Remote Sensing in Habitat Monitoring and Management

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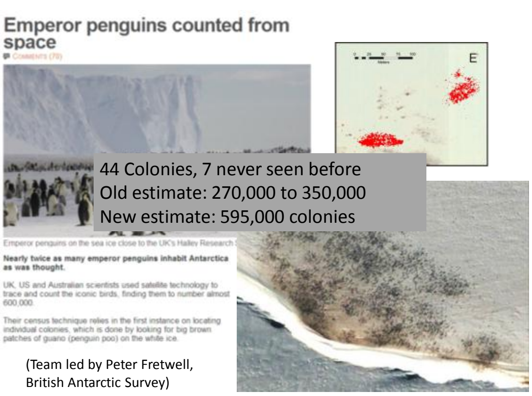
Finnish Environment Institute (SYKE) CLIMES-SYMPOSIUM: Remote Sensing in the mapping of biodiversity, habitats and ecosystem services, Helsinki, 6-7 September, 2012


Emperor penguins counted from space
Comments (78)
Emperor penguins on the sea ice close to the UK's Halley Research S
Nearly twice as many emperor penguins inhabit Antarctica as was thought.
UK, US and Australian scientists used satellite technology to trace and count the iconic birds, finding them to number almost 600,000.
Their census technique relies in the first instance on locating individual colonies, which is done by looking for big brown patches of guano (penguin poo) on the white ice.

44 Colonies, 7 never seen before
Old estimate: 270,000 to 350,000
New estimate: 595,000 colonies

(Team led by Peter Fretwell, British Antarctic Survey)

Contents

PART 1
- What do we need to monitor?
- Remote sensing
- New concepts

PART 2
- Building workable systems:
  - Mapping
  - Post-classification change detection
  - Anomalous change detection
  - Detecting non-anomalous & functional changes
  - Monitoring habitat condition

WHAT DO WE NEED TO MONITOR?

Environmental protection

1. Good maps of range, area and distribution
2. Good estimates of reference range and area
3. Regional surveillance and risk assessment
4. Protected sites taking into account 1 and 2
5. Management plans and other conservation measures
6. Monitoring structure, function, typical species
7. Monitoring of management compliance and effectiveness
8. Modelling and prediction of future prospects

The Habitats Directive

- Key directives include the Habitats Directive (92/43/EEC, 1992), Birds Directive (2009 /147 EC)
- Under Article 6 of the Habitats Directive, member states must have management plans (and other tools) for Natura 2000 sites
- Under Article 11, member states must carry out surveillance (monitoring) of conservation status of habitats and species
- Reporting is mandated under Article 17

Article 17 Reporting

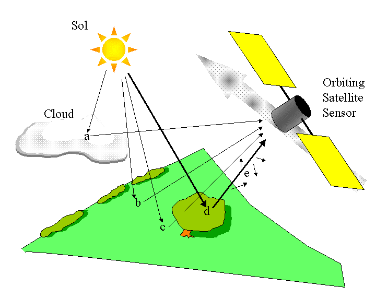
- Range and Area covered within range:
  - Stable or increasing?
  - Greater than reference range / area?
  - Any significant changes in pattern (distribution)?
- Specific structures and functions:
  - Status of typical species?
  - Condition?
  - Any deteriorations / pressures?
- Future prospects

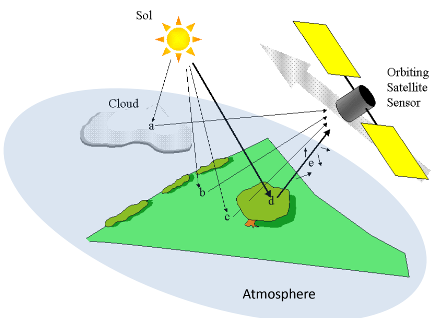
Levels of surveillance and monitoring

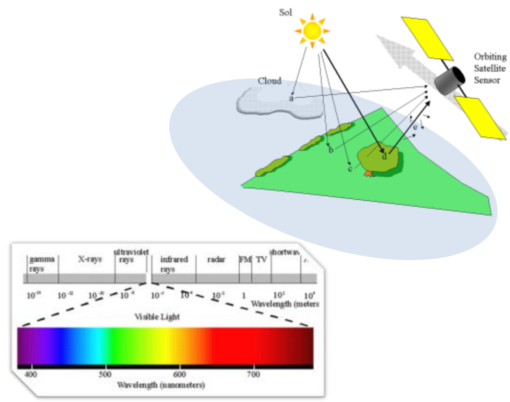
1. Landscape and habitat patch level – changes in range, area and distribution
2. Landscape and habitat patch level – changes in structure and typical species
3. Habitat condition – changes in more sensitive and scarcer species
4. Monitoring to investigate cause and effect between pressures and changes in condition
5. Monitoring to support management decisions at an individual site level

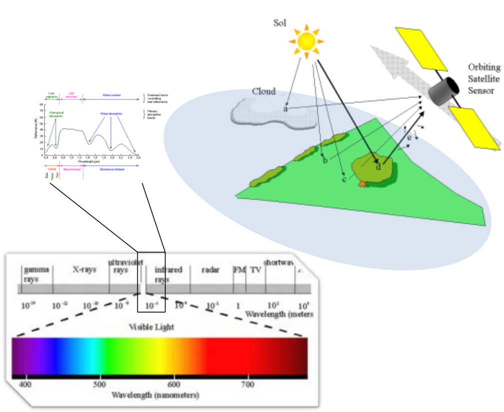
* Adapted from UK JNCC Terrestrial Biodiversity Surveillance Strategy

