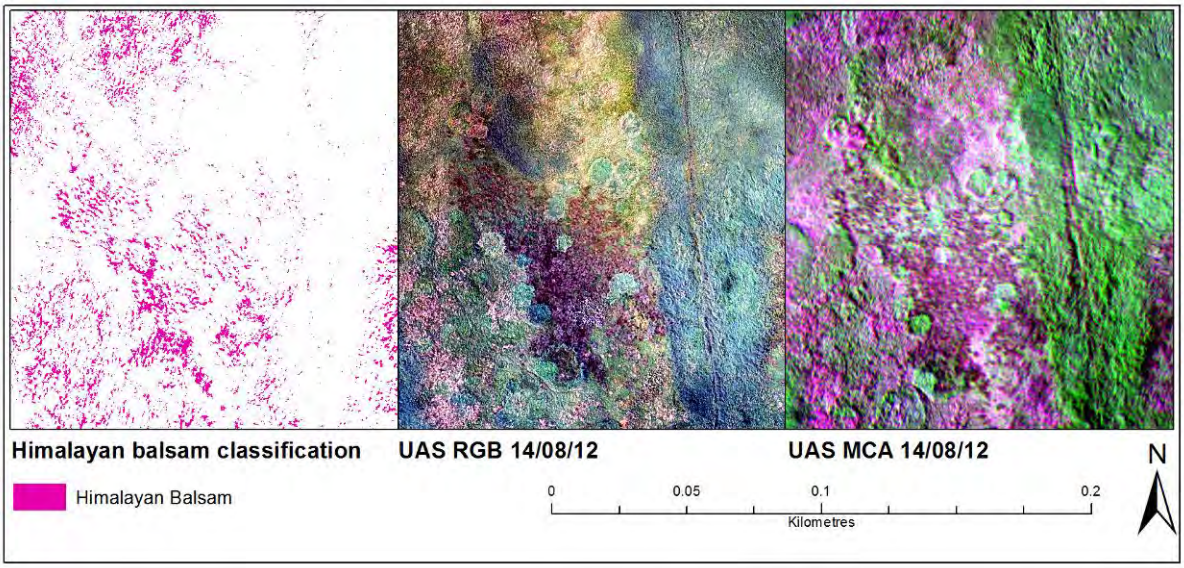


Figure 6:55: Comparison of the classification of Himalayan balsam with UAS imagery in the Broads

6.5.5 Wetness/dryness of the site

Wetness has a profound influence on mire and bog sites, it is also the case that the ecological condition of wet grasslands, saltmarshes and the woodlands in the Broads are also closely related to site wetness. In areas such as the Broads, the drying out of sites with semi-natural vegetation will result in changes in species composition and generally be regarded as a loss of site condition.

Several indices derived from EO optical data exist to describe wetness. However, as EO imagery captures information from above, it is often not possible to totally separate the wetness of the vegetation from that of the ground, or detect the wetness of the ground under the vegetation canopy. Despite these limitations it is possible to monitor changes in the overall amount of wetness, especially if the habitats on the site are well mapped. Areas of drying, and possible risks to the site can be highlighted and could be a useful way of targeting detailed field work.

The techniques investigated in the Norfolk pilot for determining site wetness using Dersingham Bog as an example were:

- the Normalised Difference Wetness Index (NDWI)
- “linear spectral unmixing”
- the natural log of the NIR of an image

The NDWI was considered likely to be the most useful measure for wetness as the trends seen can be described through ecological theory and the results of this analysis are included in this section.

The other two techniques were found to be useful for identifying areas of shade, as well as picking up variation within the site that seems to equate to wetness. These are not further considered in this section but are described in Appendix 3: Additional condition measures.

Additionally, the Modified Normal Difference Wetness Index (MNDWI) was used in the broads for the separation of wet and dry woodland.

NDWI of wetland vegetation at Dersingham bog

Box 6:2: Wetness technique 1 - NDWI for bog vegetation wetness

Normalised Difference Wetness Index (NDWI)

What it is

Whilst the linear spectral unmixing and natural log of the NIR can produce a replication for the levels of wetness, the results are heavily biased towards measuring the productivity of the area, as opposed to the actual moisture levels. Sensing in the shortwave infrared (SWIR) allows for the detection in the variations of water content within vegetation and soils. The arithmetic combination of the NIR and SWIR bands allow for the production of a NDWI.

$NDWI = (NIR - SWIR)/(NIR + SWIR)$ (Ito, et al. 2007).

Why we think it’s useful

As the SWIR band is sensitive to water and leaf internal structure, while the NIR band is sensitive to the leaf internal structure but not the water content, the combination of the two removes the effect of the leaf internal structure, but focuses on the water content. If bare earth and open water have been previously classified, what remains is an index which increases with vegetation water content.

For the creation of these NDWI values, the NIR signal has been taken from the GeoEye and MCA UAS sensor imagery, however, as the SPOT 5 imagery is the only one to contain a SWIR band, this has been used at all scales.

The NDWI (described in

Box 6:2) gave a particularly useful result when applied to the mire site at Dersingham Bog. Here the index was used to classify the mire into a number of wetness categories. Figure 6:56 also shows how implementing the NDWI sharpens the resolution of the resultant classification. The SPOT 5 SWIR band had a 10m pixel size but by using it in conjunction with the 1.65m NIR band from the GeoEye the resulting NDWI is in effect 'sharpened' to the resolution of the GeoEye and the subsequent image classification is more detailed.

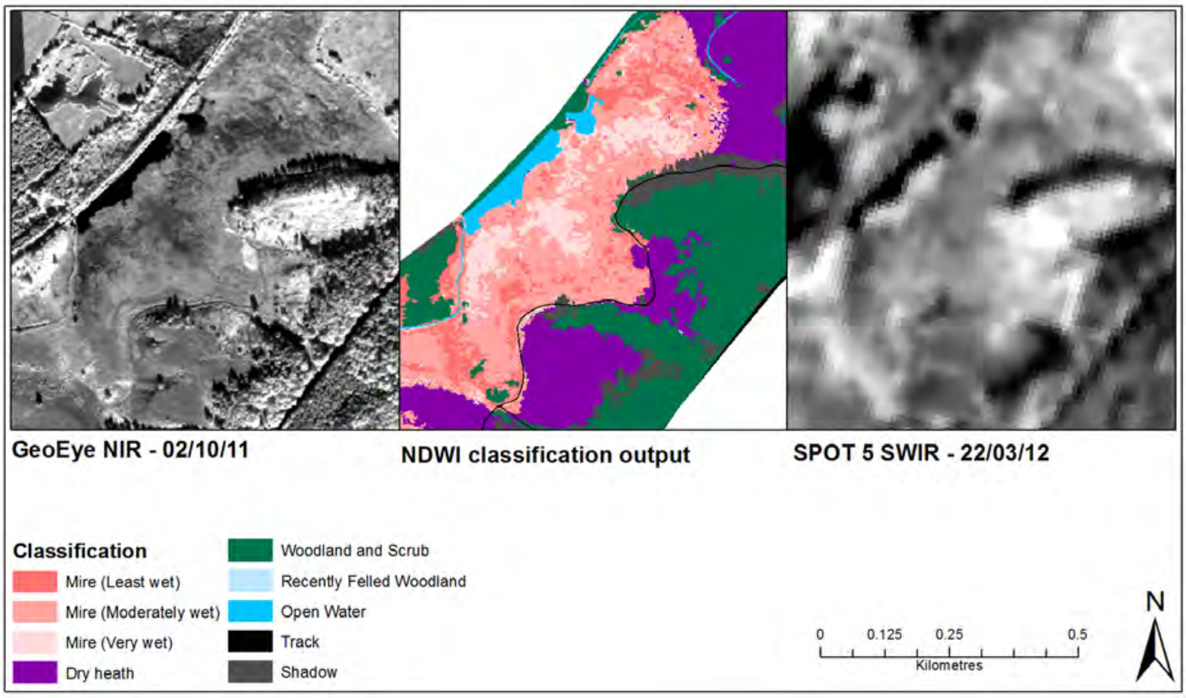


Figure 6:56: NDWI classification of Dersingham using the GeoEye and SPOT 5 imagery

A finer resolution again was achieved with the UAS NIR band and the SPOT SWIR (Figure 6:57) giving an extremely detailed plan of the site. The most useful scale for monitoring and evaluation would need to be consistent with the complexity and scale of the micro-topography of the site.

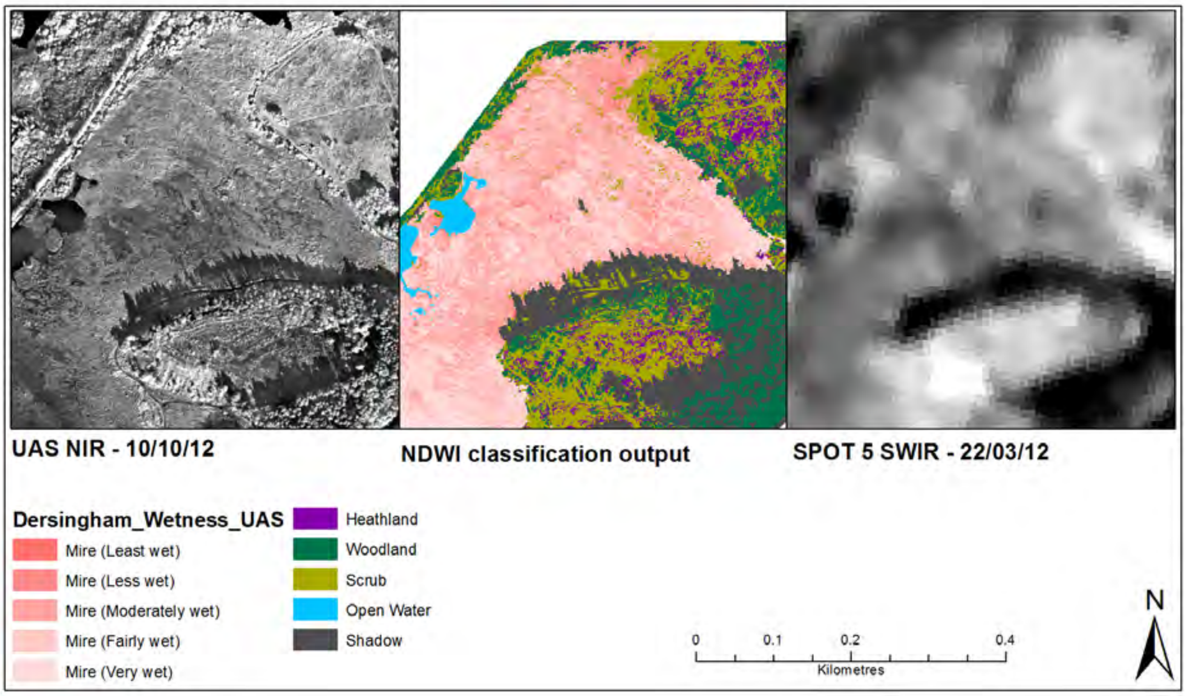


Figure 6:57: NDWI classification of Dersingham using the UAS and SPOT 5 imagery

As with the NDVI productivity index, changes in NDWI can be seen from a visual comparison of two NDWI images, although precautions should be taken to only compare NDWI images created from the same resolution of imagery. Current methods allow for NDWI values from repeat flights to be assessed as relative values so changes in areas of relative wetness across the site could be compared year on year. There is potential, although further work is required to develop calibration techniques to allow absolute values to be used, such as comparing features unlikely to change (e.g., mature trees). It would also be necessary to consider how recent rainfall events alter the indices or if they are robust to such short term changes. Additionally, seasonal growth variation will cause changes and quantification of this would be required.

Results: Case study: Surface and vegetation moisture status in the trial of a hybrid pixel and object-based approach to identify grazing marsh condition

This approach has been introduced in section 4.8.5 covering the method and section 6.4.2 where the land heterogeneity was used to classify areas of grazing marsh. This alternative OBIA approach allows each field to be characterised by its wetness and heterogeneity score and could therefore be a useful monitoring tool.

A Normalised Difference Water Index (NDWI) was used to show the moisture status (or management practices such as cutting) of grassland. The NDWI was calculated for each in a set of Landsat TM images from 2011 and the resulting NDWI images were stacked into a single dataset.

It was possible to track changes in the surface and vegetation moisture status during the growing season using the multi-temporal stack of Landsat data. The normalised difference water index (NDWI) captures the water status of the vegetation and the ground surface. For each object the average NDWI values were recorded from each image. The dates of the images in which the minimum and maximum NDWI values were recorded was also captured and is shown in Figure 6:58. This information could be used to understand the management or condition of the grassland objects.

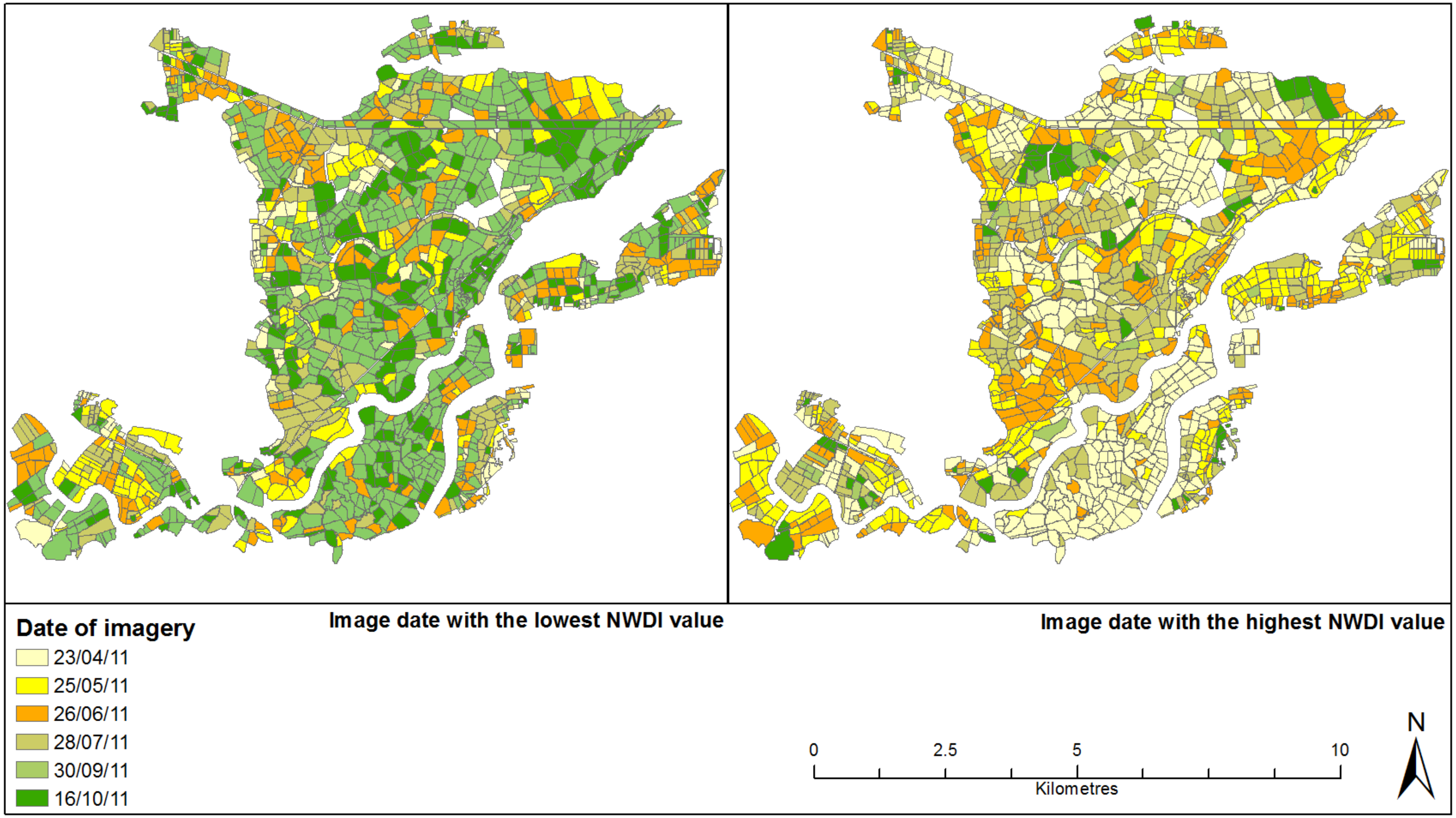


Figure 6:58: Imagery dates that contained the minimum and maximum NDWI values for each object

MNDWI of wet woodland vegetation in the Broads

Box 6:3 describes the Modified Normalised Difference Wetness Index (MNDWI) which was found to be useful for separating out wet and dry woodland vegetation.

Box 6:3: Wetness technique 2 - MNDWI for wet woodland

Modified Normalised Difference Wetness Index (MNDWI)

What it is

Similar to the NDWI described above, which used the NIR and SWIR bands, a Modified Normalised Difference Wetness Index (MNDWI) was used, substituting the green band for the NIR.

$MNDWI = (Green - SWIR)/(Green + SWIR)$ (Xu, 2006).

Why we think it's useful

The use of the green and SWIR bands provides the highest contrast in wet areas, in terms of their spectral reflectance, and allows for the isolation of water, moist soil and moist vegetation (Ho, *et al*. 2010). As with the NDWI, if bare earth and open water bodies have been previously classified, the relative moisture content of the vegetation remains. It was therefore found to be effective for distinguishing the difference between dry and wet woodlands.

An area of wet woodland in the broads around Wheat fen can be seen in the photo in Figure 6:59.

Figure 6:59: Wet woodland in the broads around Wheat fen

Figure 6:60 shows the result of the classification of wet woodland using the SPOT 5 and RapidEye for the MNDWI to separate wet and dry woodland vegetation. The SPOT imagery had to be used for the SWIR values, however, several different resolution images were tested for the green values with the 6.5m resolution RapidEye imagery giving the best compromise of information to noise to get real world meaningful objects. Two types of wet woodland could be readily identified from the imagery and these were classified as "open canopy wet woodland" (where the mire species still form an important component of the signature) and “closed canopy wet woodland” (where there is less signature from the ground flora).

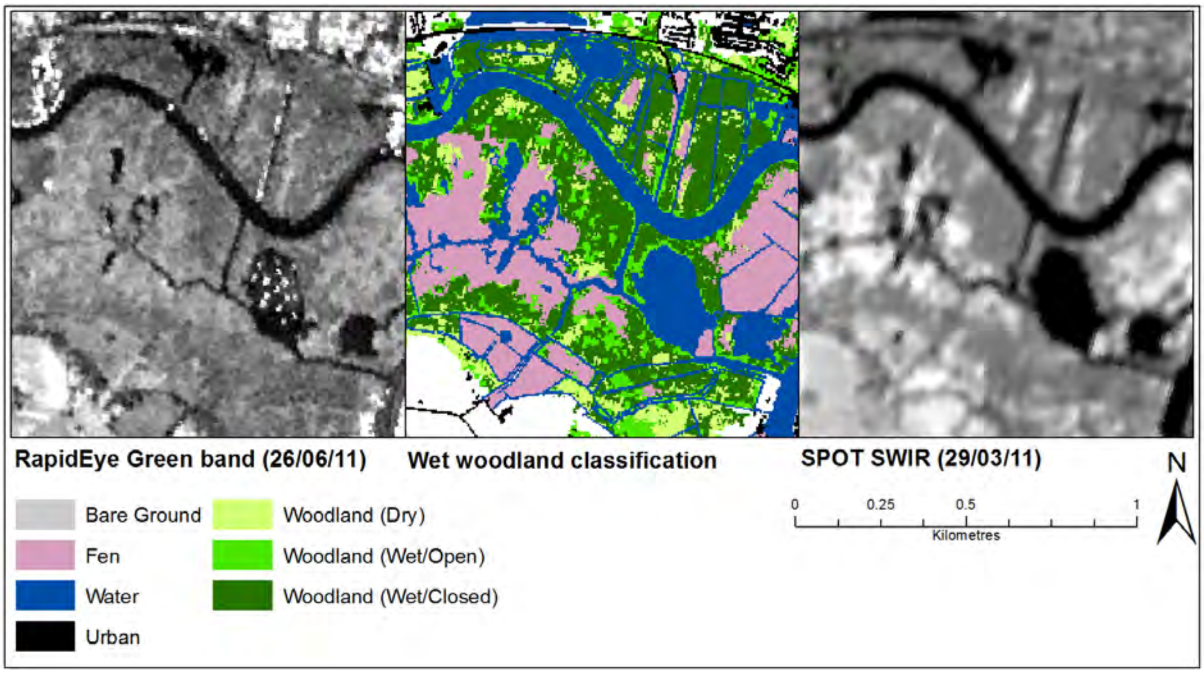


Figure 6:60: Classification of wet woodland in the Broads

Using the MCA sensor on the UAS it may be possible to distinguish individual tree species, for example alder as opposed to willow. In order to undertake this analysis it would be necessary to have several exact records of individual trees, with details of species and location. This would be an extremely interesting aspect to investigate in future research, not only to support the mapping of wet woodlands, but also for tree disease control mapping where an inventory of different tree species could be made.

Thermal

As a test of concept on one of the flights with the UAS at Dersingham bog a thermal camera captured data. This has only been captured as a video and so analysis of any stills taken from it has not been possible, and those examples shown in Figure 6:61 are for reference only as a proof of concept of the information that thermal imagery may be able to provide.

The thermal testing was undertaken as recent studies show that wetland features, in particular where floating vegetation occurs, can be better separated by their thermal properties than from their reflectance values. Peat, being black, heats up much faster than water, whilst water has a higher latent heat capacity and loses its heat more slowly. This difference throughout the day can be exploited to gain additional site information. These floating vegetation features are extremely difficult to monitor on the ground as they are dangerous to access and are key to biodiversity of the site. UAS could be a useful tool for identifying these features if enough separation is visible between different types of wet vegetation. This small trial was purely investigating an initial feasibility of using this type of sensor on this sort of platform.

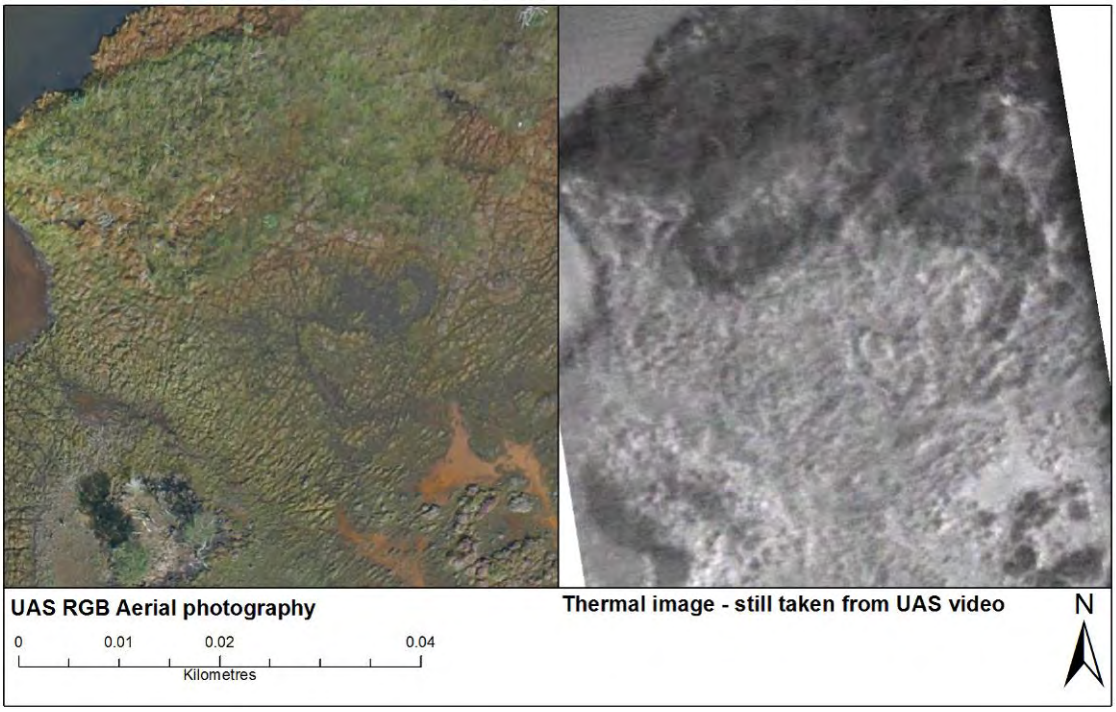


Figure 6:61: Comparison between the RGB and still taken from the Thermal video from the UAS captured on 11/09/12. Darker shades represent cooler temperatures and lighter shades represent warmer temperatures. The thermal video was captured mid-morning due to access and other imagery requirements.