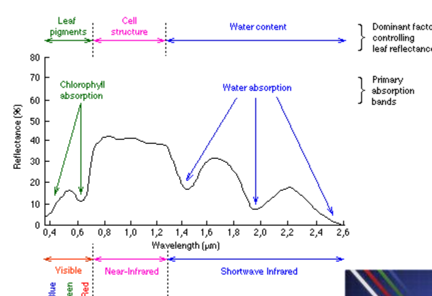
REMOTE SENSING



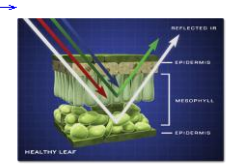




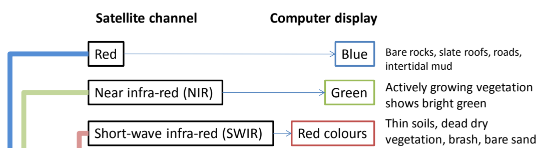


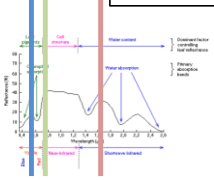


missionscience.nasa.gov

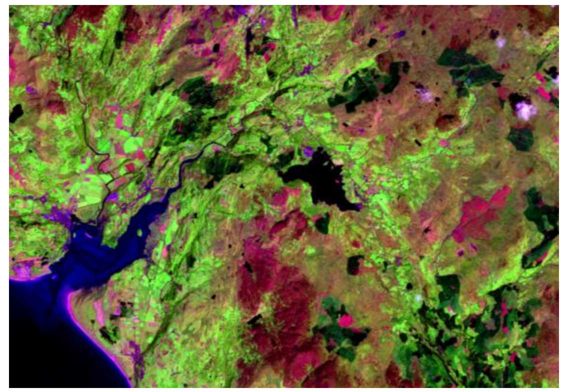


False colour Images



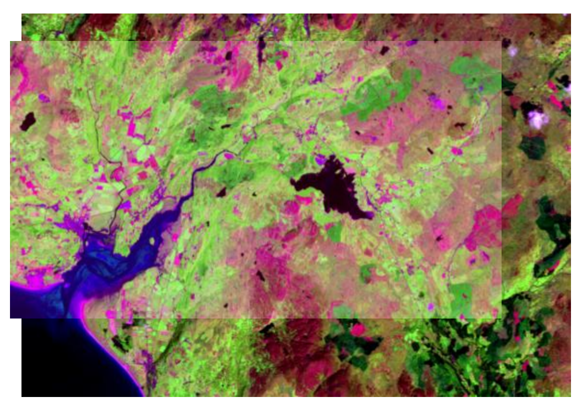


- Images capturing only visible light show very little contrast
- Adding infra-red light is much more informative

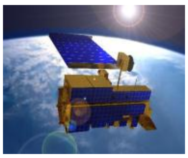


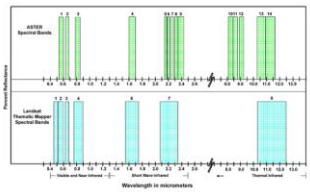
Colour and Intensity

- Variation in the intensity of the image allow us to recognise objects such as forests
- But we need consistent colour (spectral) contrasts to classify and label objects automatically
- It is easy to be frustrated because we can see objects we are unable to extract – rather like ‘window shopping’



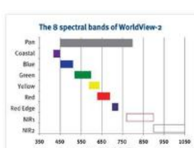
ASTER



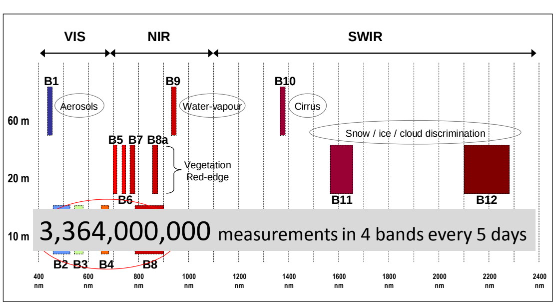


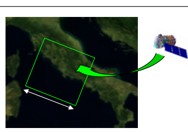
Instrument	VNIR	SWIR	TIR
Bands	1-3	4-9	10-14
Spatial Resolution	15m	30m	90m
Swath Width	60km	60km	60km
Cross Track Pointing	± 318km (± 24 deg)	± 116km (± 8.55 deg)	± 116km (± 8.55 deg)
Quantisation (bits)	8	8	12

WorldView-2



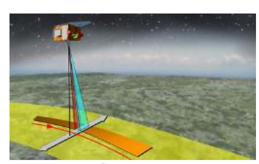
Sensor Bands	Panchromatic, 8 Multispectral (4 standard colors: red, blue, green, near-IR), 4 new colors: red edge, coastal, yellow, near-IR2
Sensor Resolution GSD	Ground Sample Distance Panchromatic: 0.46 meters GSD at Nadir, 0.52 meters GSD at 20° Off-Nadir Multispectral: 1.8 meters GSD at Nadir, 2.4 meters GSD at 20° Off-Nadir (note that imagery must be resampled to 0.5 meters for non-US Government customers)
Swath Width	16.4 kilometers at nadir



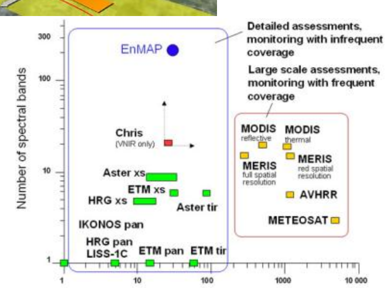


Sentinel 2 constellation (2014?)

12 channels, some 10m
5 day re-visit time
290 km swathe



http://www.enmap.de/



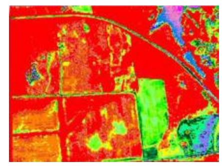
Not only satellite instruments…

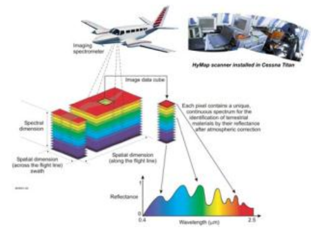
New technologies include:

- Miniaturised radio-tracking
- Dispersed, local sensors and instruments
- Cheap, high accuracy GPS
- Cheap, high quality digital cameras
- Airborne hyperspectral instruments
- Digital air photography, giving routine NIR
- LiDAR & SAR, giving structural information
- Unmanned aerial vehicles (drones)

Airborne hyperspectral imaging

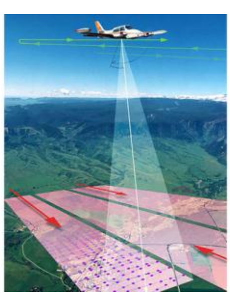
- Hyperspectral imaging





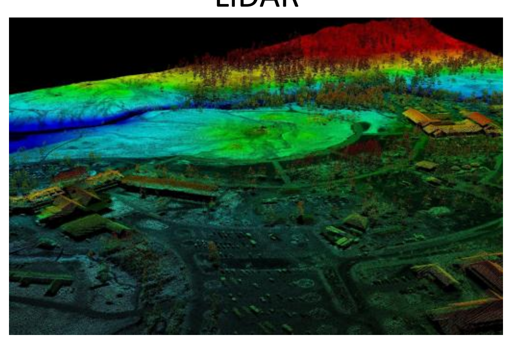
www.csiro.au

LiDAR

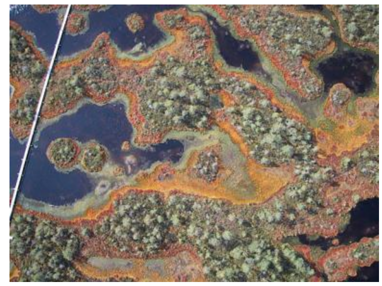


www.infobarrel.com

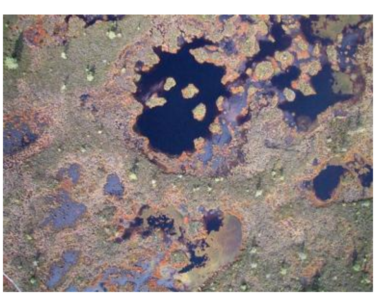
LiDAR



Geyser at Yellowstone National Park www.isgtw.org



Aber, J.S. 2004. Lighter-than-air platforms for small-format aerial photography. *Kansas Academy Science, Transactions* 107, p. 39-44



Kite photography of Estonian bog by James S Aber

Very High Resolution Imagery

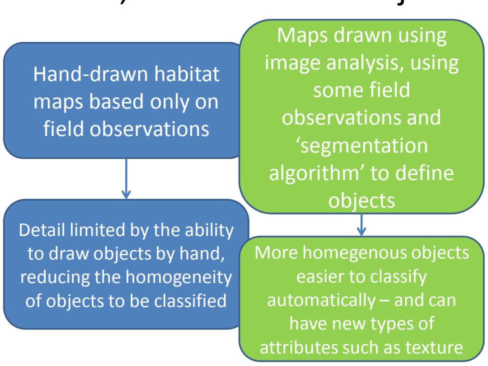
PROJECT URSULA

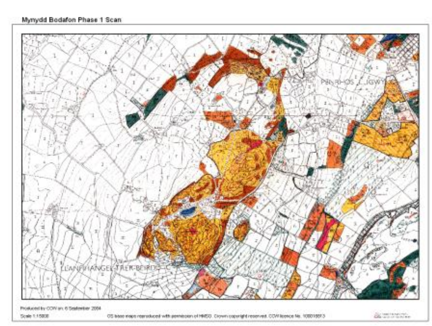
Satellite

Tellus Project,
Geological Survey of Ireland
www.gsi.ie

NEW CONCEPTS

Better, more relevant ‘objects’





More equal landscape coverage

Only a small number of well known sites are included in a monitoring programme

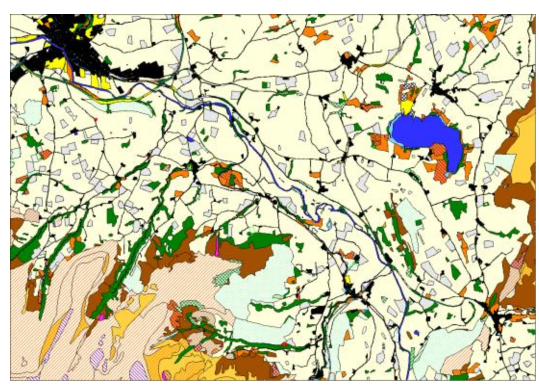
↓

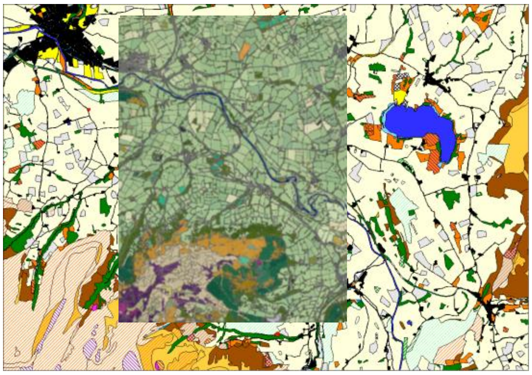
Cannot monitor e.g. catchment condition or ecosystem connectivity

Information is collected about the whole landscape to an equal standard

↓

Landscape-scale monitoring and modelling possible





Better use of samples

Sample-based surveillance networks e.g. Uk Countryside survey

Can be unrepresentative or have low statistical power

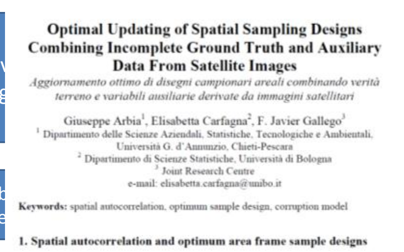
Sample measurements integrated with wall-to-wall mapping and change detection

Can now re-weight sample results to increase accuracy and precision

Better use of samples

surv
e.g

Can b
have



Optimal Updating of Spatial Sampling Designs Combining Incomplete Ground Truth and Auxiliary Data From Satellite Images

Aggiornamento ottimo di disegni campionari areali combinando verità terreno e variabili ausiliarie derivate da immagini satellitari

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[2] Dipartimento di Scienze Statistiche, Università di Bologna
[3] Joint Research Centre
e-mail: elisabetta.carfagna@unibo.it

Keywords: spatial autocorrelation, optimum sample design, corruption model

1. Spatial autocorrelation and optimum area frame sample designs

and precision

Increased statistical power

Conclusions drawn from individual, separate data-sets

These may lack statistical power or be out of date

Conclusions drawn by combining several separate data-sets

Statistical power improved by post-stratification


JRC Scientific and Technical Reports

GEOSS Community of Practice Ag 0703a

Best practices for crop area estimation with Remote Sensing

Edited by Gallego J., Craig M., Michaelsen J., Bossyns B., Fritz S.
Ispra, June 5-6, 2008

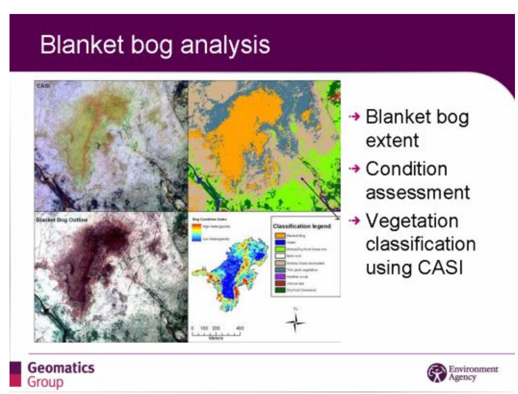
Mapping colour and structure

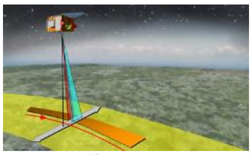
Species identified from the appearance seen at very close range

Poor ability for identification or counting from a distance

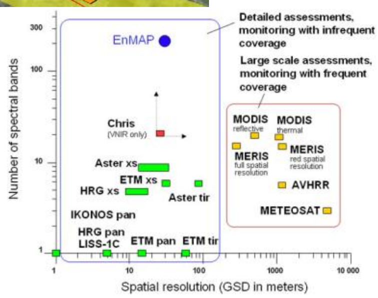
Species and condition identified from spectral (colour) properties and structure