In Figure 6:61 the water to the west and north west of the image appears very homogeneous in the images while the vegetated surfaces appear much more heterogeneous. The short vegetation contains a strong signal from the wetness underneath and is appearing paler than the dense scrubby vegetation in the top half of the image has shaded the ground underneath, meaning it is showing up as cooler. The small bog pools are appearing very pale in the thermal and bright orange in the RGB to the south east of the image. These shallow water bodies could have warmed up faster than the deeper water body to the north east.

6.5.6 Condition measures for Permanent Freshwater

The work presented in this section has only been tried as a preliminary investigation to show the types of metrics that can be used to establish the condition of water bodies. Within this section the levels and distributions of two features which impact on the condition of water bodies have been assessed, Chlorophyll-*A* and Total Suspended Solids.

- Chlorophyll-*a* is a specific form of chlorophyll used in photosynthesis. The presence of chlorophyll-*a* in standing water is therefore an indicator of the amount of phytoplankton, and can be used to identify areas suffering from eutrophication.
- Total suspended solid levels are mostly formed of sediments in suspension in the water column. Sediment loading is a primary driver of the health of water bodies. Inputs of sediments after storm events can have potentially devastating effects on the ecosystem by increasing nutrient loads, depositing sediments and decreasing light levels.

Box 6:4: Chlorophyll-*A* metrics

Chlorophyll-*A*

What it is

Red-NIR band ratios have been used for the estimation of chlorophyll-*a* concentration in coastal and inland waters in a number of projects including Gitelson *et al*. (2008). The following metric was used to estimate the chlorophyll-*a* concentrations using RapidEye imagery.

$ChlA = 5 * \log\left(\left(\frac{1}{Red\_edge} - \frac{1}{Red}\right) * NIR\right)$ (adapted from Zhang *et al*. 2010)

Why we think it's useful

The red-edge represents part of the NIR region of the EM spectrum (680nm - 750nm) which is reflected strongly by plant cells. This therefore shows the plant material present in the water column which can be used to indicate nutrient availability.

Box 6:5: Total suspended solids (TSS) metrics

Total Suspended Solids (TSS)

What it is

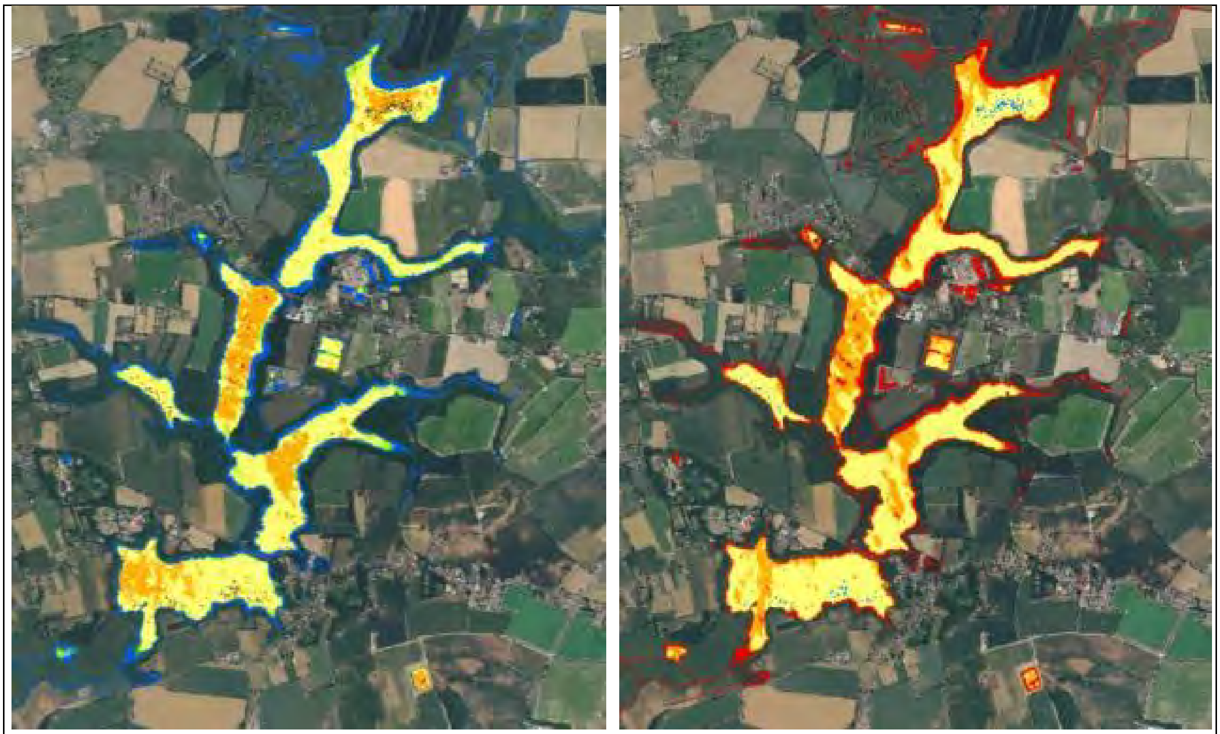
Ouillon *et al.* (2008) tested a number of channels of imagery from MODIS, MERIS TM, ETM+ SeaWiFS, and OCTS. It was found that those with a centre of 681nm and 705nm gave a very good correlation with the TSS concentration. The Red-edge band of the RapidEye sensor has a value of 710nm and therefore can be considered suitable for determining relative TSS concentrations in this preliminary evaluation.

$TSS = 15 * (Red\_edge)$

Why we think it's useful

Water body sediment concentration measurements can identify the risk of sedimentation and nutrient enrichment to an ecosystem.

Within the Broads the Rapid Eye imagery was used to test the measures of the eutrophic nature of the water and TSS, in terms of a condition analysis which are shown in Figure 6:62.



Indicative Chlorophyll-*a* presence | Indicative Total suspended sediment presence

Figure 6:62: RapidEye lake freshwater condition measures

Transferability

Summary of what these findings on condition measures mean for transferability

T17. NDVI and NDWI measures are readily transferable because they are:

- “out-of-the box” products – established ratios between imagery bands which are available from a number of satellite platforms (SPOT 5, RapidEye, GeoEye);
- useful for a range of semi-natural habitats that are widely distributed in the UK (e.g., grasslands, wetlands and woodlands);
- can be used to assess risk and mitigation factors on designated sites; the need for this is widespread.

T18. The use of Very High Resolution and Ultra High Resolution imagery allows for higher resolution NDVI or NDWI products. The resolution of the product should match that of the features that are being examined. Some sites require the intricacy afforded by this higher resolution data, while others are more influenced by overall processes and therefore less high resolution products are suitable.

T19. The techniques for mapping the extent of competitive / invasive plant species are largely dependent on the availability of NIR imagery at a suitable scale for the stands of vegetation (up to ultra-fine resolution). It also requires a specifically developed rule-base to avoid confusion with species with similar spectral characteristics.

6.6 Effectiveness of the mapping

The accuracy of the landscape mapping, the site mapping and the hybrid pixel-and-object-based classification have been assessed against field points and existing habitat mapping. The mapping accuracy has been assessed both using a traditional remote sensing comparison and a more sophisticated and robust spatial model. The usefulness in terms of the 'fitness for purpose' of the mapping within this section has been evaluated by Martin Horlock at NBIS, one of the local authority users of the outputs. The EO habitat classifications gave a good representation of the landscape and also during the case studies of Annex I and BAP priority habitats which are identified by their cover forming species. The level of spatial detail possible to attain using very high and ultra-high EO would be an advantageous addition to traditional species based site maps.

The effectiveness of the mapping can be considered in terms of how accurate the data is and whether it is fit for purpose. All maps, including those produced in the field, are a simplified representation of the real world situation. However, field maps are rarely assessed in terms of their accuracy other than in terms of a general evaluation which may be described 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?"*

Phase 1 of the project (Medcalf *et al.* 2011b) discussed the differences in accuracy between remote sensing products and traditional field mapping techniques and how the different types of errors in the two methods of collection lead to different types of inaccuracies in the maps. Therefore, it is important when considering the accuracy of a EO map to understand that they show different types of errors to a field map and to evaluate them in a robust way. This section considers the following questions in relation to map accuracy:

- Are the broad scale maps identifying habitats in their landscape context in agreement with field based ground control points (within known limits and acceptable standards, generally an agreement of 80% between the map and the control points is considered acceptable due to the inherent variability of habitats themselves)?
- Are the Annex I habitat patches identified in a manner that agrees with classification in the field (within 80% agreement to a suitable representative sample of ground control points)?
- Is it likely that change in these patches and other pertinent features relating to these changes can be identified?
- How else may the maps be used and how well do they 'fit' these purposes?

6.6.1 Results: accuracy assessment of landscape scale mapping

Earth observation derived land cover accuracy is typically described using measures of correspondence between the *classified* EO data and some *reference* data considered to be of higher quality. In most cases reference data are collected in the field or mapped from higher resolution data (e.g., aerial photography). The correspondences between classified and reference data are commonly summarised in a cross-tabulation, referred to in the literature as the *Error, Confusion, Validation, or Correspondence* matrix. This method has become the standard way for EO research to publish results about the effectiveness of classifications and has become a necessary part of any research paper.

This methodology was developed to help inform the per pixel classification analysis. It is not as robust for evaluation of object based analysis as it does not take into account the spatial distribution of errors which are an important consideration in object based analysis. The methodology can also be easily misinterpreted in the case of habitat classes which have few reference data points because they are rare or distributed in a very uneven manner across the maps. In this project the focus is on rare habitats which intrinsically have very specific environmental requirements. They are therefore unevenly distributed over the map, where suitable environments exist. These habitats are assessed for the case study areas by visual comparison and have not been included in the standard correspondence matrices which are reported in Appendix 4: Accuracy Tables. For the main analysis and reporting a more sensitive technique has been used which considers the spatial aspects of the accuracy. The spatial approach applied was based on those described in Comber *et al*. (2012) and Comber (2013). These methods incorporate recent, spatially explicit techniques for modelling spatial discontinuities and non-stationary processes. These are novel to the realm of error and accuracy reporting for EO data and are further described within this section.

Existing habitat data

To create the reference data an assessment of the existing habitat data available was undertaken. To identify what additional data was needed for validation of the landscape scale mapping of the habitats, a thorough investigation of what data was available was required. Norfolk Biodiversity Information Service (NBIS), part of Norfolk County Council, is the local records centre and they have been a partner within this project providing the reference data for these analyses. All habitat inventory data has been manually collected by API. Other habitat surveys have been localised and infrequent. Where available, existing NVC habitat surveys have been used for comparison with the more detailed mapping of the case study areas, considered later in this section. Further field points within the landscape scale mapping areas were collected by NBIS.

Collection of additional field points

As part of the validation and accuracy part of the project a number of additional ground truthing points were collected by NBIS. These were randomly selected from within the broad study areas (urban areas were excluded) and a higher density of points were selected within SSSIs to pick up a higher number of field points landing in areas of semi-natural vegetation. Although in this heavily managed environment where habitat patches are constrained by the pressures around them, the numbers of points landing on semi-natural vegetation is still limited, leaving some classes with insufficient numbers of points to state accuracy values.

In total 575 points were assessed in the West Norfolk study area and 150 points were assessed in a subset of the East Norfolk study area which included the area of analysis of the Hybrid pixel approach. For efficiency of the field effort, where suitable habitat data existed for the point, or where the habitat could be accurately determined by API this was used for the classification. For areas of habitat which could not be accurately determined remotely by API and could be accessed, visits occurred. Some points were inaccessible due to military restrictions, because the terrain was too wet or the vegetation was too dense. Figure 6:63 shows the distribution of the points and the broad land cover classification. Of the 575 points in the Western Study Area, 88 were not assessed (most of which fell in a large danger area to the south), 327 were assessed using API and 160 were field visited, of the 150 points in the East, 15 were not assessed, 119 were assessed using API and 16 were field visited.

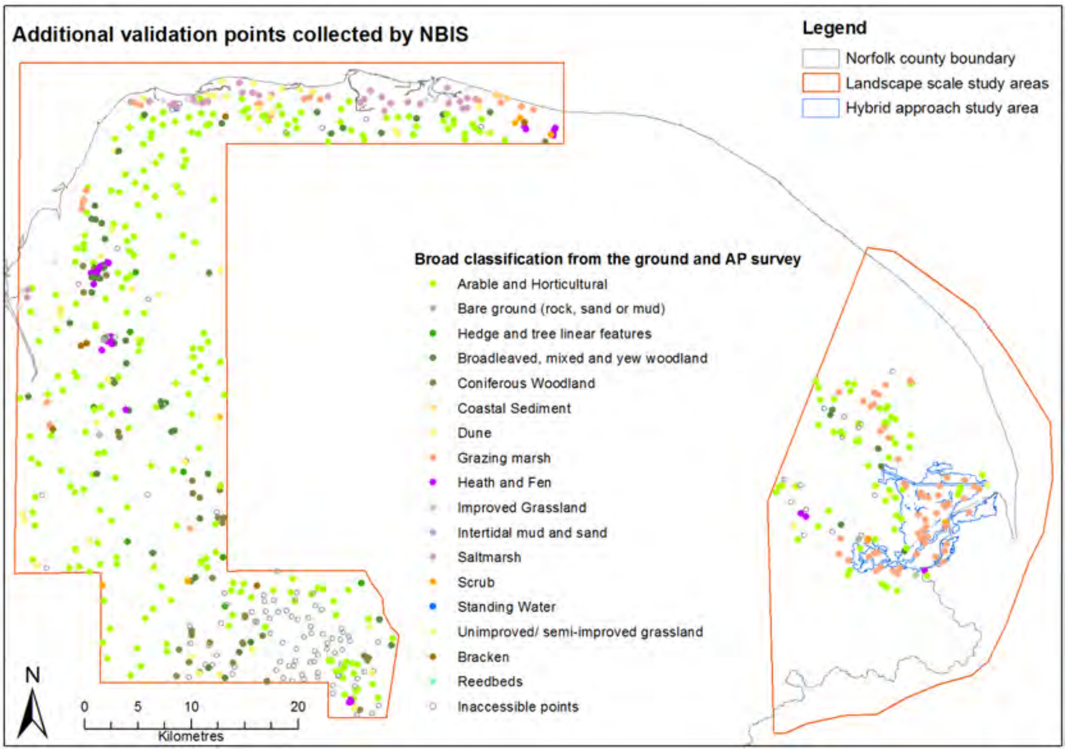


Figure 6:63: Additional points assessed for the accuracy and validation

As well as the broad land cover present at the point a number of other attributes were also recorded, which are included in Table 6:6.

Table 6:6: Data collected for each validation point assessed

Recorded attribute	What it covers
Broad classification	A broad classification of the habitat present
Sub-classification	A more specific classification of the habitat present
BAP habitat	Whether it is a priority habitat classified under UK BAP
Annex I habitat	If it is an Annex I habitat and if so what the habitat it is
Where the point fell in relation to the land cover parcel	Whether the point fell in the middle or the edge of a land cover parcel
Date of the observation	This refers to how recently the field visit was, or the date of the existing survey data or the aerial photography used
How the point was completed	Whether the point was assessed by API and other existing data or by field validation
Comments	Including any other data sources used for the assessment

This additional information can be used for assessing accuracy at different scales and for identifying any limitations in the validation data and assess the quality of the ground points. They may also provide reasons for errors in the classification.

Spatial accuracy assessment

This spatial approach uses a moving window or kernel approach to calculate *local* correspondences at discrete locations through the study area. At each location a sample of the data points are used to calculate local measures of accuracy. The contribution of each point to the local calculation is weighted by its distance to the location under consideration. Therefore these approaches are referred to as *Geographically Weighted* (Brunsdon *et al*, 1996) and they allow spatially distributed measures to be generated using point data collected as part of standard remote sensing validation.

It is possible to generate a number of geographically weighted accuracy measures. In this report two measures are considered:

- Overall Accuracy considering all habitat classes together
- Portmanteau Accuracy which is applied to individual classes, if they have sufficient data validation points

A Portmanteau measure is one that combines both specificity and sensitivity. It includes both the probability that the presence or the absence of a particular land cover class is correctly reported. Within mapping it is as important not to be classifying a saltmarsh in the middle of an inland area as it is to find it in its correct location. Portmanteau Accuracy can be explained by considering the two datasets, the classified EO data and the reference field data. For any given class, at each sample location the data can be considered to be either *True*, indicating that class is present or *False*, indicating that class is not present. These can be shown as a 2-class error matrix as in Table 6:7.

Table 6:7: The 2-class error matrix

	Reference *True*	Reference *False*
EO *True*	n_1	n_2
EO *False*	n_3	n_4

Overall Accuracy is calculated from $n_1 / (n_1 + n_2 + n_3 + n_4)$, so the accuracy value reflects only where the presence of the class is indicated in both datasets. Portmanteau Accuracy includes locations where the absence of that class is correctly indicated by both datasets and is calculated from $(n_1 + n_4)/ (n_1 + n_2 + n_3 + n_4)$. It therefore better describes the probability that the classified data is the same as the reference data.

Results of the accuracy assessment

Eastern landscape study area

The correspondences between field data and classified earth observation data in the Eastern landscape study area are shown in Appendix 4: Accuracy Tables. This shows the overall accuracy, using the traditional correspondence table, to be 89% and that the study area is dominated by two classes, *Arable* and *Grazing Marsh*, both of which have very high levels of correspondence.

A Geographically Weighted analysis was used to estimate the spatial distribution of overall accuracy in the Eastern study area (Figure 6:64). This shows that overall accuracy is high throughout the study area with very little spatial variation in accuracy. The lowest accuracies (<86%) are found to the north west of the study area and the highest to the south east. This trend is also evident in the data points, with a larger number of differences between the field and classified EO data in the North and West. On further investigation, the points which have been misclassified, causing this lower accuracy, are either on the edge of the land parcel or have been classified as *fen* rather than *Wet woodland*. In the field notes it says that the points are contained in the fen inventory therefore the EO confusion seems justified.

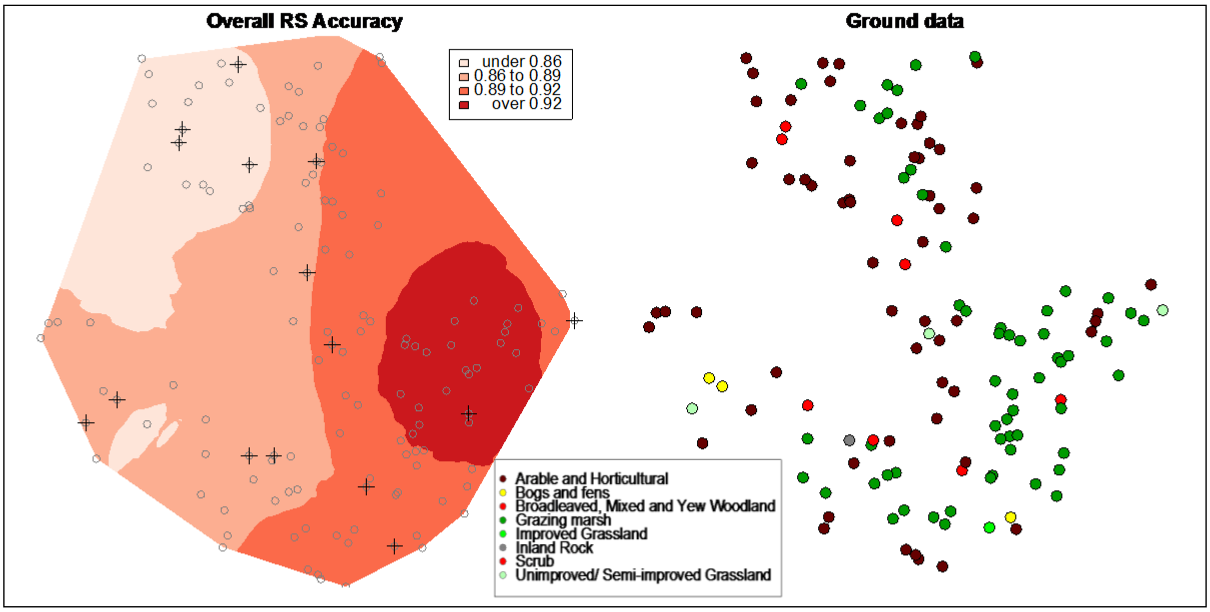


Figure 6:64: The spatial distribution of Overall accuracy for the Broad class in the East Norfolk study area. Points where the EO classification was different from the field data are indicated. ('o' indicates points where the EO and Field point classifications correspond and '+' where they do not)

The Portmanteau Accuracy for *Grazing marsh* class can be calculated from the figures in Appendix 4: Accuracy Tables (58 + 72) / (58 + 5 + 0 + 72) and shown to be 96%. This varies very little across the study area as shown by the map and the Inter-Quartile ranges of the Portmanteau measure in Figure 6:65.

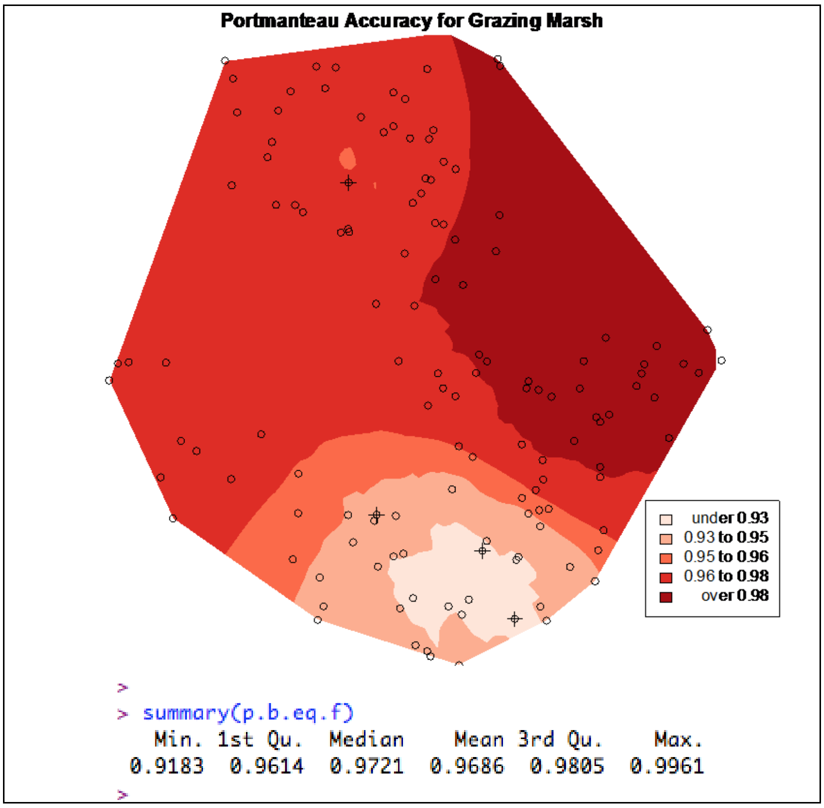


Figure 6:65: The Portmanteau Accuracy for the Broad class of Grazing Marsh ('o' indicates points where the EO and Field point classifications correspond and '+' where they do not)

The spatial distribution of all the sub classes is shown in Figure 6:66. There is little spatial variation in accuracy. The Portmanteau Accuracy for the *Grazing marsh* Sub-Classes was 98%, similarly there is little spatial variation.