Allows remote identification and counting, measuring structure and function





http://www.enmap.de/



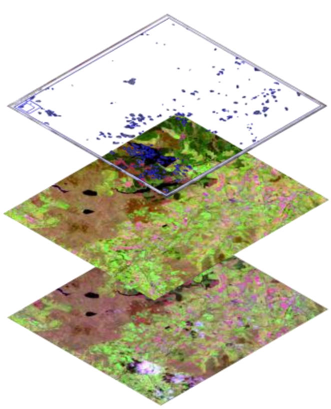
Time series observations

Field observations limited to set times of year

Key times may be missed, observations cannot be carried out in the past

Imagery from different times of year combined to increase accuracy and discrimination

Comparisons can be made using past imagery to show potential changes



Differences

18 July

13 July

Emphasis on (land) cover

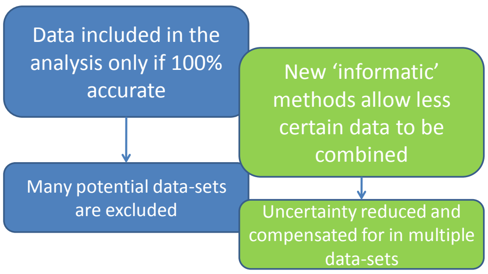
Habitat condition based on presence of scarce species, often with low cover

Limited ability to carry out field observations

Habitat condition **also** based on cover-forming species and structure

Allows remote methods to monitor condition over larger areas

Better handling of Uncertainty

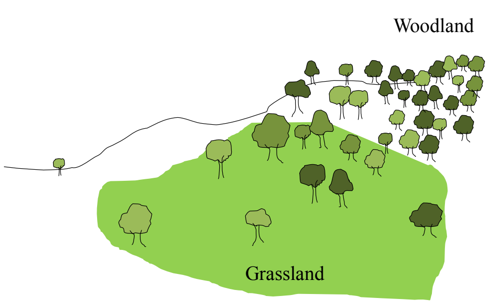


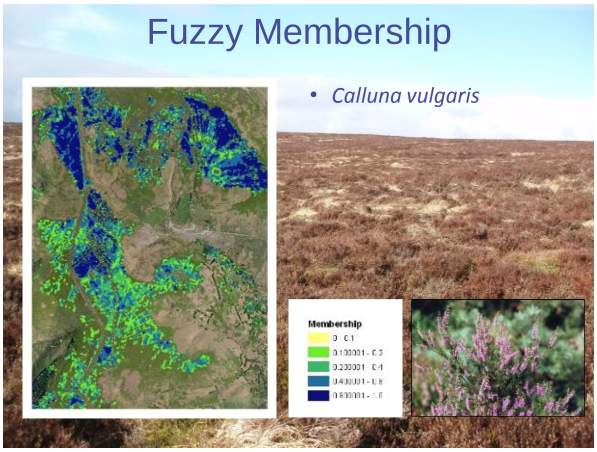
Better handling of Uncertainty

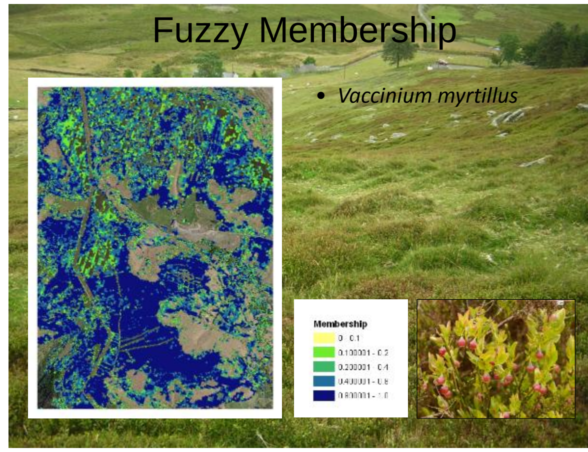
Used in our processing chain:

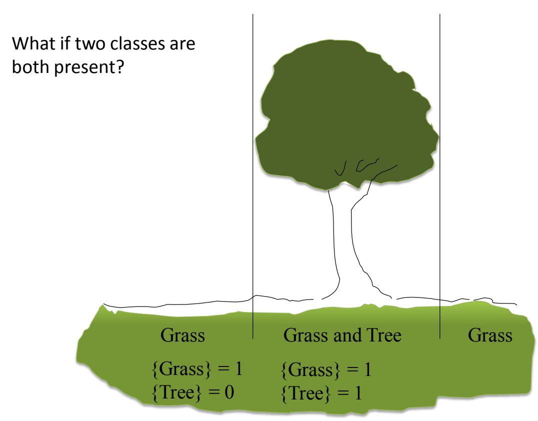
1. Error models:
   Spectral unmixing – using image processing software
   Conditional probability (to adjust stock estimates)
2. Expert systems:
   Fuzzy logic (poss / necc functions) – using Ecognition
3. Generalisations of probability:
   Dempster-Shafer (Bel / poss) – using FME

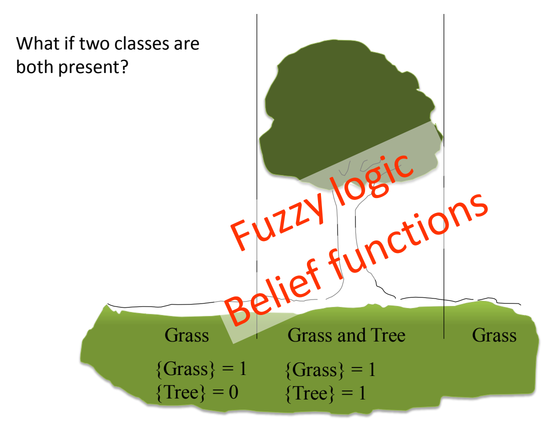
Associative, nonmonotonic if mass on Φ, can be used as a default system



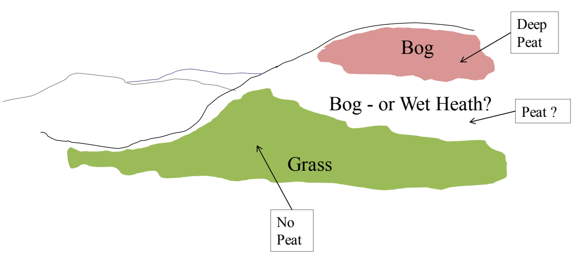

Fuzzy Membership
• Calluna vulgaris
Membership


Fuzzy Membership
• Vaccinium myrtillus
Membership


What if two classes are both present?
Grass
Grass and Tree
Grass
{Grass} = 1
{Tree} = 0
{Grass} = 1
{Tree} = 1


What if two classes are both present?
Fuzzy logic
Belief functions
Grass
Grass and Tree
Grass
{Grass} = 1
{Tree} = 0
{Grass} = 1
{Tree} = 1

What if we cannot discern whether an area is
one habitat class or another ?