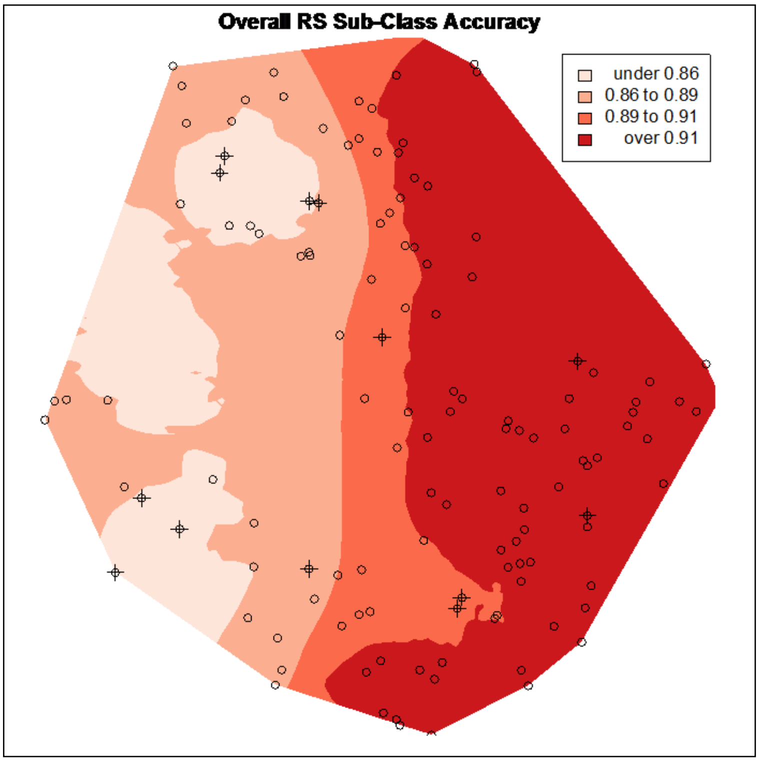


Figure 6:66: The spatial distribution of Overall accuracy for all Sub-Class classes ('o' indicates points where the EO and Field point classifications correspond and '+' where they do not)

Western landscape study area

The correspondences between field data and classified remote sensing data in West Norfolk are again shown in Appendix 4: Accuracy Tables. This shows the overall accuracy using the traditional correspondence table to be 78% and that the study area is dominated by the class of *Arable & Horticulture*, with high numbers of study points falling on: *Broadleaved, Mixed and Yew Woodland*, *Coniferous Woodland*, *Grazing Marsh*, *Heath* and *Saltmarsh*.

The main issue which lowered the traditional correspondence accuracy was between coniferous and broadleaved woodland. Further investigation showed this normally occurred where broadleaved woodland edged a coniferous plantation, and therefore the EO analysis classified a broadleaved edge, whilst the validation considered the whole block to be coniferous. This is an issue of habitat patch size rather than misidentification, as shown in Figure 6:67.

Figure 6:67: example of a field validation point identified as coniferous woodland in the field and broadleaved woodland by the EO analysis

A Geographically Weighted analysis was used to estimate the spatial distribution of overall accuracy in the Western study area (Figure 6:68). This shows that overall accuracy is high throughout the study area with very little spatial variation in accuracy. The lowest accuracies (<67%) are found to the south and the west of the study area and the highest (>76%) to the north. The data points show this trend with a larger number of differences between the field and classified EO data in the south and east. This corresponds with where there are more varied habitats within a relatively small area in the West, and limited points due to access restrictions in the South.

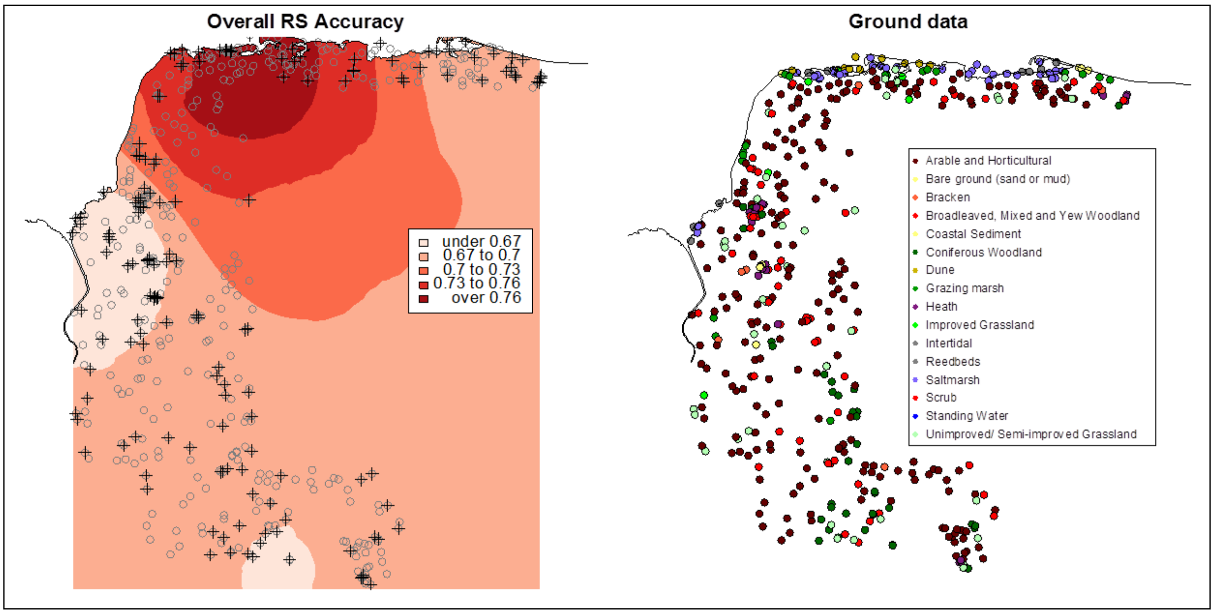


Figure 6:68: The spatial distribution of Overall accuracy for the western study area ('o' indicates points where the EO and Field point classifications correspond and '+' where they do not)

There are high correspondences between EO and field data for the Broad classes of *Arable & Horticulture* and *Grazing Marsh*. The Portmanteau Accuracies for *Broadleaved Woodland* and *Saltmarsh* class can be calculated from the correspondence tables in Appendix 4:

Accuracy Tables. For *Broadleaved Woodland* this is 91% (*(16 + 425) / (16 + 29 + 17 + 425)*) and 98% for *Saltmarsh,* (*(32 + 446) / (32+ 3 + 6 + 446)*).

Figure 6:69 shows the spatial distribution of these accuracies and these habitat features are located in distinct areas. For the *Broadleaved Woodland* class, accuracy is higher in the north and lower in the south, where most of the areas of woodland classes are located and for *Saltmarsh* the accuracies are lower in the north. This reflects one of the key features of Portmanteau accuracy: it includes in its calculation data points correctly indicating the *absence* of the class being considered. Therefore the mapping is not identifying saltmarsh in unsuitable in-land areas. On further investigation the areas of slightly lower accuracy (<95%) correspond with misclassification of points at the edges of land cover patches in the transition area between mud, saltmarsh and sand dune. Around the main areas of woodland there are some misclassifications; these can be due to broadleaved tress edging coniferous plantations and young patchy areas of coniferous woodland, so the field study describes the main block of woodland as coniferous, whilst the EO map has shown the individual clump of tress as broadleaved. The Portmanteau accuracy shows there are few areas which were wrongly recorded as woodland.

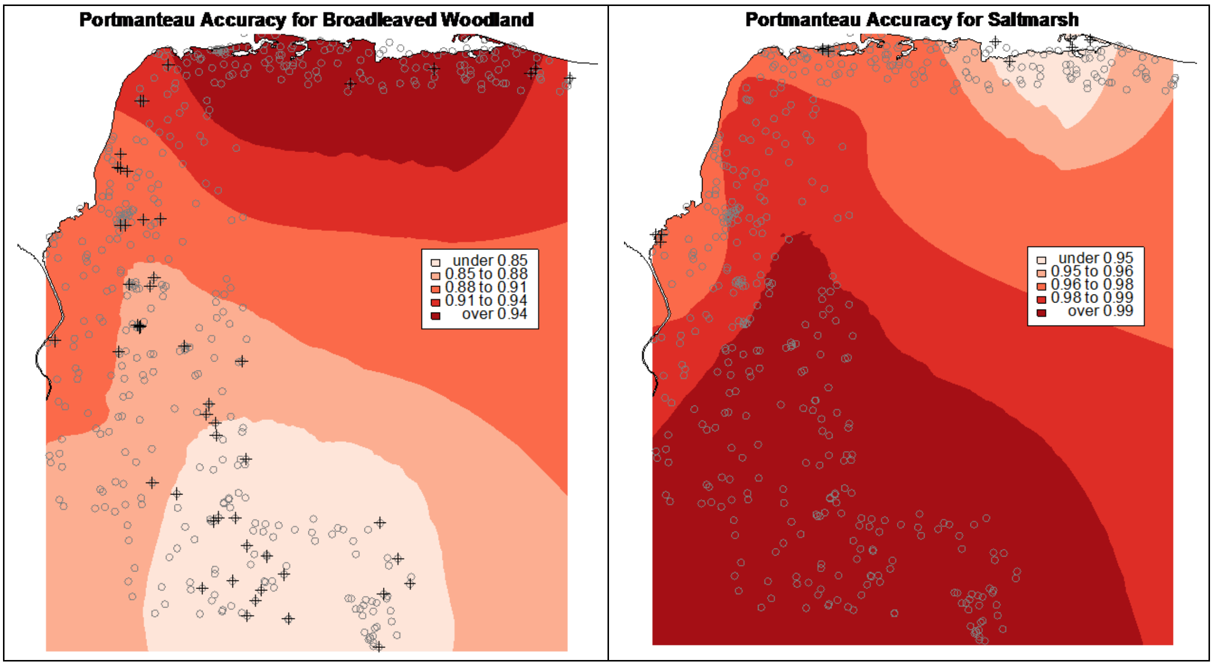


Figure 6:69: The Portmanteau Accuracy for the Broad classes of Broadleaved Woodland and Saltmarsh ('o' indicates points where the EO and Field point classifications correspond and '+' where they do not)

The spatial distribution of the Overall Sub-Class accuracy was calculated and shown to have very little spatial variation. Table 6:8 shows the interquartile range of the accuracy estimates to be less than 2%.

Table 6:8: The variation in Overall Sub-Class accuracy in West Norfolk

Min	1stQu	Median	Mean	3rdQu	Max
0.6518	0.6530	0.6542	0.6543	0.6554	0.6580

6.6.2 Results: accuracy assessment of hybrid approach

The classified EO and field data used in this analysis are shown in Figure 6:70. The broad classes from this classification were compared. The table in Appendix 4: Accuracy Tables shows the correspondence of the field points with the hybrid classification using the traditional analysis methods of the reference data to the classified data. The overall accuracy when the *Rough Grassland* class was amalgamated with the *Grazing Marsh* class was 80%, with the majority of the data points labelled as *Rough Grassland* in the classified data and grazing marsh in the reference data. By combining these the user and producer accuracies for this class are 97% (31/32) and 82% (31/38).

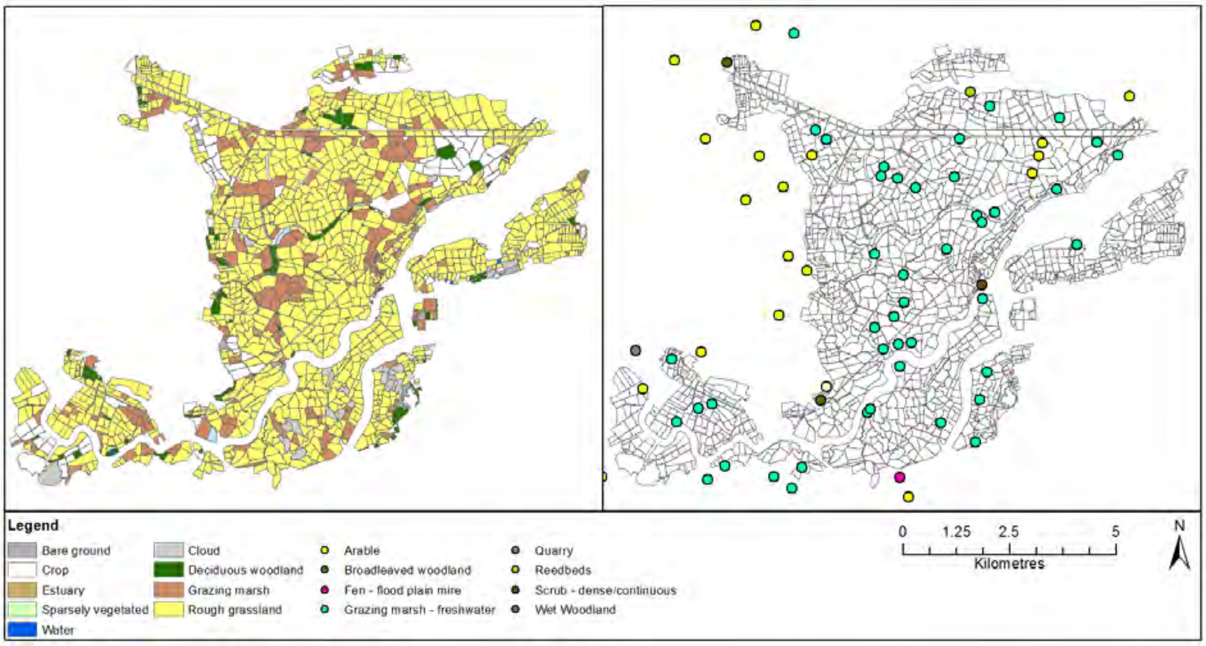


Figure 6:70: The classified land cover data and intersecting field data locations, with their broad habitat labels

The spatial variation in overall accuracy was estimated and the results are shown in Figure 6:71. These indicate greater accuracy to the north and centre of the study area. The spatial variation in the combined *Rough Grassland and Grazing Marsh* Portmanteau accuracy was estimated and shown in Figure 6:72. This shows Portmanteau Accuracy to be generally higher to the north and east of the study area and lower to the south. The hybrid method accuracy was very similar to the segmentation based method and therefore shows that the techniques are both robust and repeatable.

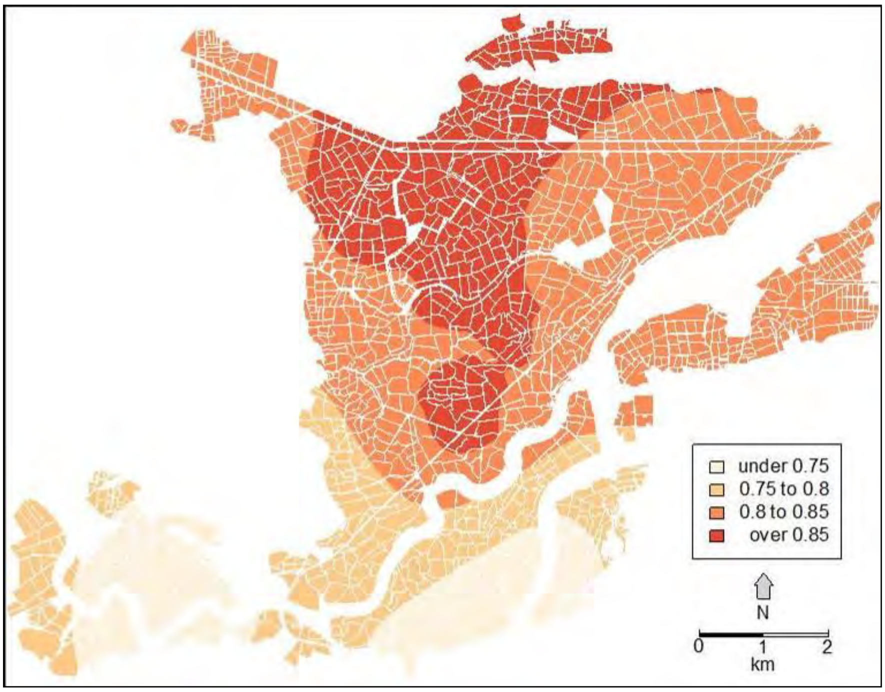


Figure 6:71: Overall Broad Habitat accuracy in the subset of the East Norfolk study site.

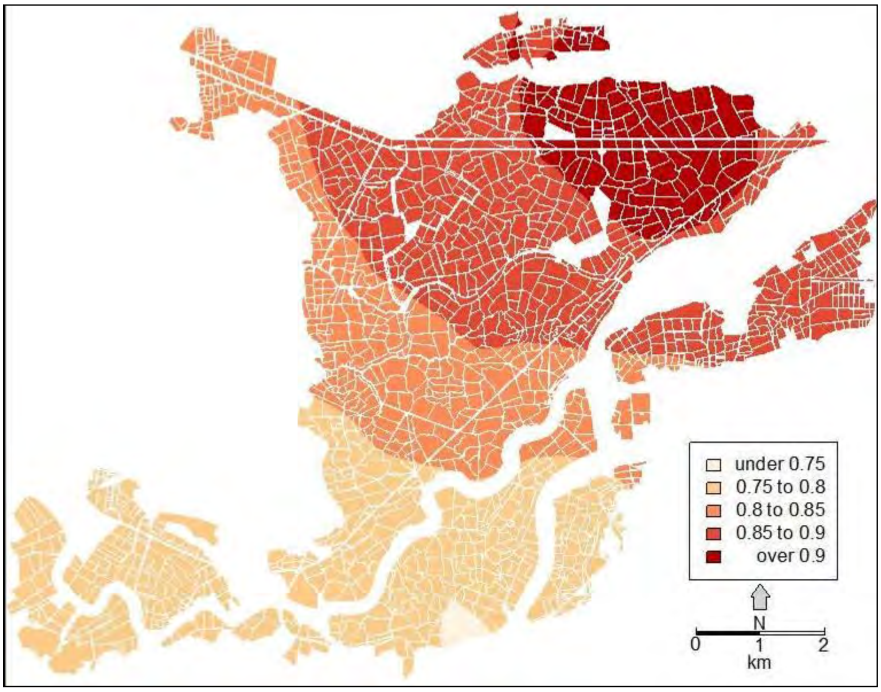


Figure 6:72: Portmanteau accuracy of Rough Grassland and Grazing marsh combined in the subset of the East Norfolk study site

6.6.3 Results: accuracy assessment of site-based mapping

The habitats in Norfolk are restricted in their spatial extent. For the individual case study sites creation of specific points over a small area are subject to a number of errors of accuracy both spatially and qualitative. Spatial errors can arise from the field based GPS systems which map to an accuracy of plus or minus 2 - 5m. Habitat boundaries recorded in the field using these devices can be up to 5m from the actual location. When very small site based areas are being considered, these errors become significant. It is therefore extremely difficult and often unsuitable to compare boundaries drawn in the field with boundaries drawn from accurately geo-referenced EO imagery.

Qualitative errors also arise from the field mapping of mosaics of habitats as there are no sub-divisions within the mosaic land cover parcels. As a result, it has been decided that the best means of comparing the accuracy of the delineation of habitat features is by a visual comparisons, using the existing field surveys and the aerial imagery. Detailed site survey maps were available for the case study areas, using the NVC habitat classification outlined in Rodwell (1991a, 1991b, 1992, 1995 and 2000), however the dates of this mapping varies by site between 1999 to 2012. No mapping was available that showed how the NVC classes had been interpreted to Annex I classes spatially. They can be compared using the look up table on the JNCC website of suggested equivalent classes between NVC type and Annex I or BAP priority habitats (JNCC http://jncc.defra.gov.uk/page-1425).

). This has been used to aid comparisons for each case study area and the habitats that occur within the case study areas have been summarised below.

East Wretham Heath

The individual classes from the remote sensing project were amalgamated to form Priority Habitat classes where these were a direct translation; other habitats were reported as their direct remote sensing class to aid in giving context. Table 6:9 shows the classes across the classification systems present in this case study.

Table 6:9: Correspondence between the BAP priority habitats, Annex I habitats, EO classification and the NVC classes present on the case study site at East Wretham Heath

BAP Priority habitat	Annex I Habitats	EO class	NVC
Lowland dry acid grassland	Not annex I habitat	Low productivity Breck heath grassland Medium productivity Breck heath grassland	**U1a,b,c,d,e**: *Festuca ovina-Agrostis capillaris-Rumex acetosella* grassland

Although extremely significant in a local context, East Wretham Heath only comprises one BAP priority habitat type, Lowland dry acid grassland and no Annex I habitats. The photo in Figure 6:73 shows the site and the combination of grassland and nettles.

Figure 6:73: Photograph showing nettle incursion at East Wretham Heath, taken from near the house to the North East of the site, looking South West across the site

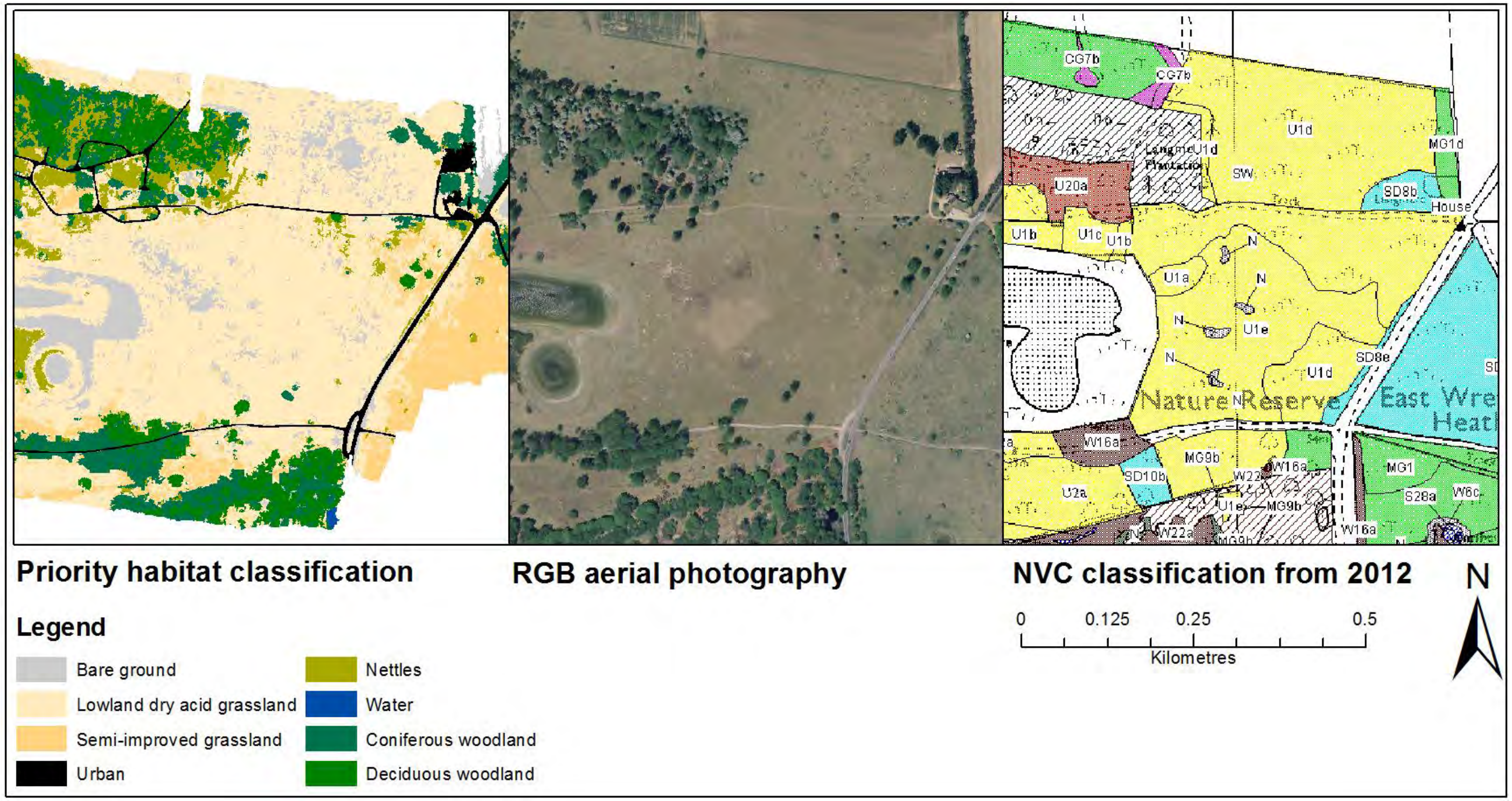


Figure 6:74: Comparison of the EO habitat classification (left) compared with NVC classification from 2012 (right)

By comparing the images in Figure 6:74 it can be seen that the classifications are very similar. The dune grassland communities (SD10b and SD8) have been classified in the EO as semi-improved, they were more productive than the rest of the grassland.

The NVC map has a less detailed distribution of bare ground and scrapes, while nettles were not mapped during the NVC survey. Nettles are a significant management issue on the site, and they were readily identified in the remote sensing.

The maps highlight the differences in the EO mapping and the field work survey. If individual species at low frequency and of small size are an important component of a habitat type then EO is not the best tool for identifying them however ,if cover forming species are the major component it gives an extremely accurate spatial distribution. As a site manager both datasets are useful, the EO mapping may highlight condition features better while the field work highlights the presence of significant plant species.

Dersingham Bog

The NVC survey of Dersingham bog was undertaken in 2006, the classification from EO was formed with a mixture of imagery types including SPOT, GeoEye, CIR photography and LiDAR. Table 6:10 shows the classes across the classification systems present in this case study.

Table 6:10: Correspondence between the BAP priority habitats, Annex I habitats, EO classification and the NVC classes present on the case study site at Dersingham Bog

BAP Priority habitat	Annex I Habitats	EO class	NVC
Lowland fens	**H7150**: Depressions on peat substrates of the *Rhynchosporion*	Wet heath	**M21**: *Narthecium ossifragum-Sphagnum papillosum* valley mire / **M3**: *Eriophorum angustifolium* bog pool community / **M25a**: *Molinia caerulea-Potentilla erecta* mire / **W4c**: *Sphagnum* spp. sub-community (and associated mosaic)
	H4010: Northern wet heaths mosaics		**M21**: *Narthecium ossifragum-Sphagnum papillosum* valley mire / **M3**: *Eriophorum angustifolium* bog pool community / **S9**: *Carex rostrata* swamp (and associated mosaic)
	Not annex I habitat	*Molinia*	**M25a**: *Molinia caerulea-Potentilla erecta* mire / **W4c**: *Sphagnum* spp. sub-community (and associated mosaic)
		Marshy grassland	**MG1**: Arrhenatherum elatius grassland / **S4**: *Phragmites australis* swamp and reed-beds (and associated mosaic)
		Bog	**M3**: *Eriophorum angustifolium* bog pool community (and associated mosaic) **S4**: *Phragmites australis* swamp and reed-beds
Lowland heathland	**H4030**: European dry heaths	Dry heath	**H1**: *Calluna vulgaris - Festuca ovina* heath
Lowland heathland	**H4030**: European dry heaths	Gappy heath	**H4**: *Ulex gallii - Agrostis curtisii* heath

The images in Figure 6:75 show the correspondence between the classifications. There is good general correspondence between these maps. The significant habitats have been identified with very similar extents in all three maps. North of the track the general shape of the M21 mosaic including wet heath and ponds equating to H7150 agrees well between these maps, the different components of the mosaic are separated out in the remote sensing classification (seen in section 6.3.3) but have been amalgamated to present at an Annex I level. As previously mentioned, communities can be identified however, the detection of the occurrence of infrequent non-cover forming species is not available by EO analysis.

There seems to have been real change since the 2006 NVC survey with forestry felling in the East and some scrub encroachment. The large patch of bracken is not shown in the NVC, and has colonised an area of woodland which has been felled since the NVC survey. This map shows that for site management the ability of EO to pull out such single species stands makes it a useful feature, and the general agreement on habitat shape and extent shows that it could be a useful tool in tracking changes in the extent of habitat features.

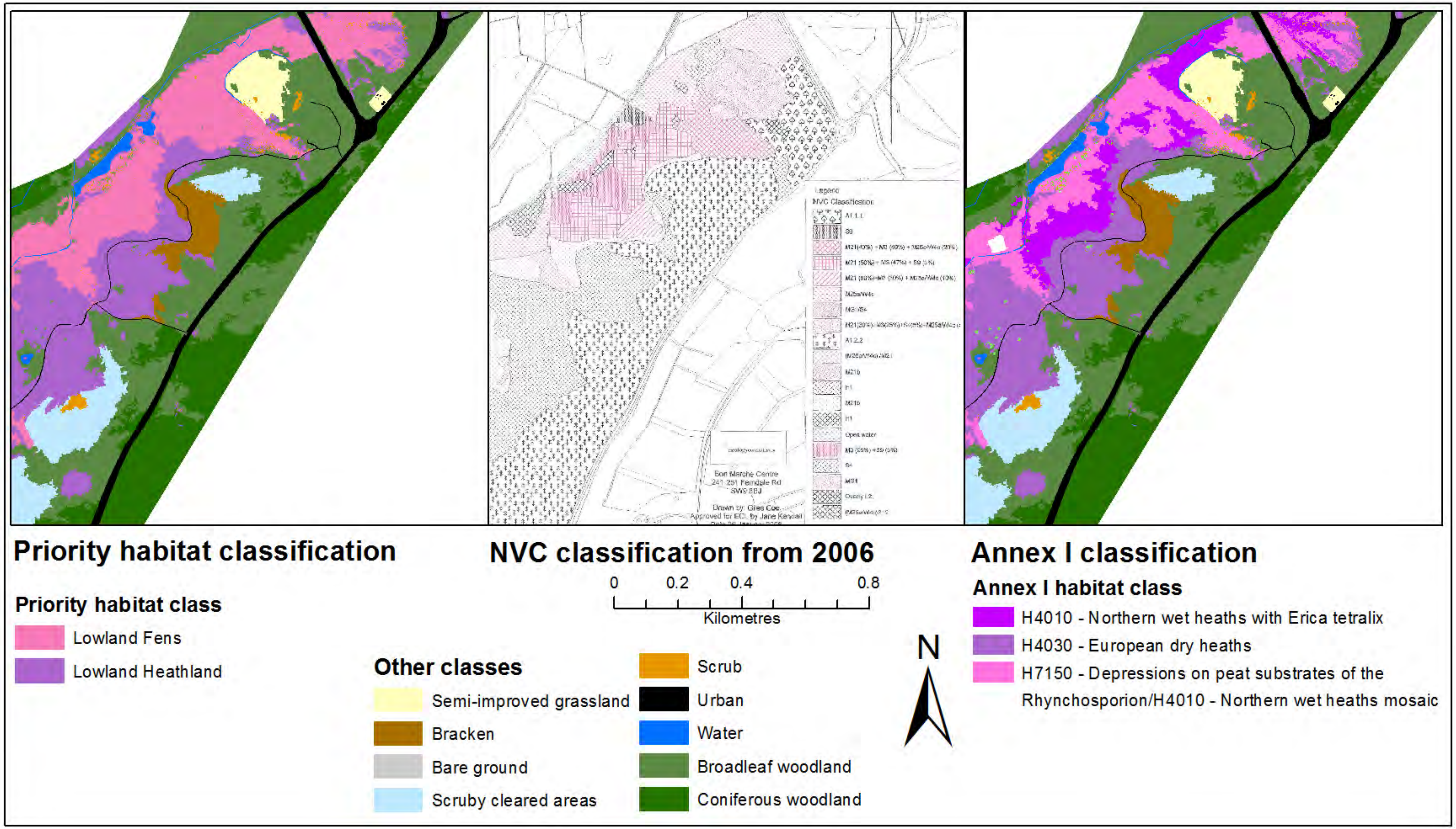


Figure 6:75: Comparison of habitats at Dersingham bog compared with NVC from 2006

Brancaster

A large number of NVC communities and Annex I habitats occur at Brancaster, Table 6:11 shows the classes across the classification systems present in this case study.

Table 6:11: Correspondence between the BAP priority habitats, Annex I habitats, EO classification and the NVC classes present on the case study site near Brancaster

BAP Priority habitat	Annex I Habitats	Remote sensing class	NVC
Coastal sand dunes	**H2130** Dune grassland	Vegetated dunes	**SD7**: *Ammophila arenaria-Festuca rubra* semi-fixed dune community **SD9**: *Ammophila arenaria – Arrhenatherum* dune grassland **SD8**: *Festuca rubra-Galium verum* fixed dune grassland **SD11**: *Carex arenaria – Cornicularia aculeate* community
	Not Annex I		**SD10**: *Carex arenaria* dune community
	H2190 Dunes with creeping willow	Dune scrub	**SD16**: *Salix repens – Holcus lanatus* dune slack
	H2160 Dunes with sea-buckthorn		**SD18**: *Hippophae rhamnoides* scrub
	H2120 Shifting dunes with marram	Dune sand	**SD6**: Ammophila arenaria mobile dune community
Reedbeds	Not Annex I	Reedbeds	**S4**: *Phragmites australis* swamp and reedbed
Coastal and floodplain grazing marsh	Not Annex I	Grazing marsh (medium productivity) Grazing marsh (high productivity)	**MG10**: *Holcus lanaltus – Juncus effuses* rush pasture
		Grazing marsh (low productivity) Grazing marsh (medium productivity)	**MG11**: *Festucarubra – Agrostis stolonifera – Potentilla anserine* grassland
		Grazing marsh (low productivity) Grazing marsh (medium productivity) Grazing marsh (high productivity)	**S6**: *Carex riparia* swamp **MG13**: *Agrostis stolonifera Alopecurus geniculate* community
Fen	Not Annex I	Reedbeds	**S28**: *Phalaris arundinacea* tall herb fen
			S12: *Typha latifolia* swamp
Salt marsh	**H1330**: Atlantic salt meadows	Saltmarsh (established)	**SM13**: *Puccinellia maritime* saltmarsh **M18** *Juncus maritimus* saltmarsh
		Grazing marsh (low productivity) Grazing marsh (medium productivity) Grazing marsh (high productivity)	**SM14**: *Halimione portulacoides* saltmarsh **SM13**: *Puccinella maritime* saltmarsh **SM10**: *Pucinellia maritime, Salicornia, Sueda maritime* transition low marsh
	H1310 Glasswort and other annuals colonising mud and sand	Saltmarsh (pioneer)	**SM8**: Annual *Salicornia* saltmarsh
	H1420 Mediterranean	Coastal scrub	**SM25**: *Sueda vera* drift line

BAP Priority habitat	Annex I Habitats	Remote sensing class	NVC
	saltmarsh scrub		**SM21**: *Sueda vera-Limonium binervosum* saltmarsh
	Not Annex I	Saltmarsh (established)	**SM7** *Arthrocnemum perenne* saltmarsh
Not priority Habitat	Not Annex I	Woodland scrub	**W21**: *Cretaegus monogyna – Hedera helix* scrub
Not priority Habitat	**H1320**: Cord-grass swards	Saltmarsh	**SM6**: *Spartina anglica* pioneer community **SM4**: *Spartina maritime* saltmarsh

Figure 6:76 shows the comparison between the aerial photography, the NVC survey and the EO classification. The habitats amalgamated to BAP priority habitats and Annex I habitats can be found in section 4.4.1.

The NVC survey was undertaken in 1999 and is therefore 14 years old. If the saltmarsh and sand dune systems are functioning as a healthy ecosystem there will be a considerable amount of change in this time. Some parts of the interface between saltmarsh and sand dune should change between habitat types as the sediments move due to the tides, currents and storm actions, and areas stabilise and are colonised by vegetation. The imagery and aerial photography confirm that there has been a significant amount of change since the 1999 survey, it is therefore not appropriate to carry out a direct comparison between the surveys. A general evaluation of the aerial photography shows that the habitats identified from the EO analysis seem to match those which can be seen from above. In the coastal area many of the Annex I and BAP priority habitats are characterised by their cover forming species. Using high resolution satellite imagery and 1m LiDAR, it is possible to identify many of the communities.

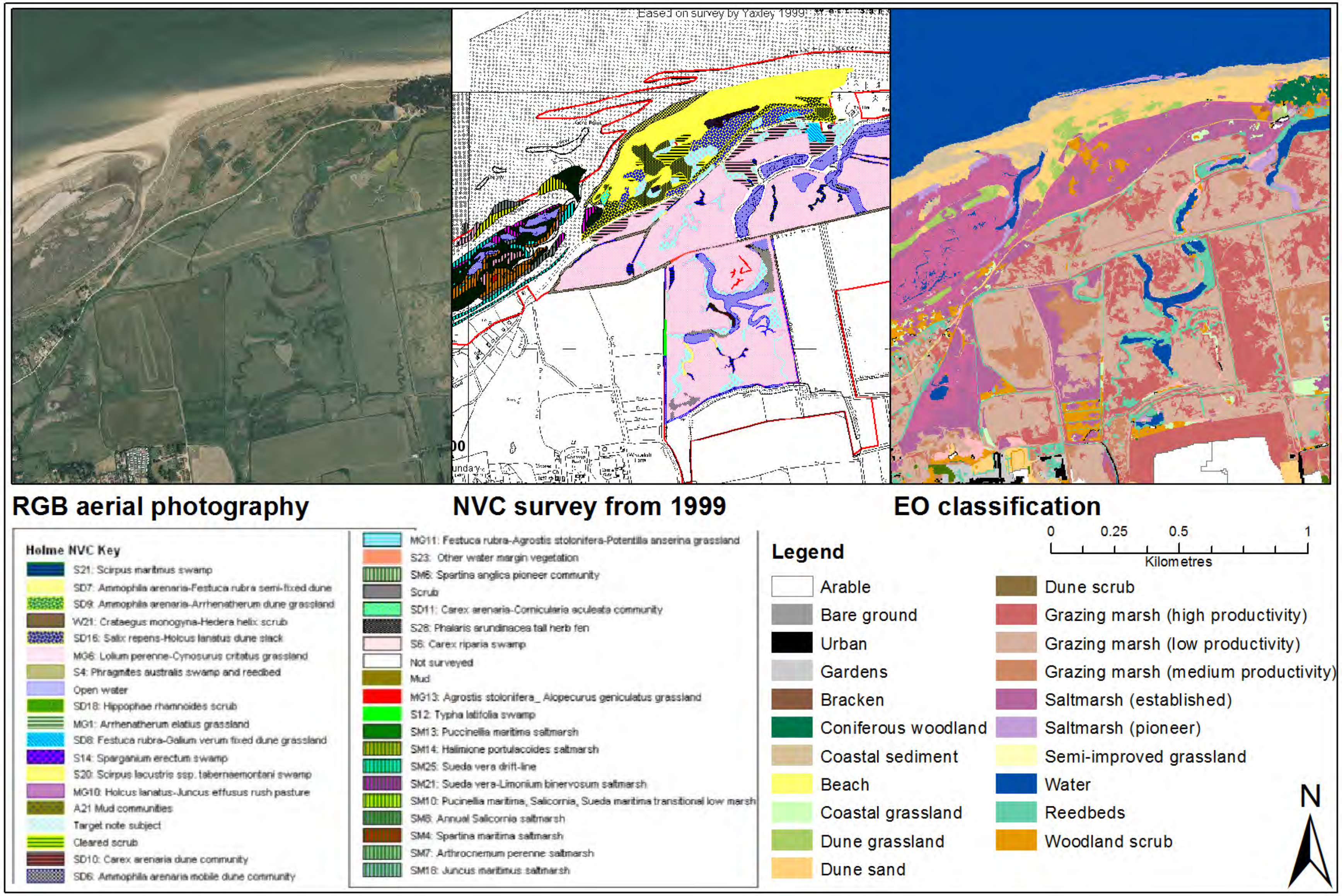


Figure 6:76: Comparison of habitats near Brancaster compared with NVC from 1999

Conclusions from comparison with field mapping

The site based analysis considered both the visual match between the field based data, aerial imagery and EO data sets in the light of using this scale of mapping to both identify individual Annex I habitats and also inform site management. This evaluation equates to the 'fitness for purpose' of the map rather than a traditional accuracy assessment, but is relevant in this discussion because the purpose of the maps varies the required accuracy or suitability. The maps demonstrate that EO classification can give a good representation of Annex I and BAP priority habitats which are identified by their cover forming species. In terms of usefulness for site managers, the level of spatial detail possible using very high and ultra-high resolution remote sensing would be an advantageous addition to traditional species based site maps, outlining features such as bare areas, stands of nettles and scrub as well as changes between saltmarsh and sand dune habits at the ecotone. EO does not allow individual species to be found if they are of small size or infrequent cover value and in these situations it is best used as a tool for targeting site based survey effort at areas most likely to contain the Annex I or priority habitat type.

6.6.4 Feedback from NBIS on the usefulness of the project outputs

When reporting on the 'fitness for purpose' of the mapping outputs it is important to consider how they may fit into existing activities and be used for a range of projects. One of the main users for this type of map in Norfolk is the County Council including their Local Records Centre, Norfolk Biodiversity Information Service (NBIS). They have provided valuable in-kind support and advice to the project through input from the staff of NBIS who have been project partners. Specifically NBIS have:

- made available existing species, habitat and site information and advised on the presence of BAP priority habitats and Annex I habitats in the county;
- provided guidance on areas which will give good ranges of land use and habitat;
- provided skilled ecologists and volunteers to collect new data where appropriate;
- helped organise, provided venues and made presentations and provided expertise for workshops and field-based project events;
- advised where there is interest from other local organisations and facilitated their engagement with project activities.

Biodiversity benefits are highly dependent on local action because biodiversity is ultimately lost or conserved at the local level. For NBIS, delivering detailed county based habitat mapping and condition assessment work is vital to support decision-making at local and regional levels. The habitat information they provide helps to protect and improve biodiversity within Norfolk and beyond and is recognised as being an essential input to the development of a new county business plan in 2013.

Alongside county based mapping, NBIS works as part of the East of England Regional LRC Forum, who are involved in regional habitat mapping projects, so investigating a multi-scale approach is very appropriate for this work. Many important landscape areas in Norfolk straddle county boundaries, so a wider scale is important.

As part of the assessment of the practicality and usefulness of the EO techniques, feedback was requested from NBIS through a series of questions. The full questions and responses can be found in Appendix 5: full answers from NBIS on the usefulness of the mapping and a summary is provided below:

Envisaged uses of the landscape scale mapping

- Adding information in our standard data search
- Developing ecological network mapping
- Habitat opportunity mapping
- Green Infrastructure mapping – Norfolk has 3 growth points involving 37000 new houses around Norwich and new major road north of Norwich
- Monitoring change in areas vulnerable to change, particularly through flooding – coast, broads, fens

Benefits compared with current approaches

Current habitat mapping from API including BAP habitat inventories:

- Limited to the habitats it is suitable for.
- Time consuming and therefore have to balance the need for detail with the ability to produce the mapping to reasonable timescales.
- Over the last four years NBIS has produced an equivalent area of mapping to the two pilot areas covered by the Norfolk pilot in one summer.
- It is hard to monitor change in a meaningful way as the baseline extends over a long period.
- The financial cost is also less compared with the staff input for existing outputs

Most useful case study outputs

- Ability to map arable field margins
- Ability to map hedgerows and hedgerows with trees
- Measures of productivity such as at East Wretham Heath to allow for much more refined targeting of habitat management.

If you had access to the maps, data and tools the project has produced, are there any issues or barriers that would prevent you from using them?

- Maps and data – no issues or barriers to their use by NBIS.
- Tools – potentially issues, as we don't have the computing capacity or software. I don't see that it would ever be cost effective for us to buy the software and training that we would need to use them.

What has NBIS gained from the experience of the project?

- Increased habitat survey skills through the ground truthing work, having to look at survey work from a different angle.
- Deeper understanding of Annex 1 habitats. (previously focussed on BAP habitats)
- Experience of working with a service provider
- The opportunity to collaborate with the private sector and national conservation bodies
- Developing the way NBIS will work in future in any use of the potential EU satellite data

6.7 Costs

6.7.1 Planning for the use of EO – cost considerations

Planning for the use of EO for habitat surveillance requires agencies and other users to consider in some detail:

- the nature and requirements of habitat surveillance;
- what role EO will deliver as part of a potential suite of techniques;
- the range of options available when using EO – starting with data acquisition and continuing right through to assessing the quality of the output of mapping;

To assist with this process, we have set out “cost considerations” in Figure 6:77; these are the main considerations for determining and specifying the requirements of EO which therefore have a bearing on the cost of the use of EO as a technique for use in habitat surveillance. The process illustrates the need to take account of the influence of variable factors that can influence costs, such as the particular environmental context in which it is taking place. Given the wide range of types of imagery and quality of data available, there are likely to be trade-offs needed to settle on an approach that results in costs that are in-line with the benefits arising from the use of an EO technique.

This has been a research project based on establishing how far it is possible to map Annex I and BAP priority habitat and condition features. The project findings that relate to the repeatability and likely cost of this approach for other regions are described in relation to Figure 6:77 and make reference to the Norfolk pilot.

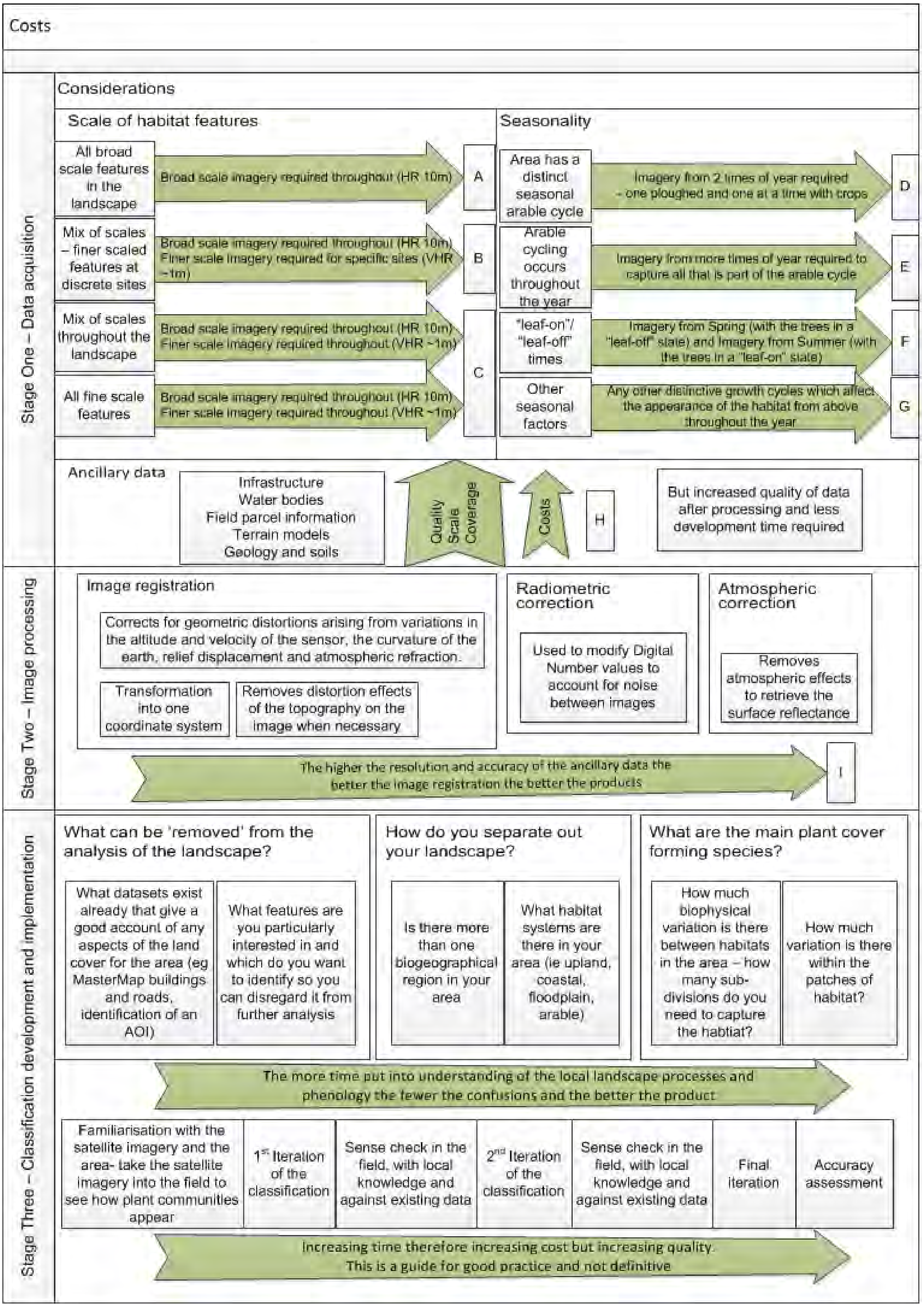


Figure 6:77: Cost flow chart for EO mapping considerations and cost implications (Descriptions of the boxes lettered A-I can be found in the following text)

Stage one – Data Acquisition

The first stage is to establish what imagery is needed. To do this it will be necessary to calculate how many satellite imagery scenes are necessary. This is a combination of what spatial and spectral scale the imagery needs to have and the temporal resolution necessary (how many temporal images are required to capture the variation). If the landscape is dominated by a distinct seasonal arable cycle, two images may be sufficient to separate arable land from other grassland environments, one at a time of year when the land is ploughed and one while the land is cropped (*Figure 6:77-D*). Where the landscape is dominated by many different arable system cycles (such as Norfolk) it is necessary to have four images from winter and spring, through summer and late summer (*Figure 6:77-E*). For an area with mostly semi-natural vegetation and a grass based agriculture season, two seasons may be sufficient ("leaf-on" and "leaf-off") (*Figure 6:77-F*). These arable considerations will be used to identify the arable cropping and then the "leaf-on" / "leaf-off" images will provide the most information about semi-natural habitats. Other specific seasonal semi-natural requirements may be present (*Figure 6:77-G*). If robust data already exists about the arable land use and therefore these areas can be masked out from analysis without imagery, this will reduce the cost. If the seasonal imagery requirements all align then fewer images are required lowering the cost, and likewise if they do not align then more images are required increasing the cost.