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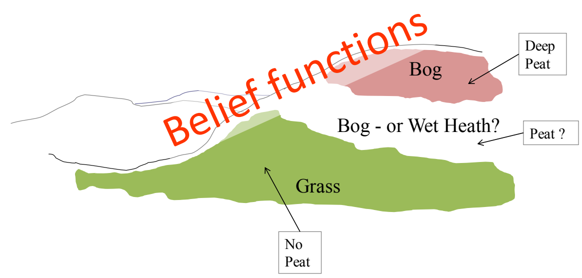
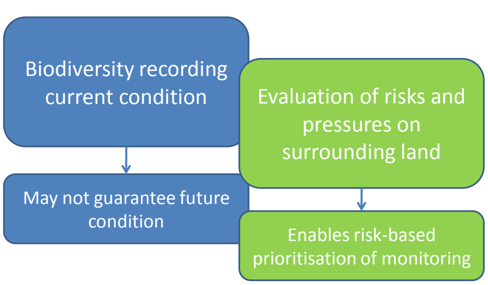
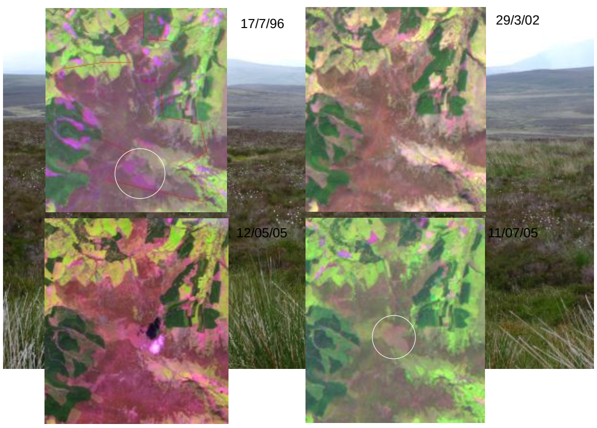
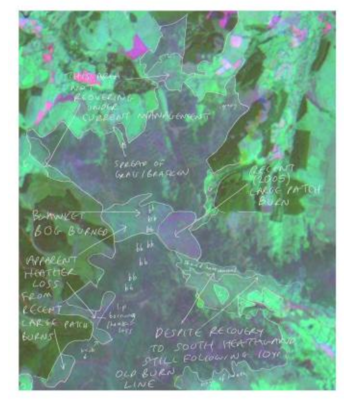


A risk-based approach



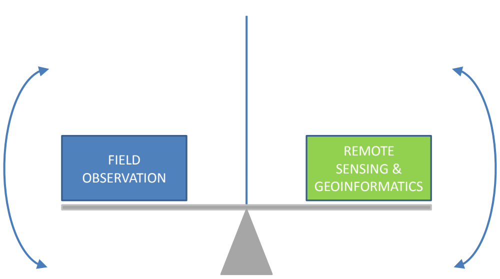




Condition of heath and bog in 2006...

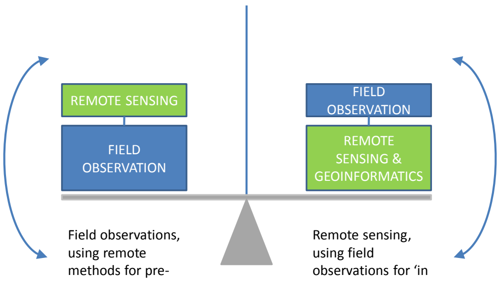
...tells us where we might want to carry out monitoring

Getting the balance right?



	Field Recording	Remote Sensing
Footprint	A few square metres	Hundreds of square kilometres
Data granulation	Chosen by observer	Depends on sensor
Extrapolation	Based on sample statistics	Wall-wall coverage, no extrapolation
Timing	One record at a time – many observations spread over several seasons	Simultaneous capture over very large areas
Ease of access	Can involve extensive travelling and risk	No problem
Potential for damage	High if dense recording in sensitive habitats	None – no contact with habitats
Recording restrictions	Weather, season	Cloud cover, sun angle (optical sensors)
Information content	Specific information on some or all species	Typically four or five highly correlated spectral channels
Recording	Presence, frequency, cover normally on one occasion	Reflectance proportional to species cover
		Characterisation of chemical composition and physical variables
		Spectral un-mixing of end-members Time-series recording
Spatial scaling	Statistical models	Automatic (convolution)
Sources of unwanted variation	Observer variation and 'human error'	Atmosphere, adjacency effects, mixed pixels, errors introduced in processing

Getting the balance right?



Field observations, using remote methods for pre- and post-stratification

Remote sensing, using field observations for 'in situ' measurements and calibration

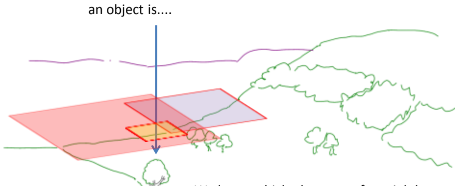
Complementary methods

Field observations, using remote methods for pre- and post-stratification

Remote sensing, using field observations for 'in situ' measurements and calibration

Spatial accuracy enables data fusion

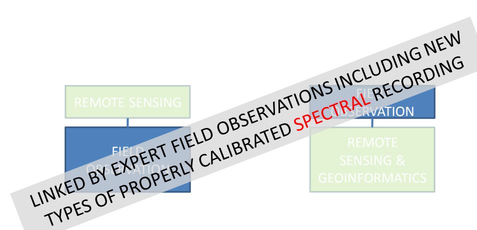
If we know exactly where an object is....



We know which elements of spatial data-sets, such as satellite image 'pixels' have information about it*.