It is not necessary to have all the images of the same spatial or spectral resolution, as a high spatial resolution image can be used to identify objects which can then be found using broader spectral scale data. *Figure 6:77-A* presents a minimum imagery requirement, for example a SPOT and LANDSAT image, and this would only allow broad scale habitats with large patch sizes to be identified. This includes CF Tier 2a habitats such as heathland and represents the lowest cost option of these scenarios. Where more intricate habitats occur, more imagery, and a more detailed spatial scale will be necessary. *Figure 6:77-C* presents the case where broad scale imagery and very high resolution imagery (such as RapidEye) is required across the whole area and presents the most expensive scenario. *Figure 6:77-B* requires higher resolution imagery in specific locations which limits the amount of the high resolution imagery required making it more expensive than scenario *A* but less expensive than scenario *C*.

Only optical imagery has been used within this project. Radar imagery including Synthetic Aperture Radar (SAR) is becoming more available although is still expensive and offers potential for picking up additional vegetation features and is not restricted by cloud cover like optical imagery.

Table 6:12 shows the imagery used in the Norfolk study and the indicative cost is included to give a guide as to image acquisition cost.

Table 6:12: cost of imagery

Source of EO data	Scene	Multispectral Spatial Resolution (m)	Spectral Resolution	Indicative Cost	Cost for the scenes used in Norfolk	Size of area
Landsat	180x170km	30	B, G, R, NIR, SWIR	Free	Free	1,071,000km^2
DMC	600x600km	30	Visible & NIR, SWIR	£	£963	360,000km^2
ASTER	60x60km	15/30	G, R, NIR, SWIR (pre-2008), TIR	£	£500	18,000km^2
IRS (Resourcesat-1)	150x150km	20	G, R, NIR, SWIR	££	£2590	22,500km^2
SPOT-5	60x60km	10/20	G, R, NIR, SWIR	£££	£4500	7200km^2
RapidEye	78km swath (AOI)	6.5	B, G, R, Red Edge, NIR	£££	£3846	5000km^2
GeoEye-1	~5x10km (AOI)	1.65	B, G, R, NIR	££££	£1430	200km^2

Additionally, ancillary data is also a consideration (*Figure 6:77-H)*. It may be necessary to purchase this ancillary data but high quality ancillary data can vastly increase the quality of the product created. In the UK, OS MasterMap buildings, roads and rivers are extremely useful to include in the segmentation and are an important consideration. Soil and geology data give context and the ability to split out types of grassland from one another. Licences for these datasets can be expensive if they are not already held by the organisation and restrictions within these licences can restrict potential users of the final mapped products. It is also extremely important to have a detailed digital terrain model (DTM), these can also be costly.

Stage 2 – Image processing

Following image acquisition, the images need to be processed (*Figure 6:77-I)*. It is necessary to obtain the imagery in as raw a form as possible (e.g. Level 1a or 1b) and process it against the most detailed DTM available, although the DTM must cover a larger area than the imagery being processed. Imagery purchased which has already been corrected will have been calculated against a general global scale DTM. It will not be an exact fit at a local field scale and therefore create artefacts and image overlay issues can result which affect the efficacy of the rule base combining different datasets.

As a general indication, each image should take approximately a couple of hours for registration, if suitable processes are in place and the imagery meets the specification stated. However, time required can vary between a couple of hours and a couple of days if the imagery is not supplied at specified levels and based on the software available, the experience of the operator, the processing power of the computers, the familiarity with the data and the DTM being used. The higher the resolution of the image and the larger the size of the area also both increase the time required for processing.

Stage 3 – Classification development and implementation of the classification

The final stage is to develop the classification; this also includes the implementation tasks as it should be undertaken in an iterative process. This is the hardest area to suggest time scales as it depends on a larger number of factors including:

- experience of the ecologists using the EO tools,
- the experience of the EO processes,
- knowledge of working with the imagery,
- intricacy of the habitats in the area,
- the agricultural processes,
- the seasonal characteristics of the landscape features,
- the level of mapping detail needed.

For the Norfolk project the rule development stage, including the case studies, took between 10-12 weeks of person days over a four month period. This included both the landscape scale mapping and the detailed case study development, including the iterations and field checking stages.

It involved the development of rule bases for the East and West, the first was created and then was adapted for the other region as they had very different biogeographical character. The coast was also a separate biogeographic zone with its own rule development. Each case study involved the specific manipulation/development of the rule-base to incorporate higher resolution imagery.

In general about a third of the time involved in this stage is in understanding the landscape ecology and the spectral variation of the data. A third will be working up the rule base and segmentation and the final third is in re-running and iterating and enhancing the project to reach a satisfactory result.

When planning this type of project, the amount of pre-existing data and ecological knowledge together with the imagery available will be a driving factor for the calculation of time requirements.

The actual person days is only a subset of elapsed time due to the need for a large amount of computer processing. The speed of this will depend on the specification of the computer and the robustness of the software and any licence restrictions (for much of this project eCognition was used). The main time issues are the spatial scale of imagery and complexity of rule-bases. For one of the landscape regions several days was required in computer time for an iteration to run.

6.7.2 Potential for development

For any EO mapping created by an OBIA Approach, it must be acknowledged that if areas of the map are shown to be inaccurate, it is possible to go back through the data and amend it. By working out where the error has arisen, the rule can be altered or additional information can be added into it to stop the confusion. During the project the map was evaluated by the project team and the project partners several times. Issues and errors were identified and action was then taken to re-evaluate these misclassifications to create subsequent iterations and to produce the final maps.

The ability to re-visit and re-interpret the data allows for additional information to be gleaned if reporting needs change, or for use as land cover mapping for additional purposes rather than needing to start the process from scratch as may be necessary with a field work survey. This is a valuable asset of any EO output.

Collaboration is also a powerful tool for pooling resources. The versatility of the EO outputs can mean that multiple stakeholders, from different departments, organisations or adjacent areas can pool together resources for sourcing data and the initial outlay for the mapping.

7 Results feeding into the Headline Questions

The findings from the Norfolk pilot provide information that enables some of the headline questions to be addressed. These are presented in this section.

7.1.1 Establishing the role for EO in on-going habitat surveillance

How well did landscape-scale mapping perform?

Overall, landscape-scale mapping **performed very well** for identifying areas of potential semi-natural habitat within the arable dominated landscape. Two factors were critical to the success of the process:

Availability of suitable data and imagery:

- for the production of "masks" to delineate areas in which particular habitats are found (and then mapped); and,
- to "segment" the landscape to create real-world objects (e.g., field parcels).

Knowledge of the landscape context – this must be well understood so that:

- appropriate datasets and imagery were chosen both to create "masks" that delineated coherent areas for further analysis in the "landscape splitting" process and for the creation of field parcels;
- limitations in the data can be identified and appropriately dealt with.

It is important to recognise that the results achievable at a landscape scale will depend upon the data and imagery used and that this can be varied within the landscape scale mapping process (section 6.1). For example, in all coastal areas in the two landscape study areas, colour IR aerial photography was used in conjunction with satellite imagery to delineate the habitats, but in arable areas medium resolution satellite imagery was used to create the arable mask.

The **main observations about data and imagery** and their use for landscape scale mapping were:

- overall, OS MasterMap provided a precise dataset for the identification of water features, roads and urban areas. However, inconsistencies in the way MasterMap portrays habitat features made the construction of the rule set complex, increasing processing time.
- field boundaries from OS MasterMap provide useful information for the production of arable and grassland masks. However, whilst field boundary data is precise, it is incomplete in areas. It is also not as robust or suitable for use in segmentation as LPIS field parcel datasets. Time spent improving the content of the OS dataset (section 6.1.3) improved the quality of the segmentation.
- an excellent topographic model is required for landscape splitting (5m or better), even in a flat county, as proximity to water and height above sea level are key ecological drivers that need to be built into the rule-base.
- using CIR aerial photography to achieve a finer scale segmentation of coastal areas (i.e., areas within a coastal mask) resulted in habitat boundaries that accord well with those found on the ground.

Habitats that should be identifiable at the types of accuracy described (e.g. above 80%) using this EO technique**:**

- stands of broadleaved, mixed and coniferous woodland and areas of felled woodland;
- lowland heathland and upland heathland where *Calluna* and/or *Vaccinium* species are dominant;
- wet and dry heathland types (required for mapping Annex I habitats) could often, but not

always, be discerned at the landscape scale with the use of contextual data;

- areas of “potentially species-rich grassland” for follow up survey using field survey, or for some grassland types using other EO techniques;
- wetland habitat types dominated by Purple Moor grass *Molinia carulea* (using SPOT and IRS data);
- the general features of saline, brackish and freshwater water environments (sand dunes, saltmarsh, fen etc.) can be discerned at the landscape scale using medium resolution satellite imagery (SPOT and IRS were used);
- scrub can be found if a suitable finer resolution image is available;
- a coastal mask provided a successful tool for separating Atlantic salt meadows from species-rich grassland. It was also possible to split between Annex I “*Salicornia* and other annuals colonising mud and sand communities”. Sediment can also be identified successfully at low tide.

Landscape scale mapping **is a pre-requisite** to mapping of semi-natural habitats widely distributed across arable landscapes, such as hedgerows, arable field margins and isolated patches of semi-natural grassland.

Once arable spectral signatures were understood and with the use of aerial CIR imagery it was possible to:

- trial mapping of arable field margins (it is necessary to know the range of the forms these take locally and they needed to be sufficiently wide);
- map hedgerows (good segmentation is necessary for hedgerow mapping).

How well did site-based mapping perform?

Overall, site-based mapping **performed very well:**

- for mapping the potential extent and range of a diverse range of high priority semi-natural habitats in differing landscape settings;
- in showing the fine detail of the complex of an ecosystem, especially on larger sites and those where natural processes are occurring;
- for the relatively consistent mapping of the extent of some BAP priority habitats and semi-natural habitats.

Site-based mapping of case-study sites employed the same approaches (rule based object-orientated) as used at the landscape scale, but had available a greater variety of higher resolution data and images (including a greater range of spectral bands). Very high resolution (<10m) satellite imagery and ultra-high resolution imagery (<1m) and DTMs (acquired from UAS or LiDAR) were used. The main findings of the case studies were:

- Breckland heathland grasslands were successfully identified using CIR aerial photography or other ultra-high resolution aerial imagery (from a UAS);
- The use of 1m resolution LiDAR in the image stack dramatically increased the ease of identification of all coastal classes;
- H1330 Atlantic salt meadows and H1420 Mediterranean and thermo-Atlantic halophilous scrubs are possible to identify using ultra high resolution imagery (from a UAS);
- The Annex I sand dune classes can be successfully identified with fine resolution data (including LiDAR);
- Reedbeds were classifiable when LiDAR “leaf-on” date data is available within the image stack;
- Coastal vegetated shingle and H1210 Annual vegetation of drift lines can be identified with GeoEye or airborne CIR resolution data;

- Fen vegetation shows as a mixture of marshy grassland, wet heath and scrub vegetation at the landscape scale. With ultra-high resolution data it was possible to separate out the various components of fen vegetation to identify more of the Annex I habitat types.

There were some general **limitations** to what could be achieved (see boxes in section 6.2 "*what worked less well*") notably:

- It is not possible to assign species rich grassland to BAP priority or Annex I habitats unless there is suitable soil information to confirm the acid, neutral or calcareous nature of the sward;
- Saline lagoons were difficult to split from other water features, as the saline influence is not possible to detect from optical imagery;
- Habitats that are defined by their understory vegetation (e.g., in wetland and woodland environments) could not be identified at a landscape scale, but at an ultra-high resolution scale, wetness classes within an open woodland canopy can be found.

It is not possible to map habitats that are similar to several other habitats in their cover forming species but are distinguished by small herbs which occur in the sward at low frequency.

What do we know about the accuracy and cost of producing the mapped information arising from the pilot?

<u>Accuracy</u>

It was not possible to produce definitive accuracy statistics for many individual Annex I or BAP priority habitats because the rarity of these habitats meant there were insufficient ground data validation points to provide meaningful results (it would be a major exercise to collect sufficient data to assess the classification accuracy in this way). The accuracy of mapping these habitats in the case study sites was therefore deduced by comparing maps produced by field survey, or aerial photographs, with habitat maps produced using the EO techniques.

For the landscape scale study areas, general habitat classes were used. For the accuracy assessment, broad and sub-class information on 622 validation points was collected by the staff at NBIS, which were amalgamated into general habitat classes to compare with the landscape classification. The traditional correspondence accuracy of the mapped information generated for the landscape scale study areas in the Norfolk pilot areas is over 78% in the west and over 87% in the eastern study area. There is variation in the accuracy levels achieved for the constituent classes, but for the classes with the highest numbers of validation points the accuracy is consistently high.

The overall spatial accuracy and the Portmanteau accuracy (for specific habitats with sufficient field points) presented values of over 90% showing that there was good consistency in mapping habitats within the two landscape study areas.

The accuracy levels appear to be in line with other techniques such as visual interpretation of aerial photography and habitat mapping from field survey, although each approach to mapping has particular strengths and weaknesses. This is an important point because the EO techniques do not simply duplicate what other methods provide but compliment them. For example:

- in field survey, a greater range of habitats of high conservation value can be mapped, because distinctions are made based on particular species which are not cover forming.
- using EO techniques habitat mosaics and features such as scattered scrub or stands of nettles can be more readily delineated and correctly located by EO than they can be by

field survey (Parker *et al.* 2010).

In this respect, the techniques are complementary; mapping of habitat extent can be enhanced by using suitable imagery with ancillary data while field survey is used to classify areas with specific indicator species.

In relation to the Crick Framework, where suitable imagery and ancillary data were available:

- Habitats in Crick Framework **Tiers 1, 2a, 2b, 2c, 2d** could be mapped in their entirety.
- Some but not all of the habitats in **Tiers 3a, 3b, 3c, 3d** could be mapped. (When ultra-high level DSMs were available most Tier 3d classes could be mapped. The lack of accurate soil data meant Tier 3c habitats could not be mapped).
- Habitats in Crick Framework **Tiers 4 and 5** could not be mapped to a specific level, but the general habitat group could be mapped, for example, broadleaved woodland could be mapped but not the Annex I class H9160 which needed species within the understory to be identified.

BAP habitats: It was possible to map BAP priority habitats distinguished by their cover forming species (see sections 6.6.1 and 6.6.3). Where these occurred at a small spatial scale then these have been mapped from case-studies but some (notably lowland heath) have been mapped from the landscape scale mapping using broader-scale imagery.

Annex I habitats: It was possible to map Annex I habitats where they are distinguished by their cover forming species. All Annex I habitats that could be mapped were mapped using very high resolution imagery, often in conjunction with ancillary data such as very high resolution DSMs.

Environments: EO has been found to be extremely effective at dividing the landscape into broad habitat groups (e.g., separating grasslands from heathlands from woodlands). This is a useful feature that could significantly aid habitat data collection by targeting field survey at areas potentially containing Annex I and BAP priority habitats.

Cost

Feedback from NBIS suggests that the landscape scale mapping offers a cost saving over traditional mapping of habitats from visual interpretation of API. An area that had taken over four years to map by visual interpretation of aerial photography was completed in just a few months.

A cost consideration model has been developed to allow habitat practitioners to consider their particular needs and identify the key factors that will influence cost of using EO both at a landscape and site-based scale.

How transferable are the results of the pilot and what considerations need to be taken into account to ensure success?

Transferability of the findings

In terms of the environments and habitats studied: The approaches developed in the five environments studied should have direct applicability outside Norfolk. Whilst set in a lowland context, the five environments studied are widely distributed elsewhere in the UK as are the BAP PHs they contain and to a lesser extent the Annex I habitats.

In terms of the Crick Framework tiers: The Tiers within the Crick framework give a good indication about what sort of imagery, and how many images at what spectral detail are needed for identifying the habitats.

The importance of context: Habitats of interest can be separated more easily in some areas than others, depending on what the surrounding vegetation is, the scale at which features occur and what the spectral difference between the vegetation types is. Therefore the exact habitats identified in this study may be easier or more difficult to identify in another area dependent on the habitat context.

In terms of data availability: one of the key requirements for transferring methods to different areas is the availability of suitable data, in terms of resolution, spatial coverage and spectral information.

Transferability has not been quantified but there will be benefits to agencies considering using the techniques, in first looking at key datasets to identify what data are available, gaps, options, opportunities and benefits.

The availability of satellite imagery in other parts of the country varies and cloud free images are more difficult to find in areas with higher rainfall. This has been illustrated in national projects such as LCM 2000 and LCM 2007. However, landscape scale mapping, particularly where supported by in-house RGB or CIR aerial photography should be achievable for most areas of the UK and allows features such as hedgerows and scrub to be mapped with a good field parcel segmentation in place.

Ultra-high resolution imagery and airborne ultra-high resolution height data, (derived UAS or from LiDAR) brought clear benefits to the production of detailed site based products. These data can be acquired for any site at a cost. There is good coverage of airborne LiDAR data for UK coastal areas, collected by the EA however, much of it has been flown in winter in “leaf-off” conditions and is therefore less useful for vegetation analysis.

Building on previous work in Wales: similarities and differences of relevance to transferability

Overall, the rule-base developed in Wales was adapted successfully to a very different landscape context. Some rule-bases were directly transferable (e.g., for *Calluna* heath) but more commonly there was a need to adapt and create new rules (e.g., grazing marsh); this required local knowledge and careful development. This suggests that the rule base can be further adapted and developed for other parts of the UK.

<u>Differences</u>:

- Land use in the wider countryside was completely different and needed many more images in year to identify habitat patches amongst arable land. Demands for imagery and ancillary data were particularly high in Norfolk (compared with in Wales) and it is not envisaged that all parts of the country will require so much imagery. For landscape scale mapping some of the imagery was however, freely available.
- Little use was made of the Aster SWIR in Norfolk, yet it was a major requirement for mapping upland wetland communities in Wales.
- Habitats in Norfolk needed higher resolution to identify one from another as they exist at a finer spatial scale within sites of high conservation priority or are fragmented within spectrally complex arable landscapes.

<u>Similarities</u>:

- Finding the major landscape ecological drivers and setting these up as image masks for targeting sets of rules, works as well in Norfolk as it does in Wales, although the landscape drivers were completely different. In Norfolk, as an aquifer and salt water driven system, wetland features have a completely different context to those in Wales, and an upland / lowland mask was not necessary in Norfolk.
- Matching the level of segmentation to the ecological feature of interest is key to successful mapping in Norfolk and Wales, so hedgerows and dykes needed a different level of segmentation to grazing marsh and arable fields.
- Within Norfolk it is necessary to have images from different times of years. Just as in Wales a “leaf-on” and “leaf-off” image was needed to accurately identify many of the important habitats, but the times of year required are different. In Wales the “leaf-off” image before March contains too much shadow from the hills to be useful however, in Norfolk March is often well into the growing season and is only just within the ‘leaf-off’ criteria and a February image may be more suitable.

Condition monitoring

- The techniques developed are universal and should be transferable, in particular those for productivity and wetness measures. Currently they are very effective as relative measures however, further development work is needed to translate these measures into absolute values for a robust monitoring programme. It is necessary to further understand the effect of seasonal difference and real environmental change in the measures.
- The techniques developed for single stand species are transferable but will require rule-base development locally.

Considerations for successful implementation

- It is important to be aware of the context in which you are working when dealing with the transferability of the rule base. It is important to know the types of habitat locally, and how they interact with the wider countryside. This will inform any similarities or differences that are likely to cause habitats to be spectrally different to that given within the Crick framework.
- It is not possible to use one scale of segmentation for all habitats, those larger areas such as the arable fields need a different scale of objects identified than for the intricacies of the fen surface at Dersingham. Understanding the scale of the habitats in terms of their landscape components is therefore a key factor for successful transferability. Within Norfolk, the habitats are generally more fragmented and occur as smaller blocks, they therefore require a higher spatial accuracy within the imagery than the large upland complexes in other parts of the UK.
- With knowledge of landscape context, it is possible to create masks that successfully delineate areas in which particular habitats are restricted.
- LiDAR or other high resolution DSM (such as from the UAS) is needed to successfully identify some habitats, for example reedbeds and saltmarsh creeks.

There are features of vegetation that evidence suggests EO can detect and that may be useful for the assessment of condition - could these features be mapped in the pilot area? If so, how well?

Three condition features meeting these criteria were assessed: productivity, wetness and single species stands of potentially damaging vegetation.

Fine (10 m) and ultra-fine (0.1m) multispectral imagery were used; alone and in combination.

The results were good – maps and measures were produced that accorded well with what was known about the sites and their landscape context:

- **Productivity** maps enabled visualisation and quantification of the nutrient balance within and around sites.
- **Sources** of nutrient risk and mitigation features could be identified at the scales at which they occur. There were benefits to utilising a range of scales of imagery in this respect.
- **Competitive / invasive plant species** that can be damaging to sites (such as nettles, Himalayan balsam, gorse and birch scrub and purple moor grass) were successfully classified and their extent mapped.
- **Wetland habitats**, such as mires, were classified and graded to reflect variations in site wetness.
- **Wetland measures** were effective for discriminating wet and dry woodlands.
- The addition of finer resolution imagery “sharpened” and improved the detail of maps of condition measures (although this increases the occurrence of ‘mixed pixels’ and this

must be considered in the interpretation).

- A hybrid-pixel object based approach has enabled the “high” and “low” wetness values during a growing season to assign additional value to fields within the Broads. The practical value of the information produced in this analysis requires further assessment.

Are these types of condition measure likely to be useful for habitat surveillance?

Yes, because they provide **new** information about the functioning of sites and are factors which management action can influence:

- **Productivity** and **wetness** measures show information about sites and their surrounding context that are not readily detectable or mappable from standard (RGB) aerial photography or field survey.
- Because the measures are detectable at a range of scales, risk and mitigation features for nutrients can be identified at the scales at which they occur, including from external land, to help inform site management.
- **Competitive / invasive plant species** are a known and common problem on designated sites and their extent is difficult to map by field survey. EO techniques therefore can complement and support field survey.
- Relative measures are generated that can act as a baseline for assessment of change. This information is lacking from other sources.
- They allow the classification of some habitats that are difficult to map from conventional EO techniques or by field survey (wet and dry woodland).