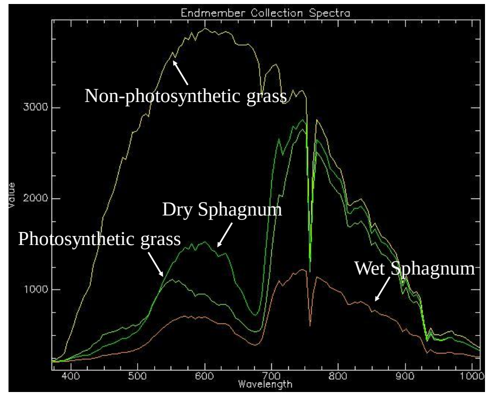
* Pixels do not actually record evenly from squares as shown here, more like diffuse ovals

Complementary methods



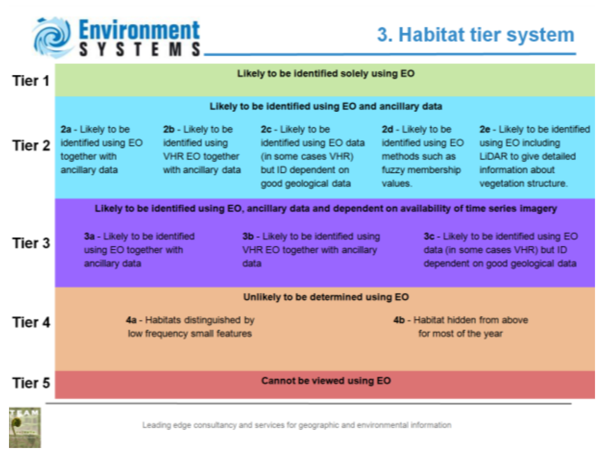
Field observations, using remote methods for pre- and post-stratification

Remote sensing, using field observations for 'in situ' measurements and calibration



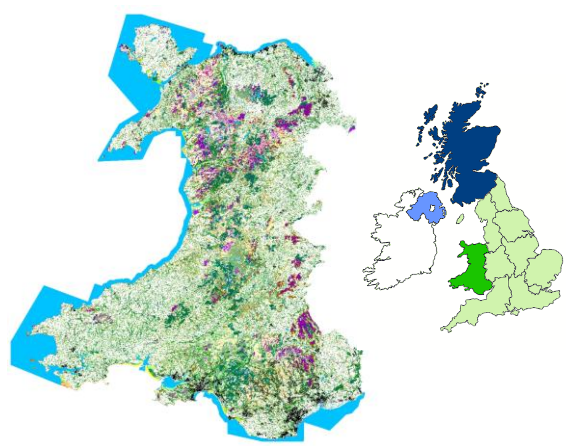
Understand what can be measured from space

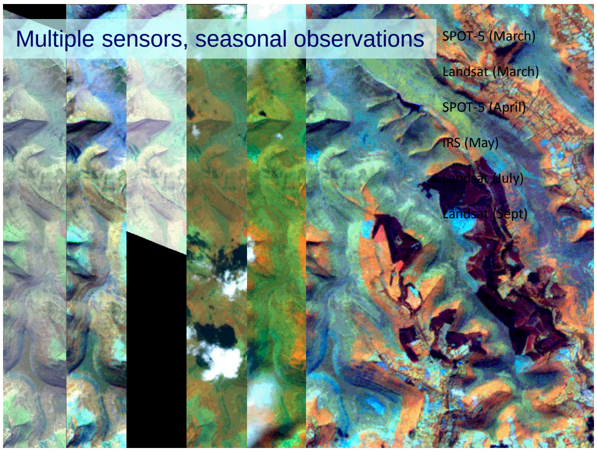
- Vegetation productivity
- Wetness / dryness
- Dead / living material
- Vegetation cover and structure
- Big patches of single-species
- Mapping of location and extent
- Anomalous changes in appearance

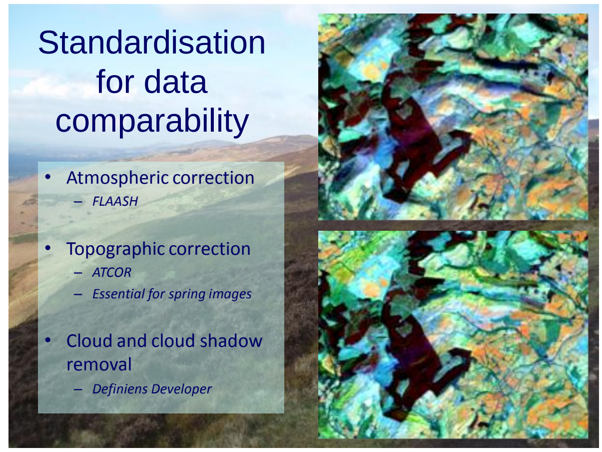


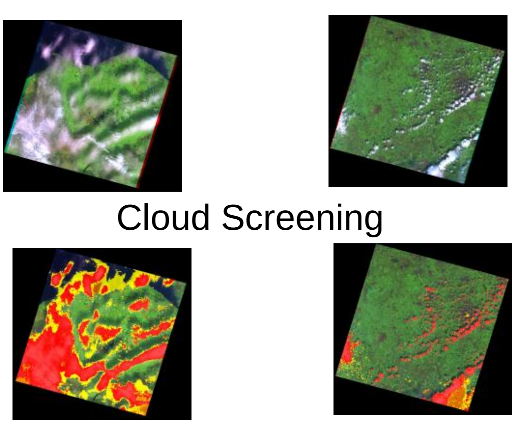
BUILDING WORKABLE SYSTEMS

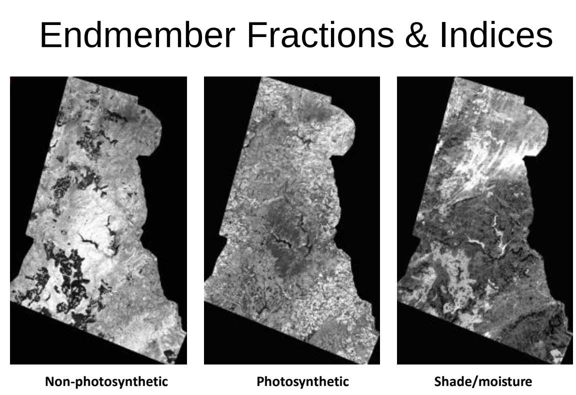
HABITAT MAPPING

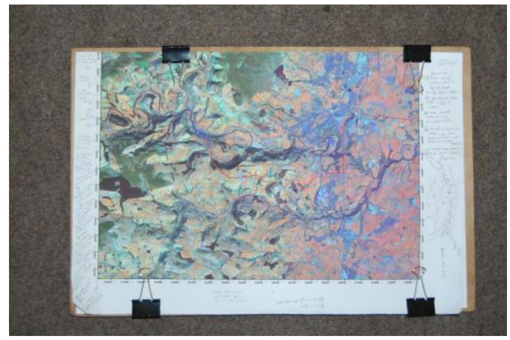



Multiple sensors, seasonal observations
SPOT-5 (March)
Landsat (March)
SPOT-5 (April)
IRS (May)
Landsat (July)
Landsat (Sept)