What is the evidence for the potential of the techniques for monitoring, forecasting and hindcasting?

The Norfolk pilot investigated a number of monitoring metrics however, it did not specifically examine forecasting and hind casting techniques. There are a few observations of relevance based on the results of the pilot:

- The productivity (NDVI) and wetness (NDWI) condition measures allow quantification of the nutrient and wetness balance within and around sites. Currently they are only able to show relative values although with further development it is likely these measures can be further understood to allow for calibration and direct measurements. Even as a relative gauge these EO condition techniques lend themselves as a tool for site condition monitoring and on-going site assessment.
- The hybrid pixel object-based method produces a range of quantitative descriptors for field parcels at a landscape scale; these too might form the basis of useful tools for monitoring or modelling using forecasting and hind casting techniques.
- There is demand for good quality habitat maps and data to provide a baseline to support a range of site assessment and monitoring activities, particularly for designated sites. Contemporaneous baselines for county or landscape level activities would support the work of Local Sites Partnerships, Local Nature Partnerships, NIAs and others.

7.1.2 Learning

What benefits arose from increasing the resolution, spectral range and seasonal spread of imagery used and what difference did it make?

Benefits arising from increasing the **spatial** resolution of imagery (rather than the spectral range available):

- The spatial scale of the imagery needs to match that of the habitats, with ideally at least five pixels available to identify separate habitats patches. So for a sand dune where a dune slack may only be a few metres across in places, a spatial scale of 0.5m would give an ideal resolution, whilst for a heathland of 3ha, a 10m resolution would be sufficient. Understanding the spatial scale of the habitats is key to selecting suitable resolution of imagery needed for the site of interest.

- The addition of finer resolution imagery can be used to “sharpen” and improve the detail of maps of habitats and condition measures either by using remote sensing techniques, such as ‘pan-sharpening’ or by providing detailed segmentation objects against which to compare the spectral values. Care must however, be taken as pan-sharpening gives rise to more mixed pixels throughout the image therefore, when interpreting the pixel values this must be considered.
- Use of high resolution imagery improved boundary delineation and the description of areas of mosaic in heathlands, wetlands and coastal areas.
- Producing condition measures and indices using high resolution through to very high resolution imagery allowed condition features to be assessed at the range of scales at which they occur; these gave insight into site conditions and highlighted risks arising from outside the site.
- Small objects need a suitably fine resolution of imagery to successfully identify them; when available, features such as scattered scrub, hedgerows, nettles and a more complete range of types of field margins could be mapped.

Benefits arising from increasing the **spectral resolution** of imagery:

- The NIR bands from the MCA instrument mounted on the UAS (ultra-fine resolution and high spectral specificity) made identification of single stands of negative indicator species possible as it picks up the differences in leaf physiology. This was necessary for mapping birch scrub and Himalayan balsam.
- The general features of saline, brackish, freshwater and woodland environments (sand dunes, saltmarsh, fen, broadleaved, coniferous woodland, potentially species rich grassland etc.) can be discerned at the landscape scale using high and medium resolution satellite imagery. With the addition of ultra-high resolution imagery and a fuller range of spectral bands (in particular along the red edge) it was possible to separate out various component vegetation types in coastal and wetland environments (BAP priority habitats and some Annex I habitats).
- It appears that natural processes (such as water movement through wetland systems) are detectable using wetland condition measures derived from ultra-fine resolution imagery and detailed DSMs.

Main benefits arising from having imagery taken **throughout the season**:

- Acquiring “leaf-on” and “leaf-off” imagery is essential for many habitats (Tier 3) as the difference between “leaf-on” and “leaf-off” reflectance is important to separate many vegetation types including coniferous and deciduous woodland.
- Norfolk is an area with a complex agricultural cycle. Multiple images throughout the season enable the range of arable crops to be identified to create an “arable” mask. Without this (or an alternative arable mask from another pre-existing dataset), the habitats cannot be adequately identified as there will be confusion with different types of cropping and land management, which have spectral values that can mimic effects of natural vegetation.

What benefits arose from the use of a range of other spatial data and what difference did it make?

Two spatial datasets brought benefits that were instrumental to the success of the mapping process and integral to it:

OS MasterMap

- OS MM provided data for the creation of general landscape scale **masks** and for initial **image segmentation**, both key stages in the rule base development (section 4.8).
- OS MM was crucial for creating an accurate mask for urban areas, roads and water features so these features can be excluded from classification of other areas.
- OS MM was a useful data source for starting the rule base for some of the specific land cover classes (e.g., arable, grassland, woodland and coastal); but this did have limitations due to inconsistencies in the labelling of some natural features.
- OS MM was the starting point for **segmenting** the field parcel polygons (as there was no LPIS dataset available to the pilot) further segmentation was required to achieve a suitable representation of the field boundaries.

Digital Terrain Model

- A high resolution DTM is essential for accurate image registration during processing.
- The DTM is also a critical part of the coastal and the grazing marsh masks as the regions of aquifer feed systems and surface water flooding relate to the height above the water table.
- High resolution Digital Surface Models (DSM) give detailed information about the vegetation structure.

LiDAR

- Detailed DSMs from LiDAR or UAS (derived from the RGB sensor) increased the amount of information that could be extracted about the habitat presence, extent and condition (e.g., allowed identification of reedbeds).
- Use of 1m resolution LiDAR in the image stack dramatically increased the ease of identification of a range of coastal and heathland classes.
- LiDAR at 2m resolution was found to be insufficiently detailed to bring added benefits for habitat separation.
- "Leaf-off" LiDAR was much less useful for identification of vegetation features than "leaf-on".

Note: EA has approximately 70% of England covered by LiDAR (at a range of scales 0.5m, 1m and 2m) – however, much of this is "leaf-off".

What were the main issues encountered?

The main issues encountered were:

- The complexity of cropping regimes in Norfolk made separation of the arable land much more difficult than in a grassland-based agricultural area, such as in Wales. Multiple temporal images throughout the year were necessary to reduce this confusion.
- OS MasterMap objects were often useful, although incomplete field boundary delineation in OS MasterMap caused issues. Inconsistencies in the MasterMap classifications for semi-natural habitats such as woodland and coastal habitats in Norfolk meant that only the water and urban classifications were directly used in the landscape mapping and the case study mapping. This is described above and made the construction of the rule set complex and increased processing time (see section 4.7.1).

Other issues encountered during the development of the rule base are outlined in a technical annex which is separate to this report.

How was the Crick Framework used in the planning, delivery and evaluation of the pilot project and how useful was it as a tool to support these activities?

The Crick Framework was useful in planning the delivery of the project as it allowed an evaluation of the likely need for satellite imagery (in terms of spectral, temporal and spatial scales) for the habitats occurring in Norfolk. This allowed the imagery needs to be assessed and assisted with project planning.

- The “User Manual” sets out the stages necessary to complete a project and this methodology was followed for the pilot project, both at a broad scale for the two landscape scale study areas and for the case study areas.
- When developing the rule base, the descriptions of the habitats and the level of detail available in the additional evidence tables was helpful. This enabled the team to anticipate the landscape context of the habitats and identify areas of search where they might be found at a local scale.
- The Crick framework builds on ecological knowledge and remote sensing knowledge together; these two knowledge sources are essential as the project must be tested in the field or against field data to refine and further develop the rules. Numerous iterations of the rule-base were created in Norfolk and checked in the field (more than three times). This level of input is necessary to identify habitats and map them consistently across the whole landscape (see section 6.6.1).
- When considering the results of the habitat mapping during the evaluation, the Crick Tiers were found to provide a useful way of describing the mapping of the habitats, with the increasing resolution of imagery from (a) high resolution, (b) very high resolution and (d) need for LiDAR or high resolution DSM.
- The high temporal frequency of imagery used in in Norfolk was required to describe the very complex arable systems so that they could be masked out from areas of other habitats. The ability to classify habitats in Tier 2 and Tier 3 in Norfolk was enhanced by this high temporal resolution of imagery.
- Although Tier 4 habitats are not identifiable down to their specific class, the case studies showed that the general habitat could be found; this information in itself is a useful tool for targeting field work.
- In addition, the ultra-high resolution UAS data allowed some Tier 4 classes to be mapped by incorporating existing ecological knowledge, or additional field data. For example at Dersingham the bog pools are clearly visible. Previous knowledge existed to show these were H7150, meaning they could be mapped in this case. Similarly with the wet woodland H91E0 within the case study around Rockland and Surlingham Broads, the signal from the ground flora could be identified from a visual assessment of the UAS imagery and potentially individual tree species could be seen. It may be possible to analyse the image and map this habitat in specific locations using a very high spatial scale of imagery and sufficient validation data or species knowledge.

The Crick Framework is a useful way of describing and mapping Annex I and BAP priority habitats as well as habitats in the wider countryside. It is transferable to other regions and contexts.

8 Evaluation

This section evaluates the findings, using the evidence generated by the project and drawing on other available information, to determine the effectiveness, practicality and value-for-money of the EO techniques developed and piloted in this research namely:

- landscape scale splitting and site based mapping – using an object orientated rule-based approach tested in the Norfolk Pilot;
- condition measures developed and tested in the Norfolk Pilot

It focusses on the potential for adoption of the techniques by the UK conservation agencies and their partners in support of the surveillance of high priority habitats in the UK, such as the Annex I habitats and the former BAP priority habitats.

The evaluation is based mainly on the results of the Norfolk pilot study (see section 7 and 8) which reports on surveillance techniques and the results of mapping those high priority habitats found in the study areas (Appendix 1: Priority and Annex 1 habitats present in Norfolk).

The evaluation incorporates findings from other relevant studies employing similar techniques (e.g., Wales) to help inform discussion on the likely transferability of the techniques to other areas of the UK, and takes account of and further development of the Crick framework.

8.1 Effectiveness

Effectiveness: Key findings

KF55. The results of accuracy assessment, feedback from local habitat practitioners and the assessment by the research team of how well the techniques worked, all suggest that the EO techniques developed are fit for purpose for supporting the mapping and surveillance of high priority habitats. Work in Norfolk and Wales demonstrates that the techniques are capable of consistent implementation and evidence suggests that the technique is transferable and so can be rolled out to the UK, and beyond.

KF56. This does not mean that the techniques can be used to identify, map and assess the condition of all Annex I and BAP priority habitats found in the study areas or elsewhere and it is not suggested that they replace field survey. However, they can support and augment current surveillance techniques in a practical way, sometimes improving upon the accuracy of habitat mapping and can add to the suite of surveillance tools available, including for condition monitoring.

KF57. There are already examples of the practical implementation of the techniques in Wales, Dorset, Norfolk and Anguilla (in the UK Overseas Territories (UKOTs)) that demonstrate demand for the outputs that can be produced and evidence that they meet user needs. Further studies as part of MS-MONINA (Lang, 2012), BioSOS (Lucas *et al.* 2011a) and the Environment Agency (Petchey *et al*. 2011) are also demonstrating the value of similar approaches. The EO techniques are considered applicable to a wide range of other biodiversity related activities that support government biodiversity policy, and these are described as part of the evaluation.

KF58. The EO techniques developed have particular advantages that help deliver efficiencies in accordance with the principle of "*gather once use many times*". Mapping habitats will become really cost-effective when the inputs (imagery, data, rule-base) or outputs (maps, measures) are reworked, further developed or reused. The rule-based object-orientated technique lends itself well to this because the rule base and image segmentation work can be built upon or adapted. This keeps the cost of any subsequent analysis using automated techniques very low in comparison with repeat survey, manual re-interpretation of imagery or other traditional survey techniques.

Evaluation of effectiveness considers whether overall the techniques developed, from a technical and practical perspective, are likely to be fit for purpose when used as part of a suite of techniques for mapping high priority semi-natural habitats in the UK.

The project has built up a body of evidence and this is summarised in the key findings in the boxes in Section 6 (Results) and Section 7 (Results feeding into headline questions) and is not therefore repeated here. Instead, the key findings are applied to address four high level questions that cover:

- the practicality and compatibility of the techniques for surveillance of high priority habitats,
- whether they are 'fit-for-purpose',
- added value - other potential uses for the outputs,
- any barriers to uptake.

8.1.1 Practicality

The results of piloting the technique in Norfolk for Annex I and BAP priority habitats have demonstrated that the techniques have real practical application both at the landscape and site scale. It was technically feasible to transfer the approach developed in Wales to a very different agricultural environment and possible to identify and map some of these high priority habitats. Where it was not possible to identify specific habitats, areas with potential high priority habitat were identifiable for follow-up checking by other means. Condition measures were demonstrated and particular applications to which they could be used were identified.

Practicality of the implementation of EO requires a number of considerations, firstly to determine whether EO is the right path for your needs. A suggested path for this could be:

- Run through the user manual (available on the JNCC website) and determine what data you need, ensuring you can obtain access to the right types of data.
- Apply the cost framework (Section 6.7.1) to estimate the costs and compare this with your alternatives.
- Appreciate the added value in relation to the product, how it may be used by other departments/organisations/areas and therefore may be able to pool funds.
- Determine the nature of field survey and training requirements involved so the costs of these can be included.
- Consider the long term needs, updates, uses and costs.
- Use the products effectively and understand their limitations before investing.

During the period of the research the techniques developed in Wales have been taken forward by CCW (soon to become part of NRW) and others as a practical tool and cost-effective means of:

- mapping invasive and alien species;
- producing maps of potentially species-rich grassland as a means of targeting field survey for identifying Local Wildlife Sites for designation;
- mapping features of habitat connectivity to help green infrastructure planning

In Dorset and Anguilla (in the UKOTs) an image analysis approach utilising medium resolution imagery with aerial photography identified broad habitat classes to allow the modelling of ecosystem services delivery and habitat mapping respectively.

8.1.2 Fitness for purpose

Earth Observation is identified as an important development area for habitat monitoring of Annex I Habitats within all the conservation bodies and Defra (JNCC, 2012). This section assesses how fit-for-purpose the mapping has been for meeting policy needs and local needs for spatial biodiversity data and how the techniques developed complement existing surveillance activity.

The 2013 reporting round for Annex I habitats is currently underway, as part of the six yearly cycle of Article 17 reporting. The majority of information comes from Common Standards Monitoring, a condition monitoring technique based on field survey undertaken by the country conservation agencies for SACs. However, most widespread Annex I habitats are not well covered by current surveillance and the major gaps in knowledge are for habitats outside of SACs.

On the basis of the findings of the Norfolk pilot we have identified a number of ways in which the EO techniques developed can support, and in some situations augment, current surveillance techniques for Annex I habitats (Table 8:1 and Table 8:2).

Annex I reporting requires the UK to provide information on very specific reporting parameters (e.g., extent, range, structure and function etc.) for Annex I habitats.

Table 8:1 summarises the way in which we think the EO techniques offer a practical proposition for assisting with this.

Table 8:1: EO in relation to specific Annex I reporting requirements

Reporting parameter	How can the EO techniques support specific Annex I reporting requirements?
Range and Extent	Broadscale mapping can be used to identify specific sites in the wider countryside where high priority habitats (potentially Annex I habitats) might be found. For a few habitats, the types of Annex I habitat can be mapped; for others the range of Annex I habitats can be narrowed down and flagged. This map of potential could then be used to direct targeted field survey to establish the actual range of particular Annex I habitats. The EO techniques are flexible. So for example, within a regional context effort could be funnelled into particular geographic areas to fill gaps in knowledge about Annex I habitats in the wider countryside (as described above) and / or towards providing more detailed maps of large complex sites with mosaics of semi-natural vegetation. There can be a particular focus on areas where there is a high perceived risk of loss or change in extent. Checks could be made of the status of habitats at the edge of their range. What is possible to achieve would be guided by the Crick Framework, image and data availability and a cost-benefit analysis based on particular requirements.
Structure and function	Few Annex I habitats have a conservation status that is favourable mainly due to deficiencies in structure and function - restoration of habitats is a long-term process. EO has been shown to provide a useful and potentially cost effective mechanism for looking at risk features that can affect the condition of the sites and particularly track negative invasive indicator species. The development of productivity and wetness indicators could also be used to help inform management decisions that will maintain habitats in good ecological condition.

Reporting parameter	How can the EO techniques support specific Annex I reporting requirements?
Future prospects	The metrics investigated are currently able to determine relative values. In order to turn these metrics into quantifiable condition monitoring techniques, more research is needed into their response to the daily, seasonal and climatic perturbations of the natural environment to identify real change to a site.

There isn't a rigidly prescribed approach to the surveillance requirements of Annex I habitats; rather it is led by the 'Principles for assessing surveillance requirements' (JNCC 2012). Decisions on the potential for use of an EO approach to assist in the specific circumstances of a conservation agency should be driven by the important principles (Table 8:2). We have illustrated the ways in which the EO techniques fit with the important principles to help illustrate the sorts of situations where use of EO techniques could be used in practice. A costing tool has been developed (section 6.7) to help support assessment of the relative cost of implementing the techniques so that they can be considered as part of the overall surveillance approach.

The practical experience of delivering the Norfolk pilot is very much in line with the approach encapsulated by these principles. In the Norfolk pilot, for example, the decision was made to use a finer resolution data for the mapping of all coastal areas to improve habitat definition and mapping of mosaics of vegetation; in arable areas the extra detail wasn't considered necessary given the extra expense that would be incurred.

Following the publication of the new Framework, the UK BAP partnership no longer operates but many of the tools and resources originally developed under the UK BAP, including the habitat classification and associated habitat inventories for priority habitats remain in use and form the basis of much biodiversity work at country level (NERC Act S41).

Using EO, it was possible to identify many BAP habitats and features of significance to their condition status. For example, features of Breck heaths, which are a type of acid grassland, can be well mapped with EO using the methods proposed.

This analysis provides a high level and generalised perspective, so does not mean that the techniques can be used to identify, map and assess the condition of all Annex I and BAP priority habitats found in the study areas, or elsewhere, and it is not suggested that they replace field survey. However, they can support and augment current surveillance techniques in a practical way leading to enhanced value for money, sometimes improving the accuracy of mapping habitat presence and extent. In addition they add to the suite of surveillance tools available. Good spatial land cover data can be used collaboratively for all spatial planning applications including but not limited to the provision of green space, local biodiversity management, the siting of biodiversity offsetting projects and ecosystem service provision.

Table 8:2: Ways in which the EO techniques fit with the important Principle for assessing surveillance requirements for Annex I habitats

Factor	Important Principle	Added value and way EO approach can interact with field survey to address these
Risk	Habitats at high risk of a significant negative impact will generally require a high frequency of sampling. Assessment of risk can build on the six-yearly assessment of Future Prospects and should take into account the best available information and information on pressures.	If the pressures relate to assessing nutrient status, wetness or invasive species then baseline metrics can be established. This can be carried out at a range of scales appropriate to need. Pressures may be seen from multi-spectral sensors that are not obvious from field survey or interpretation of RGB photography. Baseline measures can be established from the imagery. Monitoring can be scheduled to look for signs of change. At the site level, mitigation opportunities can be examined and any management to deal with the pressures monitored for effectiveness.
Ecology and Management	Very dynamic habitats will need a greater frequency of surveillance to get a clearer understanding of their status. Frequency of surveillance of different parameters (e.g., range/extent, condition) should be appropriate to their sensitivity to change.	Good quality EO derived habitat maps of coastline habitats (section 6.4.2) can act as baselines for monitoring change and the impact of management more precisely than field survey in areas that are very difficult to access and map on the ground.
Existing knowledge:	The level of existing knowledge of the habitat/species itself and/or of pressures affecting it should be taken into account. Habitats lacking basic inventory information have a high requirement for surveillance to solve this information gap because we cannot usually assess if it is under threat until we know where it is.	Identify areas of potential Annex I habitat or areas or potential high priority habitat (e.g., potentially species-rich grassland) for follow up field survey to fill gaps in knowledge. In inaccessible areas or those difficult to map by field survey (e.g., mosaics) more resource could be input (e.g., higher resolution imagery, further development of a rule base) to improve upon the separation of habitats using EO techniques where the Crick Framework supports this.
Quality of existing evidence:	The confidence we have in the overall conservation assessment should influence surveillance required. Habitats for which assessments are based on poor evidence are generally at a higher need of surveillance in the next period.	If sites are extensive and difficult to access, targeted survey by EO, using fine or ultra-fine resolution image and DTM data could be used to improve knowledge of the habitat resource
Assess need in context:	Surveillance should be balanced against other activities that can help achieve FCS. Reviews of pressures can be particularly useful in helping to understand causes of decline. This is needed to inform action that can be taken to reduce negative impacts.	Provide a contextual site analysis using simple EO condition measures and monitor for change. Supply as tool to inform site management and reporting.
Take a broader view and seek efficiencies:	Habitats Directive surveillance requirements should be integrated with the requirements of other drivers and local site management plans. This may increase the surveillance needed (e.g., where needed to provide useful feedback for site management). For terrestrial habitats extent and condition are currently measured using field based techniques, or air photo interpretation using the NVC classification and are relatively costly to do. The required frequency of condition assessment is ideally determined by local threat and management needs.	The EO techniques developed have particular advantages that help deliver efficiencies: • the same imagery (if suitable) can be re-processed and re-interpreted to deliver maps utilising different habitat classifications or to produce and map condition measures. • more imagery can be incorporated into mapping to improve the resolution of the outputs allowing more detailed maps to be developed that can form a baseline map for site management. This could be cost-effective for a very large SAC or in areas where several SACs lie within the coverage of the desired additional imagery. • mapped outputs, masks and scene objects (field parcels) can be reused for other purposes

8.1.3 Added value from the use of EO techniques

Value is demonstrated by the capacity to cost effectively produce a product that is fit for purpose. The techniques bring added value to existing activity to map, protect and manage priority habitats. They also offer additional value and benefits that extend beyond this primary use, due to the flexibility of reuse or refinement of the techniques. Added value includes;

1. **Improved ability to consider sites in the context of the surrounding landscape**

This is valuable both for the management of designated sites (where active management is normally supported by site management plans) and for assessing the status of high priority habitats in the wider countryside, which may or may not be under active management. Site condition may be strongly influenced by the management of the surrounding land, for example, by water and nutrient inputs. The EO techniques offer the ability to adopt a multi-scale approach to mapping and produce a range of concurrent information relevant to a particular site. It is therefore possible to view processes affecting the site at the scales at which they occur and this can be used to help target appropriate site management. This includes external pressures, internal pressures, site dynamics and processes and opportunities for habitat expansion. These are demonstrated in the case studies for condition monitoring in Section 6.5. Looking ahead, there is potential for the effectiveness of site management to be assessed and also indicators developed to allow site risk features to be identified before they impact too much on the site.

2. **Potential for more accurate mapping of habitats that are difficult to assess on the ground**

Habitats can be difficult to assess on the ground because of awkward conditions, (dense vegetation) dangerous conditions (marshes/wet woodland/coastal marsh areas) or because of sensitive ecology.

Mapping of the coastal mosaics in the coastal case study identified the potential to track changes in habitats and build in extra spatial detail not available using field mapping techniques.

3. **Developing new and complementary condition measures relevant to major current issues** (such as climate change, ammonia deposition and invasive species monitoring where rapid change is anticipated and a rapid response is required);

Site management and opportunities for habitat expansion or creation need to take into account existing pressures in the face of environmental threats, particularly in the form of climate change, air pollution and intensification of agricultural land management. Measures have been developed which have been shown to be useful for habitat surveillance because they provide **new** information about the functioning of sites and are factors for which management action can have an influence:

- **productivity** and **wetness** measures show information about sites and their surrounding context that are not readily detectable or mappable from standard (RGB) aerial photography or field survey.
- because the measures are detectable at a range of scales, risk and mitigation features for nutrients can be identified at the scales at which they occur, including from external land, to help inform site management. Opportunities for habitat expansion can also be identified.
- **competitive / invasive plant species** are a known and common problem on designated sites and their extent is difficult to map by field survey. EO techniques therefore can complement and support field survey.