Standardisation for data comparability
• Atmospheric correction
– FLAASH
• Topographic correction
– ATCOR
– Essential for spring images
• Cloud and cloud shadow removal
– Definiens Developer


Cloud Screening


Endmember Fractions & Indices
Non-photosynthetic vegetation
Photosynthetic vegetation
Shade/moisture



Rules based on ecological knowledge

- Reflectance data
- Derived data
  - Endmember fractions
  - Vegetation Indices
  - Band ratios
  - Seasonal Differences
- Contextual information
  - Proximity to the coast
  - Relative proximity
    - Saltmarshes
  - Enclosures
  - Adjacency
- Transfers within hierarchy
  - Arable crops

- Topographic information
  - Elevation
  - Slope
  - Aspect
  - Concavity
- Ancillary data
  - Urban areas
  - Rivers and lakes
  - Field boundaries

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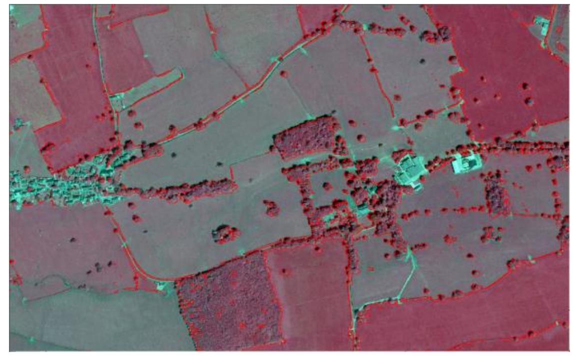
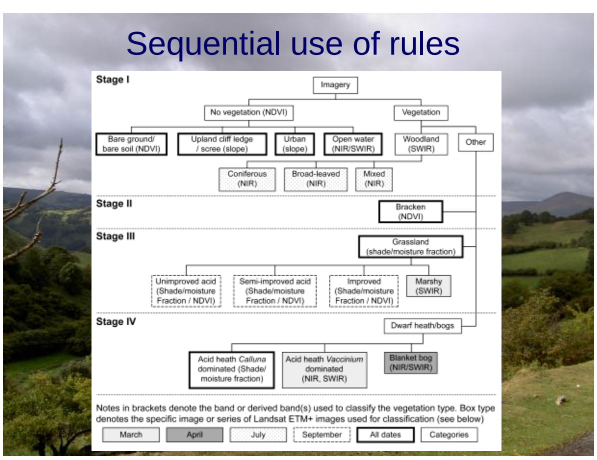
Table 2
Image acquisition periods by sensor for biogeographical regions 1–16.

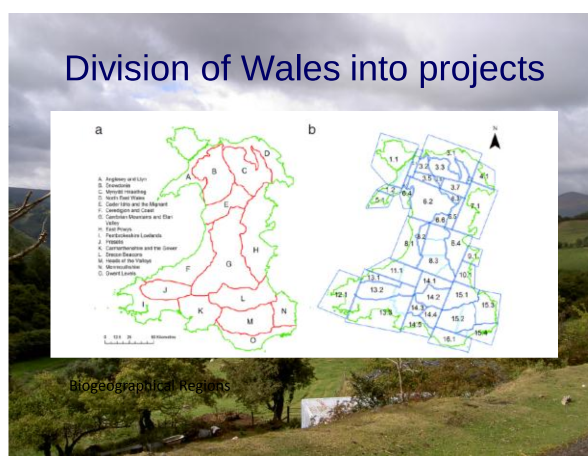
Sensor	Year	Month	Bioregion 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SPOT HRG	2003	Feb		•					•						•	•		
	2003	Mar				•		•		•							•	
	2003	Apr																•
	2003	Sep			•									•	•	•		
	2004	Apr										•						
	2005	Jul	•							•			•		•			
	2005	Sep	•				•	•										
	2006	Nov						•										
Terra-1 ASTER	2003	Apr	•		•			•	•	•	•	•				•	•	
	2003	Jul		•				•		•						•		
	2004	Apr												•				
	2004	May																•
	2005	Jun															•	
	2005	Sep															•	
IRS LISS 3	2005	May															•	
	2006	Jul	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

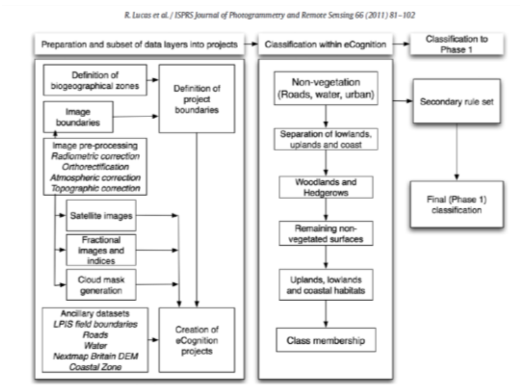
Denotes spring imagery

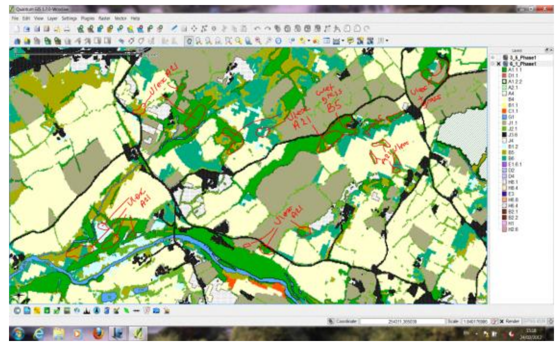

2006 air photographs – visible bands

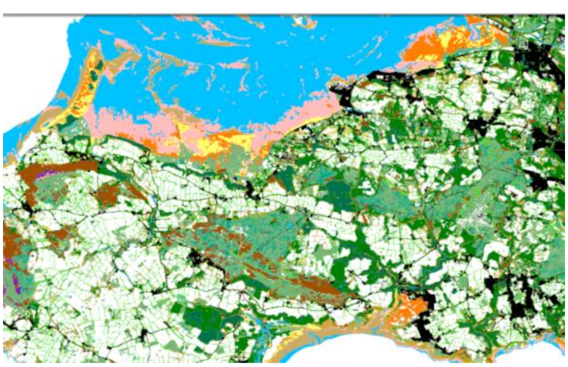



Sequential use of rules
Stage I
Imagery
No vegetation (NDVI)
Vegetation
Bare ground/ bare soil (NDVI)
Upland cliff ledge / scree (slope)
Urban (slope)
Open water (NIR/SWIR)
Woodland (SWIR)
Other
Coniferous (NIR)
Broad-leaved (NIR)
Mixed (NIR)
Stage II
Bracken (NDVI)
Stage III
Grassland (shade/moisture fraction)
Unimproved acid (Shade/moisture Fraction / NDVI)
Semi-improved acid (Shade/moisture Fraction / NDVI)
Improved (Shade/moisture Fraction / NDVI)
Marshy (SWIR)
Stage IV
Dwarf heath/bogs
Acid heath *Calluna* dominated (Shade/ moisture fraction)
Acid heath *Vaccinium* dominated (NIR, SWIR)
Blanket bog (NIR/SWIR)
Notes in brackets denote the band or derived band(s) used to classify the vegetation type. Box type denotes the specific image or series of Landsat ETM+ images used for classification (see below)
March
April
July
September
All dates
Categories