- absolute measures are generated that can act as a baseline for assessment of change. This information is lacking or is of an imprecise nature for these measures.
- they allow the general discrimination of some habitats that are difficult to map from conventional EO techniques or by field survey (wet and dry woodland).

4. **Production of datasets, rule-bases and outputs that can be re-used in new applications** (e.g., connectivity mapping)

The EO techniques developed have particular advantages that help deliver efficiencies in accordance with the principle of "*gather once use many times*".

The rule-based object-orientated technique lends itself well to this. The more the inputs (imagery, data, rule-base) or outputs (maps, measures) are reworked, further developed or reused the more cost-effective the technique becomes. Clearly, this will be driven by demand. There is an increasingly wide range of activity at local, regional and national scales to protect and enhance the natural environment in order to improve quality of life, support the economy and provide a healthy environment for wildlife and people. We have identified a range of activities that we believe could make use of the type of data the EO techniques can produce (Table 8:3). This is not intended to be a comprehensive list but to demonstrate the breadth and quantity of on-going activity that needs good quality information about habitats and habitat change. These activities are mainly at the landscape scale but there are also applications that are "issue driven" or relate to site management (these are discussed later in this section).

The rule base and image segmentation work can be built upon or adapted. This keeps the cost of new analysis low, particularly when compared with repeat survey, manual re-interpretation of imagery or other traditional survey techniques.

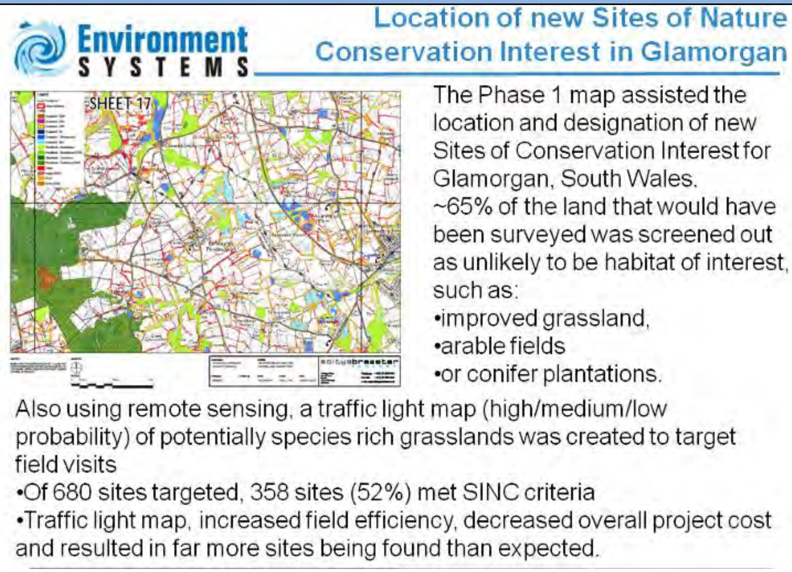
These data can be used for any local planning and public engagement as well as for understanding and underpinning the description of ecosystem function and service delivery.

Table 8:3: Potential additional uses for the mapping of habitats

Landscape scale	What they do	The type of data they need
Biodiversity Opportunity Areas (BOAs)	Areas where conservation action, such as habitat creation, restoration or expansion, is likely to have the greatest benefit for biodiversity. They are centred on existing areas of biodiversity interest, but have a key role as areas which offer strategic opportunities for biodiversity enhancement. They provide local authorities and partners with vital information to support a robust, climate-proof, long-term landscape-scale vision for the benefit of the natural environment, society and the economy.	Biodiversity Opportunity mapping typically uses data on existing biodiversity and geodiversity interests, coupled with information about land use, topology, soils, hydrology and other physical parameters. If there are gaps in the information available about habitats then this will impact on the quality of decisions arising from the use of BOAs.
Biodiversity offsetting	Biodiversity offsets are conservation activities designed to deliver biodiversity benefits in compensation for losses, often from development activities, in a measurable way. It is thought that biodiversity offsetting has the potential to deliver planning policy requirements for compensation for biodiversity loss in a more effective way. A Defra pilot is underway from April 2012 to April 2014 to test the efficacy of different offsetting approaches.	For planning based decisions of where to best site offsetting schemes, knowledge of the spatial distribution of existing habitats and the identification of opportunities for habitat restoration help target areas where the restoration will be more effective.
Ecosystem Services Mapping	Ecosystem service mapping is a rapidly-expanding area, but it poses significant technical and practical challenges.	For meaningful modelling of the environment to quantify ecosystem features, habitat mapping and other derived layers are a good starting point.
Green Infrastructure (GI)	Green infrastructure is a strategically planned and delivered network comprising the broadest range of high quality green spaces and other environmental features in urban areas (street trees, gardens, green roofs, community forests, parks, rivers, canals and wetlands).	These plans have to take into account habitat value and their landscape context. It is therefore important to have good information on what habitats are present, where they are and to ensure they are in good condition.

<table>
<tr><th>Landscape scale</th><th>What they do</th><th colspan="2">The type of data they need</th></tr>
<tr><td>Integrated Biodiversity Delivery Area (IBDAs)</td><td>Natural England has been working with the England Biodiversity Group to trial new methods of improving nature protection through the establishment of IBDAs. These cover areas of regional significance and encompass entire landscapes. Their creation is a response to the limitations of protecting species though a fragmented network of nature reserves, which are often only a few hectares in size. IBDAs seek to create connectivity between such sites and restore habitats across a wider area in order to meet the needs of species better.</td><td>
</td><td>Maps of the existing location of habitats in the wider countryside, particularly those that can contribute to planning a coherent connectivity network – such as hedgerows, field margins, road verges and areas of potentially species-rich habitat.

Maps that identify pressures or risks to the existing network of habitats or that might pose a risk to restoration activities.</td></tr>
<tr><td>Living Landscape initiative</td><td>A Living Landscape is a recovery plan for nature championed by The Wildlife Trusts since 2006 to help create a resilient and healthy environment rich in wildlife and to provide ecological security for people. In A Living Landscape habitats are restored and reconnected on a large scale with the local community closely engaged. Across the UK there are over 100 Living Landscape schemes covering an area of nearly 1.7 million hectares. The schemes are being delivered in Partnership with a huge number of individuals and organisations.</td><td colspan="2">As above (IBDAs)</td></tr>
<tr><td>Local Nature Partnerships (LNPs)</td><td>A government initiative and one of the proposals in The Natural Environment White Paper, which recognised that Partnership working is the best way to achieve effective action for the natural environment. Once established, their purpose will be to create a vision and plan of action of how the natural environment can be protected and enhanced in order to improve quality of life, support the economy and provide a healthy environment for wildlife and people.</td><td colspan="2">As above (for IBDAs)</td></tr>
</table>

Landscape scale	What they do	The type of data they need
Local Sites	These non-statutory sites form part of the hierarchy of international, national and locally designated sites. A Local Wildlife Site (also known locally as SINCs). All sites that meet the selection criteria are included. It is widely acknowledged that there are LWSs that encompass sites of equivalent value to biological SSSIs in terms of the importance of the interest they contain. There are over 40,000 LWSs in England. They help buffer and connect natural areas, providing ecological networks and increasing resilience of biodiversity to pressures of land use and climate change (Lawton, 2010). Recent work (Parker, 2012) identified that access to sites for survey can be a problem as is reliant on owner permission. Survey data is considered key to the provision of evidence of change in the longer term and for many Local Sites Partnerships it has not been possible to achieve the frequency of resurvey recommended in the 2006 Defra guidance. There remain a high proportion of sites where habitat condition is not known (for many Local Sites survey data is over 10 years old). Overall, based on their experience, interviewees considered the condition of Local Sites to be in slow decline, largely as a result of neglect, agricultural improvement and overgrazing.	 Further data to identify candidate sites (see slide above) as survey work for designation largely reliant on API or survey from PROWs. Information to support on-going assessment of condition.

Landscape scale	What they do	The type of data they need
Nature Improvement Areas (NIAs)	NIAs are places in England where opportunities to deliver ecological networks, both in terms of large area scale and valuable benefits accruing to wildlife and people, are particularly high. The Natural Environment White Paper commits Government to assist Partnerships of local authorities, local communities and landowners, the private sector and conservation organisations to establish NIAs, based on a local assessment of opportunities for restoring and connecting nature on a significant scale. NIAs should enhance the ecological network by undertaking the following actions: • Improving the management of existing wildlife sites; • Increasing the size of existing wildlife sites; • Increasing the number of wildlife sites; • Improving connectivity between sites; • Creating wildlife corridors.	 As above
Strategic Coastal Monitoring Programmes Shoreline Management Plan	The National Network of Strategic Regional Coastal Monitoring Programmes makes use of aerial surveys and ecological mapping. Monitoring data is used to inform strategic studies, evidence based decisions, determine design conditions, plan intervention strategies and to check compliance with environmental requirements. A Shoreline Management Plan (SMP) is a large-scale assessment of the risks associated with coastal processes and policy helps reduce these risks to people and the developed, historic and natural environments. They cover the entire 6000 km of coast in England and Wales. Coastal processes include tidal patterns, wave height, wave direction and the movement of beach and seabed material, these features can be affected by activity on-shore or off-shore and monitoring is therefore extremely important.	Habitat data (for Coastal Habitat Management Plans of SACs or for other coastal areas) to inform future planning. Data for assessing potential impacts of the SMP on habitats, monitoring of actual impacts, preparing compensation measures (i.e., creation of new habitat to offset losses) Monitoring of coastal processes and changes to the shoreline.

Landscape scale	What they do	The type of data they need
River Basin Management Planning (Water Framework Directive)	River Basin Management is a continuous process of planning (to develop River Basin Management Plans) and delivery. The Water Framework Directive introduces a formal series of 6 year cycles. The first cycle will end in 2015 when, following further planning and consultation, the River Basin Management Plan will be updated and reissued. The River basin management plans acknowledge the impact that the whole catchment has on water quality and quantity.	Habitat maps allow the distribution, extent, and possible land management related features to be quantified which will impact on water quality such as erosion scars.
Non-native invasive species	Some non-native species (Himalayan balsam, Japanese knotweed) can become invasive causing harm to our native biodiversity and the economy. The Invasive Non-Native Species Framework Strategy for Great Britain provides a co-ordinated and structured approach to dealing with non-native species. The Economic Cost of Invasive Non-Native Species to the British Economy indicates the economic cost of invasive non-native species can be wide ranging and invasive species cost the British economy £1.7 billion every year.	Habitat maps that allow the distribution, extent, rate of spread and likely impacts to be assessed. Data on the impact and effectiveness of management.
Tree health	Threats to tree health have increased with the globalisation of trade generally with a marked increase in the volume and diversity of plants and plant products entering the UK. This has increased the likelihood of plant pests and pathogens also being introduced, spreading through gardens and woodlands and potentially causing serious damage to either our native flora or commercial crops (Defra and Forestry Commission, 2011). These threats have been highlighted by an increasing number of plant pest and pathogen outbreaks in the UK, including for example, *Phytophthora ramorum* and *Phytophthora kernoviae* affecting trees, heathland plants and heritage gardens; oak processionary moth (*Thaumetopoea processionea*) with its associated threat to human health; and red band needle blight (*Dothistroma septosporum*).	Spatial knowledge of the habitats and land cover allows the extent of the problem and potential pathways of disease spread to be identified, as well as effectively targeting action.

8.1.4 What barriers remain and are these likely to be overcome?

Barriers to the use of EO for habitat surveillance have been identified in the user manual produced to accompany the Crick framework. The extent to which approaches and techniques have overcome any of these barriers will be discussed and any remaining challenges identified:

Barrier 1: Perceived issues

EO has potential to assist with mapping habitats but there are perceived issues with:

- Proof of the suitability of EO for detailed habitat mapping,
- Proof of the cost-effectiveness of using EO compared with current fieldwork methods,
- Availability of suitable imagery for the feature of interest and contextual ancillary data,
- The amount of expertise and software required for image processing and analysis.

Barrier 2: Fitting EO classification into existing habitat classification systems

Habitat classification systems have often been derived from a field survey perspective. There are many commonly used systems which vary in detail from broad species assemblages, to very specific habitats defined by one or two species present within the sward. Trying to apply EO-based approaches to what is seen on the ground becomes difficult.

For broad habitat types, difficulties arise when there is a very wide variation of phenotypes within the assemblage, or where the habitat varies significantly in its constituents across the country.

Where the habitat is defined by only one or two small and low frequency indicator species, they are often obscured from above by the rest of the sward and not visible in EO imagery.

Barrier 3: Lack of understanding of the differences between expertise and process

For those less familiar with remote sensing it is easy to confuse the software and hardware used with the methods and expertise required.

OBIA techniques require a range of software and hardware together with considerable remote sensing and ecological skills and knowledge. Software packages used for this sort of analysis such as eCognition are not ‘tools’, meaning suitable results are unlikely to be produced by non-specialists. Similarly having access to a word processor does not ensure that you have suitable skills to produce a well written novel.

Many different UAS platforms are available fitted with a range of different sensors. This project used a G2 UAS fitted with scientifically calibrated sensors with NIR and Red Edge bands. The results gained in this trial would not be achievable with a UAS mounted with a less sophisticated camera set up, which would only produce RGB images suitable for visual interpretation, not automated analysis.

The BioSOS project is developing software tools which use open sourced software that aim to allow an ecologist to produce an OBIA type result. At the moment this is in the research phase of development. There will still be significant training required, as the ecologists will need to understand basic remote sensing concepts to use this sort of ‘tool’ when it is available.

8.1.5 Knowledge exchange

Communication and outreach occurred throughout the project. A steering group of key end users from DEFRA, JNCC, Natural Resources Wales, Scottish Natural Heritage, Environment Agency and Natural England were involved in all stages of the project. Norfolk Biodiversity Information Services (NBIS) who were project partners and end users of the project outputs were also consulted throughout. A workshop was hosted at the inception of the project to inform key stakeholders in Norfolk of the work and to gain a further understanding of the biodiversity priorities and pressures present in the pilot study area. A further workshop on habitat condition monitoring was hosted in Norfolk for habitat practitioners from the wider Steering Group. This condition workshop included establishing the needs of users for condition monitoring, the biodiversity of Norfolk and a field visit in the Norfolk Broads.

Work from the project has been presented by JNCC and Environment Systems at conferences and workshops for both National and International audiences, including at the Eurosite/CCW Natura 2000 monitoring workshop in Swansea, March 2013.

OBIA techniques require a range of software and hardware together with considerable remote sensing and ecological skills and knowledge. Software packages used for this sort of analysis such as eCognition are not ‘tools’, meaning suitable results are unlikely to be produced by non-specialists. For effective use of the techniques, both EO expertise and ecological expertise should be drawn on. This has been communicated throughout the project to key end users.

Further knowledge transfer is required to support conservation agencies and others to develop image analysis classification systems that are suited to their particular needs.

9 Suggestions for further research

The following are research needs that have been identified during the project:

1. When the SAR data becomes available from the Copernicus programme itsc potential to significantly enhance the identification of habitats should be explored. Multi-year SAR data could also potentially be useful for creating the arable mask. SAR picks up the roughness of ploughed fields well and a series of images in the autumn may allow cultivated land (including temporary leys) to be separated from uncultivated land, so this should be investigated.

2. Explore further the potential for the development of measures (indices) to assist with the site based assessment of the condition of Annex I habitats. This would include addressing questions such as:
   - How do we translate these measures into absolute values for a robust monitoring programme?
   - How can we take account seasonal variation and how do we record this?
   - How do we relate change in the value of the indices to real change on the ground and how do we know when an absolute value or change in value means that management action should be taken?
   - How can the risk features be recorded to allow tracking of the issues?
   - How can the information be translated into tools that site managers would find informative?
   - What do the measures produced using the hybrid pixel-object based approach show us about the condition of land? Can this information be translated into useful products for land management?
   - Can the findings be applied to issues of atmospheric nitrogen deposition and critical loads? Recent research has demonstrated a causal link between atmospheric deposition of nitrogen and ozone, with damage to semi-natural vegetation.

3. Further exploration of the use of UAS data in relation to identification of species of trees in woodland as this would increase the number of identifiable Annex I woodland habitats. Detailed and highly accurate ground data would be necessary to develop these findings further to produce maps of tree species.

4. Investigate the potential of the rule base technique to map road margins of possible conservation value.

5. Consult with others and investigate user's needs and capabilities, data product needs and uses etc. at local levels to determine range, scope and activities in using EO for different purposes and the nature of the purposes.

6. Apply the ecologically meaningful rule base and other methods applied and developed to other habitats and landscapes, to test their applicability in other conditions.

7. Undertake some cost benefit analysis to demonstrate more fully the efficiencies of EO techniques.

10 Conclusion

A series of pilot projects in Norfolk have demonstrated a number of ways in which EO techniques developed as part of this study can support, and in some situations augment, current surveillance techniques for Annex I and priority habitats.

The techniques developed are considered to be particularly valuable for:

- assisting with filling gaps in knowledge of habitats in the wider countryside;
- generating habitat maps and data to meet a wide range of landscape scale approaches to biodiversity delivery;
- producing management plans for larger sites or discrete areas;
- identifying threats to habitats and ways of mitigating against and monitoring these threats.

In addition, a desk based review of the Crick Framework confirmed its validity as a tool to support habitat mapping. A 'User Manual' has been produced to provide habitat specialists with examples, explanations and illustrative scenarios of how the Framework can be used to support the evaluation of opportunities for mapping habitats using a range of EO and other existing spatial data.

The results of piloting the technique in Norfolk for Annex I and BAP priority habitats have demonstrated that the Crick Framework and the EO techniques developed have real practical application both at the landscape and site scale.

At a landscape level, a range of high priority habitats, distinguished from above by their cover forming species, can be identified at good levels of accuracy (greater than 78%) using the EO techniques developed. About a third of the Annex I and priority habitats studied can be identified in this way. EO techniques also provide an efficient way of mapping large areas or areas that are difficult to access. They can also provide key data sets for targeting identification of all the remaining habitats.

At a site based level the EO techniques are capable of producing high quality site-based habitat maps suitable for use as management products to assist with monitoring, survey and site maintenance. In areas that are difficult to map by field survey, maps of habitat extent and condition features can be generated that improve upon the mapped information already available, especially in terms of delineating the position and extent of specific habitats.

Measures have been developed that provide new information about the functioning of sites. These measures provide information on factors that management action can influence:

- **measures of productivity** and **wetness**: show information about sites and their surrounding context that are not readily detectable or mappable from standard (RGB) aerial photography or field survey. These are detectable at a range of scales, so risk and mitigation features (e.g. for **nutrients)** can be identified at the scales at which they occur, including from external land. Opportunities for habitat expansion can be identified. Absolute measures are generated that can act as a baseline for assessment of change.
- **measures of the presence and extent of competitive / invasive plant species:** these are a known and common problem on designated sites and their extent is difficult to map by field survey. EO techniques therefore can complement and support field survey.

Such measures allow the general discrimination of some habitats that are difficult to map from conventional EO techniques or by field survey (e.g. wet and dry woodland).

The approaches developed do not simply duplicate what other habitat surveillance methods provide but compliment them. They can support and augment current surveillance techniques in a practical way, sometimes improving upon the accuracy of habitat mapping and can add to the suite of surveillance tools available, including for condition monitoring. The EO techniques are considered applicable to a wide range of other biodiversity related activities that support government biodiversity policy.

The results of accuracy assessment, feedback from local habitat practitioners and the assessment by the research team of how well the techniques worked, all suggest that the EO techniques developed are fit for purpose for supporting the mapping and surveillance of high priority habitats. A framework for calculating the data needs and cost considerations has been suggested.

The techniques add value to existing activity to map, protect and manage high priority habitats. The techniques are very adaptable because the developed rule bases and processed imagery and data can be built upon or adapted as necessary to produce additional outputs or products tailored to other policy needs that utilise habitat mapping. This keeps the cost of follow-on work very low in comparison with repeat survey, manual re-interpretation of imagery or other traditional field survey techniques. In this way they provide value for money.

EO expertise is needed to produce the maps but ecological input to the process is essential. For successful mapping, EO and ecological expertise, together with GIS and geoinformatics knowledge is needed. These skills are rarely present in just one individual and a team based approach is recommended. The maps cannot be produced in isolation using EO alone. Fieldwork, the use of local knowledge and/or existing data are integral to the map production.

Evidence from work in Norfolk, Wales and Anguilla (a UK Overseas Territory) demonstrates that the techniques are capable of consistent implementation and the technique is therefore considered to be ‘transferable’ and so can be rolled out to the UK, and beyond. The successful transfer of the techniques depends on obtaining imagery at suitable spatial and temporal scales for the habitats present in the area of interest.

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12 Appendices

12.1 Appendix 1: Priority and Annex 1 habitats present in Norfolk

Priority and Annex 1 habitats present in Norfolk, organised into the groupings used to present the results in this report.

UK BAP Priority Habitat	Annex I Habitat
Environments dominated by tree canopy cover	
Hedgerows	**9190**. Old acidophilous oak woods on sandy plains
Lowland mixed deciduous woodland	**9120.** Atlantic acidophilous beech forests with *Ilex*
Traditional orchards	**9160.** Oak-hornbeam forests
Wet woodlands	**91E0.** Alluvial forests with *Alnus glutinosa*
Wood-pasture and parkland	
Environments dominated by shrub canopy cover	
Lowland heathland	**4010**. Northern Atlantic wet heaths with *Erica tetralix*; Wet heathland with cross-leaved heath
	4030. European dry heaths
Dry environments dominated by graminoid species	
Arable field margins	**6210.** Semi-natural dry grasslands and scrubland facies:on calcareous substrates (*Festuco-Brometalia*)
Lowland calcareous grassland	**2330.** Inland dunes with open *Corynephorus* and *Agrostis* grasslands.
Lowland dry acid grassland	
Lowland meadows	
Open mosaic habitats on previously developed land	
Environments dominated by a saline and brackish water influence	
Coastal saltmarsh	**1110.** Sandbanks which are slightly covered by seawater all the time
Coastal sand dunes	**1130.** Estuaries
Coastal vegetated shingle	**1140.** Mudflats and sandflats not covered by seawater at low tide
Maritime cliff and slopes	**1150.** Coastal lagoons
Saline lagoons	**1160.** Large shallow inlets and bays
Intertidal mudflats	**1170.** Reefs
Blue mussel beds	**1210.** Annual vegetation of drift lines
Intertidal chalk	**1220.** Perennial vegetation of stony banks
Mud habitats in deep water	**1230.** Vegetated sea cliffs of the Atlantic and Baltic coasts

UK BAP Priority Habitat	Annex I Habitat
Sabellaria spinulosa reefs	**1310.** *Salicornia* and other annuals colonising mud and sand
Seagrass beds	**1330.** Atlantic salt meadows
Sheltered muddy gravels	**1420.** Mediterranean and thermo-Atlantic halophilous scrubs
Subtidal chalk	**2110.** Embryonic shifting dunes
Subtidal sands and gravels	**2110.** Shifting dunes along the shoreline with *Ammophila arenaria*
Coastal & floodplain grazing marsh	**2130.** fixed dunes with herbaceous vegetation *priority feature*
	2150. Atlantic decalcified fixed dunes (*Calluno-Ulicetea*).
	2160. Dunes with Hippophae rhamnoides
	2170. Dunes with *Salix repens* ssp. *argentea* (*Salicion arenariae*).
	2190. Humid slack dunes
Environments dominated by a freshwater influence	
Purple moor grass & rush pasture	**6410.** *Molinia* meadows on calcareous, peaty or clayey-silt-laden soils
Reedbeds	**7140.** Transition mires and quaking bogs
Lowland fens	**7150**. Depressions on peat substrates
Aquifer-fed naturally fluctuating water bodies	**7210.** Calcareous fens
Eutrophic standing waters	**7230.** Alkaline fens
Mesotrophic lakes	**3110.** Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*).
Oligotrophic and dystrophic lakes	**3130.** Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*.
Rivers	**3140.** Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.
Ponds	**3150.** Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation.
	3260. Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation.

12.2 Appendix 2: UAV additional operational information

Regulation considerations

Within Europe civil operations of UAV's with a mass less than 150kg are regulated at a national level. In the UK the Civil Aviation Authority (CAA) has this responsibility. Legally, all aircraft (even models) are subject to the provisions of the Air Navigation Order (ANO) although many 'Small Aircraft' are exempted from much of this legislation depending on their mass and the purpose for which they are used.

The UK CAA have long provided a framework under which it has been possible for competent organisations to conduct commercial operations of unmanned aircraft and this policy has been published as CAP722. CAA policy was updated at the beginning of 2010 to accompany an amendment to the ANO whereby the law governing lighter unmanned aircraft (under 7kg) was both strengthened and simplified. The new rules placed restrictions on all 'surveillance equipped' unmanned aircraft in terms of their operation in proximity to people and infrastructure and further required CAA permission for 'Aerial Work' conducted by aircraft of any mass. The main purpose of these changes was to provide suitable regulation for the anticipated rapid expansion in availability and use of small, camera equipped helicopters and other aircraft to the inexperienced user as the technology becomes more affordable.

The current CAA regulation is actually amongst the most accommodating in the world for the competent operator, whereby regular commercial use of UAV's is encouraged and managed effectively. By comparison the FAA in the US has simply banned all commercial operation of all UAV's other than by federal or state agencies for the time being.

The operating organization is required to have competent staff, appropriate processes for safety management and able to integrate with the wider air traffic and airspace user community.

One key legal limitation in the UK is that operation of UAV's beyond the line of sight of the operator (for the purpose of avoiding collisions) is not yet possible. In the UK CLA have established greatly increased ranges of operation for all airspace and can operate beyond line of sight in segregated airspace. In practice however, since the advantage of UAV's over manned aircraft or satellite RS is in providing timely, high resolution data in smaller areas, the regulatory environment is suitable for effective RS operations of this nature.

Flight planning

Consideration has to be given to the nature of the airspace within which the UAV has to be operating in. Airspace is defined internationally in classes A to G with Class G being effectively 'open' for all users and Class A generally being the high altitude airways effectively reserved for commercial traffic and many subtle differences amongst the remaining classes, some of which don't exist in the UK. Classes A to D are normally referred to as 'controlled airspace' and with the exception of Heathrow (which has Class A) all large airports have a Class D Control Zone (CTR) which typically extends to up to 10 miles in some directions from the airport and typically starts at ground level to several thousand feet.

The nature of this project required operations in close proximity to Norwich Airport (NA) and this represented a typical scenario quite well from an operations perspective since NA is an international airport with all the airspace and air traffic management infrastructure typically found at all major airports.

Since NA has a large Class D CTR it can be considered typical from an airspace perspective. Operations of UAV's in controlled airspace are certainly novel in the UK and CLA were unable to find any precedent for operations in airport CTR's in terms of planning or protocols. Whilst each airport is responsible for managing its own allocation of airspace, this cannot simply be done on a commercial basis as the holder of any airspace must make all reasonable efforts to allow it to be used by all aircraft operators. However it would also be reasonable for an airspace operator to be quite unwelcoming of such a novel activity in such a safety critical environment. It was therefore important to establish a trusted relationship at an early stage with the Manager Air Traffic Services (MATS) there and this was successful.

CLA provided information to NA on the nature and scope of their operations along with evidence of their CAA approvals at an early stage in order to inform the decision regarding how to authorize this activity. It was decided to take the opportunity to conduct a full Hazard Analysis in accordance with CAP760 (*Guidance on the Conduct of Hazard Identification, Risk Assessment and the Production of Safety Cases: For Aerodrome Operators and Air Traffic Service Providers*). It was considered that taking this approach would produce an auditable process that could be used in the future as a precedent or best practice at other airports. The hazard analysis was conducted jointly between the CLA Head of Flight Operations and the Norwich MATS.

The output of the hazard analysis was the issue of a Temporary Operating Instruction, approved by the CAA covering UAV operations by CLA in the Norwich CTR.

Flight operations

All UAV operators in the UK are required by law to obtain CAA Aerial Work Permissions for commercial operation within UK airspace. This gives the operator accreditation and relates to elements such as:

- Commercial operation of the UAV platform
- Advance planning and assessment of target data acquisition sites to identify any aviation or safety management issues or other permissions required.
- Issue of a navigation warning (NOTAM) which publishes the activity to other airspace users and provides contact details for further information.
- An Operating Site Safety Assessment to identify and assess any hazards associated with a particular operating site and a safety briefing is given to any observer or bystanders.

The UAV element of the exercise was undertaken throughout the summer and autumn following permissions to fly being granted by Norwich Airport. The imagery data was captured in combination on-board the ‘G2’ UAV, a bespoke platform manufactured by CLA.

The G2 is a 2.1m span electric tailless UAV with a maximum operating mass of 6kg. It can be configured to carry a variety of payloads with flight duration of up to 45 minutes. CLA hold

CAA Aerial Work Permissions for the commercial operation of this system throughout the UK and operations of the G2 are in accordance with the CLA Flight Operations Manual.

For this task the target sites were defined by ESL in discussion with Norfolk CC and the Broads authority and sent to CLA as shapefiles. CLA then planned the operating locations to allow the most efficient operational coverage of the target sites. An advance planning assessment of any new activity is done by the Head of Flight Operations and this process identifies any aviation or other safety management issues (such as setting-up the TOI in this case) or other permissions required. In this case a recce visit was also conducted in advance of the flying deployment. Once tasked with a survey the UAV Commander UAVC involved issues a navigation warning (NOTAM) usually a day or two before, which publishes the activity to other airspace users and provides contact details for further information.

The system is normally deployed in a Land Rover and is operated by two crew members, the UAVC and an Internal Pilot. Where slack winds are anticipated or heavy payloads used a pneumatic launcher is also deployed, otherwise the system is hand launched by the Internal Pilot. The UAC conducts an Operating Site Safety Assessment to identify and assess any hazards associated with a particular operating site and a safety briefing is given to any observer or bystanders.

A software flight plan is plotted on the ground control station laptop consisting of imaging legs running parallel to ensure sensor image overlap and this is done according to the wind and other conditions on the day. Following an equipment inspection the flight plan is uploaded to the aircraft and it is launched, initially in manual flight to ensure all controls are functioning normally. Once switched to automatic flight the UAV follows the planned flightpath extremely accurately and automatically takes images based on the ground track and speed to ensure sensor image overlap.

At the end of a flightplan the UAV returns to the launch point and orbits until the UAC takes control once again for a landing in a planned area of crop, on a track or other relatively clear area. Imagery is immediately downloaded to hard drive before any further flights take place.

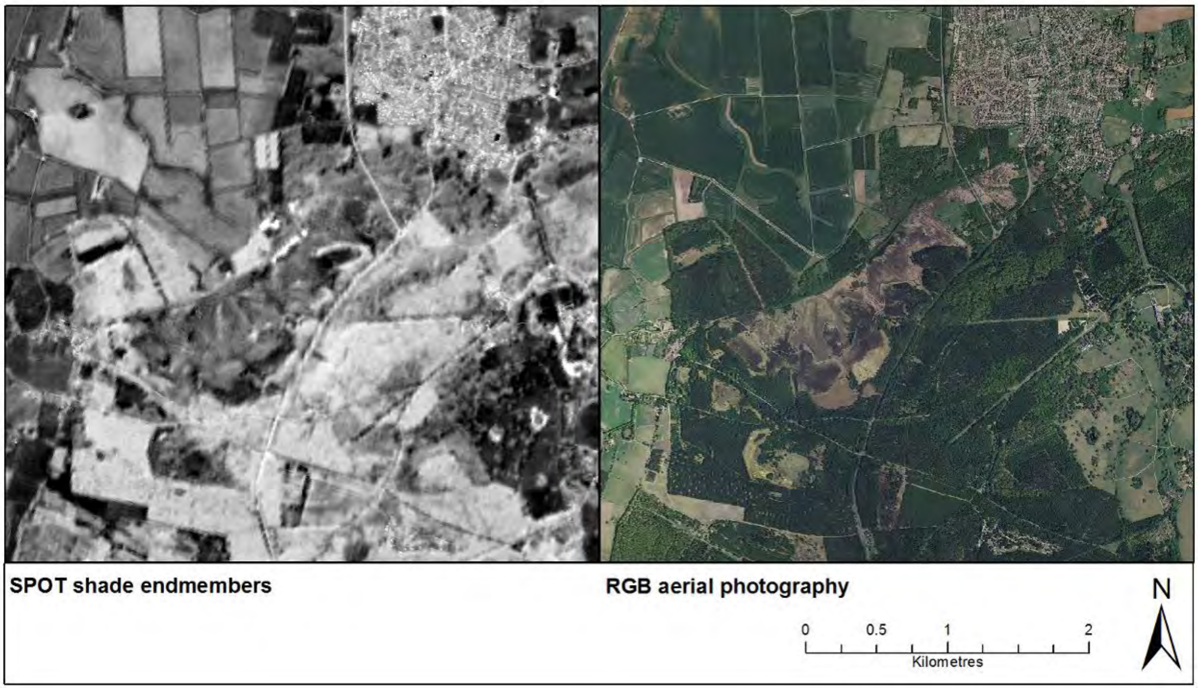
12.3 Appendix 3: Additional condition measures

Wetness technique 3 – Using shade endmembers as a proxy for wetness

Linear Spectral Unmixing for wetness

What it is

Linear spectral unmixing compares the pixel values in an image to that of ‘pure’ reference pixels, based within the same image (Lillesand, *et al*. 2004). This requires the identification of spectrally unique pixels as the ‘pure’ ground component, known as endmembers (EMs), and the application of a calculated combination of these EMs to the image. Principle component analysis can be implemented to identify the individual EMs; whereby a scatterplot of two image bands against one other result in a triangle, with the ‘pure’ EMs located at the corners (Smith, *et al*. 1985). Using the NIR and Red bands in the scatterplot “shade EMs” can be identified, analysed and applied to an image, showing relative concentration of those EMs per pixel. The method therefore resolves the pixel values to a fraction of the spectral components of a known EM.



Why we think it’s useful

The “shade EM” can be shown to correlate with moisture as the two spectral characteristics remain similar, particularly with dark objects within the visible spectrum (Rashed, *et al*. 2001), with high EM values relating to areas of concentrated shade/moisture. By previously classifying the shaded and open water areas of an image, the remaining gradients of the fraction map could be used as a surrogate for relative moisture within vegetated areas.

Wetness technique 4 – Using the natural log of the NIR band as a proxy for wetness

The natural log of the NIR band

What it is

It was found that extracting the inverse natural log of the NIR band transformed the histogram to reduce the effect of any skewed distribution (where there may be a few, very large values in the NIR).

$$Inverse\ natural\ log\ of\ the\ NIR = \frac{1}{\ln(NIR)}$$

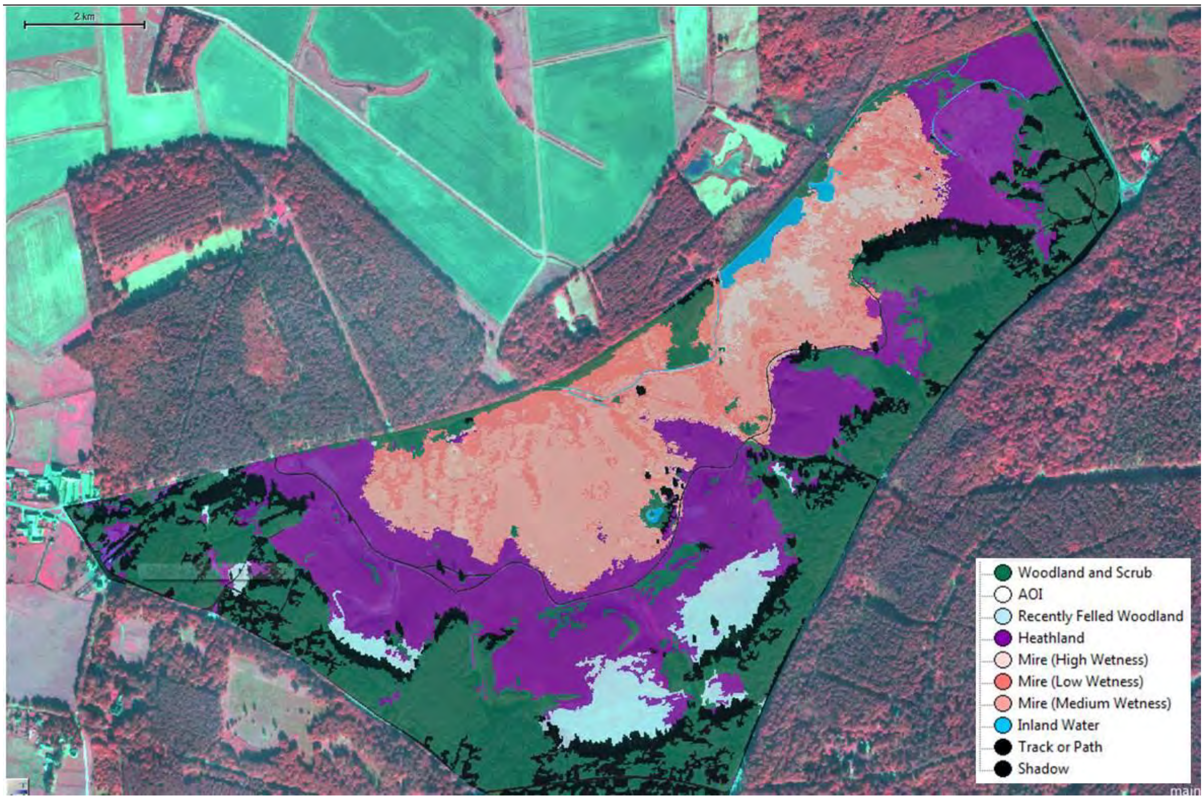


Figure 12:1: Approximation of wetness of the bog surface using 1/ln GeoEye NIR

Why we think it's useful

A log transformation aids in making the variance of the data more constant and normalised in distribution. The effect of the inverse of the natural log of the NIR band seems to replicate that of the shade endmember relative concentrations, though with the two extremes (shade/moisture and unshaded/dry) more greatly defined, with a smoother gradient for those values in between. This allows for greater control over the wetness boundaries and reduced confusion between the classifications.

12.4 Appendix 4: Accuracy Tables

For any statistical evaluation, the population that is being tested against has to be large enough to draw meaningful conclusions. The confidence in the classification being correct, when compared with a set of reference data varies significantly with the population size, being much lower when the population is small. The Bayesian credibility limits at the 95% confidence level, define the upper and lower limits of the correspondence values. The beta distribution is used as a priori distribution for binomial proportions in Bayesian analysis (Evans *et al*. 2000). By using the beta distribution values for the 5th and 95th percentiles of the classes assessed, the range of probabilities can be established.

When you only have a population of 5 points, and 4 of them are correct the correspondence would be 80%, however when you consider the probability that this class has been correctly identified, (on the evidence of these 5 points) it varies between 42% and 94%, a very broad range leading to low confidence. Conversely when you consider the Arable class from the western study area the number of points for the validation is 241 of which 207 were correctly identified giving an accuracy of 84%. From this evidence it can be interpreted that the probability that the arable areas have been correctly identified is between 82% and 89%. Therefore the larger population size gives a much narrower range of confidences and much higher confidence in the stated accuracy of this class.

Due to the high variation in the probabilities for classes with limited points, they have only been included in the following correspondence tables for reference and are greyed out.

West Landscape classification correspondance table

Field data broad groupings and sub headings

	Arable and Horticultural				Boundary and Linear Features				Bracken		Broadleaved, Mixed and Yew Woodland			Coniferous Woodland		Dune					Heath							Saltmarsh				Unimproved/ Semi-improved Grassland				Urban					
West landscape EO classification	Arable	Arable Field Margins	Garden	Bare ground (sand or mud)	Coniferous Belt of Trees	Coniferous Row of Trees	Hedge with trees	Mixed Belt of Trees	Bracken	Nettles	Broadleaved Plantation	Broadleaved woodland (S-N)	Mixed woodland	Coniferous woodland	Felled Plantation	Coniferous woodland	Dune grassland	Open dune	Bare Sand	Grazing marsh	Bare Soil	Breck heath	Dry acid dwarf shrub heath	Fen - valley mire	Wet heath	Improved Grassland	Reedbeds	Saltmarsh - dense/continuous	Saltmarsh - scattered plants	Scrub - dense/continuous	Standing water - brackish	Calcareous grassland	Neutral grassland	Semi-improved	Parkland	Buildings	Road	Coastal Vegetated Shingle	Intertidal - mud/sand	Total	User accuracy (%)
Arable	207	1				1	2				3	3		1						1						3						1	2	18	1		2			241	86
Gardens			2									2																		1						1				6	83
Bracken									2					1									1	1	1															6	33
Broadleaved and mixed woodland			1		1						2	14	10	11	1										1					3				2						46	59
Coniferous woodland													5	17	1	1																								24	75
Felled woodland														1											1															2	0
Woodland scrub			2					1	2			3								1			1		2			1											1	14	36
Dune grassland																	1											1												2	50
Dune sand																	3	5	2									1	1											12	58
Coastal grassland																				1								1						1						3	33
Coastal sediment																		2																				3	4	9	78
Grazing marsh	4			1						1										14						1		1		1				4						26	54
Dense heath				1								1	1								1		1							1										6	33
Scattered heath												1	1										3	8	2															15	87
Fens																									1															1	100
Improved grassland																				1																				1	00
Saltmarsh (established)																											1	18	3											22	82
Saltmarsh (pioneer)																												8	3										2	13	23
Water																															1								1	2	100
Semi-improved grassland	3						2		1		1	3		2						1		3				2	1					1	2	7						29	45
Grand Total	214	1	5	2	1	1	5	1	5	1	6	27	17	33	2	1	4	7	2	19	1	3	6	9	8	6	2	31	7	6	1	2	4	32	1	1	2	3	8		
Producer accuracy (%)	97	100	100	NA	0	0	NA	NA	40	NA	33	70	NA	52	0	100	25	71	100	74	100	100	67	89	38	0	NA	58	43	17	100	50	50	22	NA	NA	NA	100	63	Total	78%

East Landscape classification correspondance table

	Field data broad groupings and sub headings															
	Arable and Horticultural			Bogs and fens	Broadleaved, Mixed and Yew Woodland					Inland Rock				Urban		
East landscape approach EO classification	Arable	Arable Field Margins	Garden	Fen - flood plain mire	Broadleaved Plantation	Broadleaved woodland - semi-natural	Wet Woodland	Grazing marsh	Improved Grassland	Quarry	Scrub - dense/ continuous	Unimproved/ Semi-improved Grassland	Reedbeds	Road	Grand Total	User accuracy (%)
Arable	52	2								1		3	1		59	92
Gardens			2												2	100
Fens				2			2								4	100
Broadleaved woodland						1	1								2	100
Coniferous woodland															0	0
Grazing marsh		1				1		58	1		1		1		63	92
Semi-improved grassland				1	1										2	0
Urban														1	1	100
Water											1				1	0
Woodland scrub													1		1	0
Grand Total	52	3	2	3	1	2	3	58	1	1	2	3	3	1		
Producer accuracy (%)	100	67	100	67	NA	50	100	100	NA	0	0	0	0	100	Total	89%

Hybrid approach Correspondence table

	Field data										
Hybrid approach EO classification	Arable	Arable Field Margins	Garden	Bogs and fens	Fen - flood plain mire	Woodland	Grazing marsh	Scrub - dense/continuous	Semi-improved	Grand Total	User accuracy (%)
Cloud							1			1	NA
Crops	4						1			5	80
Woodland	1					1	1			3	33
Grazing marsh							4			4	100
Rough grassland							31	1		32	0
Grand Total	5	0	0	0	0	1	38	1	0	Combined grazing marsh and rough grassland total	
Producer accuracy (%)	80	NA	NA	NA	NA	100	11	0	NA		97%

12.5 Appendix 5: full answers from NBIS on the usefulness of the mapping

Would NBIS envisage using the types of outputs produced through the "landscape scale mapping"? If yes, please describe the areas of NBIS work the mapping might inform.

Yes, very much so. We will use the maps for the following:

- Information in our standard data search
- Developing ecological network mapping
- Habitat opportunity mapping
- Green Infrastructure mapping – Norfolk has 3 growth points involving 37000 new houses around Norwich and new major road north of Norwich
- Monitoring change in areas vulnerable to change, particularly through flooding – coast, broads, fens

A major part of our work here at NBIS has been producing maps of land use and in particular BAP habitats which can then be used in the production of opportunity, ecological network and Green Infrastructure mapping. An example of such work being the production of maps to identify priority areas for inclusion in the Greater Norwich Joint Core Strategy. Our present method for producing such land use maps is mapping to GIS from aerial photography. This is time consuming and does not allow for differentiation between certain habitats, for instance grassland types. Therefore, anything which can automate the process and add further analysis of the images is of great value to us. We are also unable to map features such as hedgerows and field margins that are time consuming to identify as we have to balance the need for detail with the ability to produce the mapping to reasonable timescales.

A good example of the potential benefit to NBIS (and therefore our clients and partners) is the time saved using the methods developed in this project. Over the last four years we have produced an equivalent area of mapping to the two pilot areas covered by the Norfolk pilot. Whilst we haven't spent four whole years on the work (as we have to balance this with other tasks) it has been a significant amount of work. Progressing at the rate we have previously achieved is problematic as it means that it is hard to monitor change in a meaningful way as the baseline extends over a long period.

The financial cost is also greater - at our standard day rate the cost of the using EO to map the two pilot areas would equate to 128 days or just over 25 weeks of mapping effort. This certainly wouldn't produce anywhere near as much mapping.

Do any of the case studies look like they have outputs that are useful? If so, why? (e.g. relating to level of detail of maps, useful in particular environments that are difficult to access etc.)

Yes.

Ability to map arable field margins. Haven't been able to before even with HLS/ELS data. In some areas of the county the arable margins maintain the rare plant resource so being able to map networks of margins between key sites will helps us to maintain the ecological networks

Hedgerows. Likewise we have been unable to map these. In some areas of the county hedgerows are the main ecological network linking up small fragmented sites and so being able to map the resource will directly benefit conservation work. The ability to map hedgerows with trees would be beneficial as these habitats are important for conserving key bat species in Norfolk.

Breckland Heath. The productivity map that was produced for East Wretham heath SSSI in Breckland SAC whilst not directly of benefit to NBIS (who don't do any direct management work) is obviously a very useful tool. The Environment Department of Norfolk County Council (of which we are part) do manage sites and this sort of map would allow much more refined targeting of habitat management.

If you had access to the maps, data and tools the project has produced, are there any issues or barriers that would prevent you from using them?

Maps and data – no issues or barriers to their use by NBIS.

Tools – potentially issues, as we don't have the computing capacity or software. I don't see that it would ever be cost effective for us to buy the software and training that we would need to use them.

Do you feel it has been a valuable experience being involved and contributing to the project? If so, what have NBIS gained from the experience?

Yes.

Although it might not be the benefit that you were looking for we all feel that our general habitat survey skills have increased through the ground truthing work. Slightly contradictory I know as this project is about automated mapping.

Deeper understanding of Annex 1 habitats. Prior to the project we have largely worked in BAP habitats so it was interesting to shift our thinking slightly.

Experience of working with a service provider. It has been really interesting to see how this project has worked. It has been much more collaborative than our previous work with consultancies. With this project it feels like we have been much more involved and have been contributing in the development of the work.

The opportunity to collaborate with the private sector and national conservation bodies in producing a product of benefit to the people and wildlife of Norfolk. The county council as a whole is being restructured to work more closely with the private sector and facilities such as NBIS will need to develop and become more about adding value to data rather than just collecting it then handing it back out.

Developing the way we will work in future in any use of the potential EU satellite data. Though we will have a use for it we won't have the in-house skill or IT capacity to undertake the production of maps from the raw data.