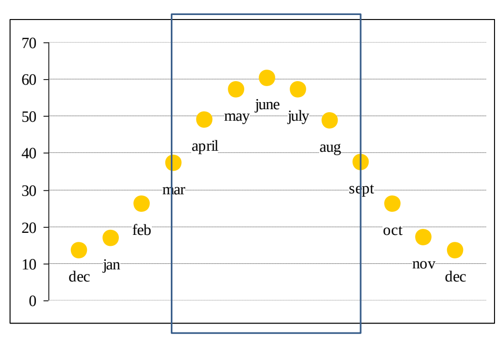

Division of Wales into projects
a
b
Biogeographical Regions







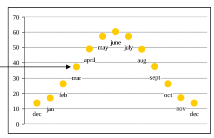
Most useful imagery 21s March to 21st September

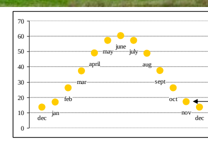


Apparent sun altitude (degrees) on 21st of each month
For **Wales** (53 degrees N, 4 degrees west)

SPRING

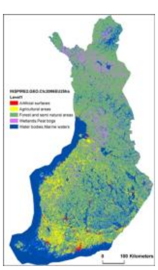
Spectral contrast with…
High sun angle



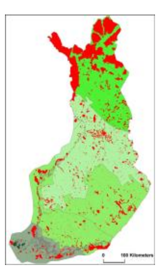


AUTUMN

Spectral contrast but…
Low sun angle

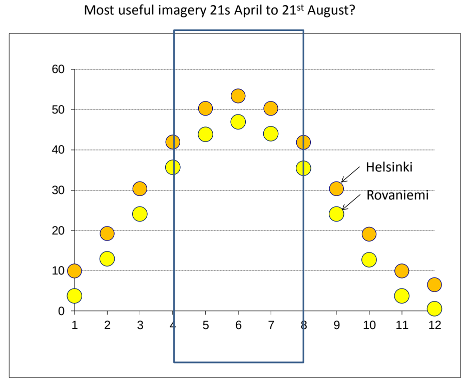


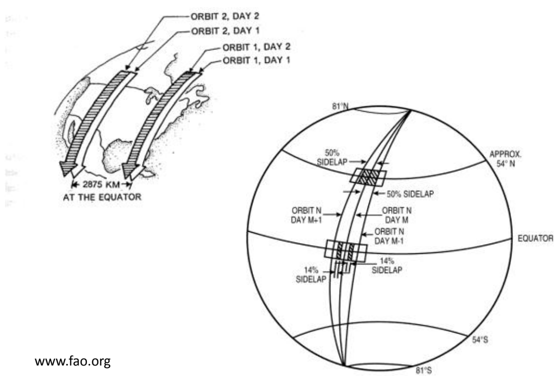
Land cover



Protected sites

Most useful imagery 21s April to 21st August?





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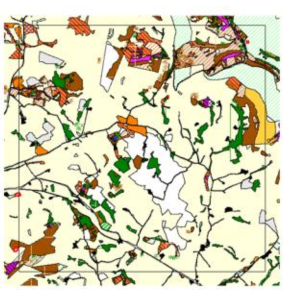
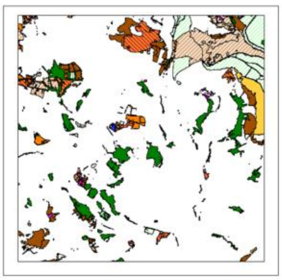
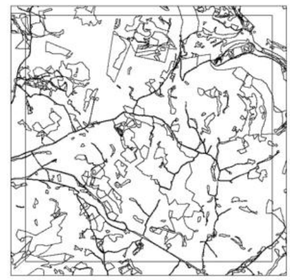
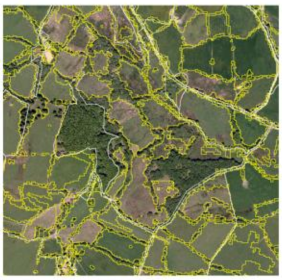
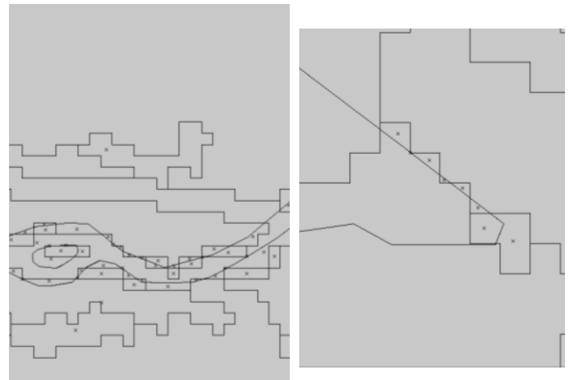
POST-CLASSIFICATION CHANGE DETECTION

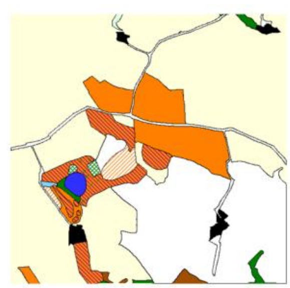








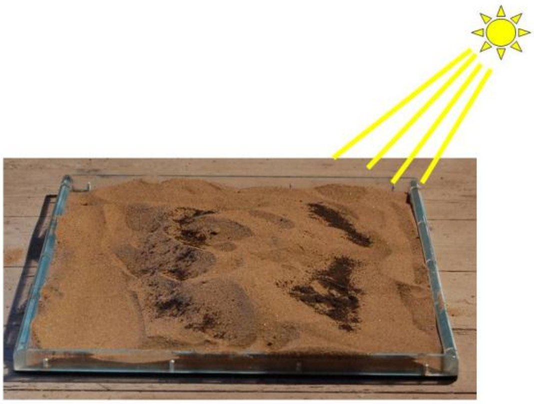


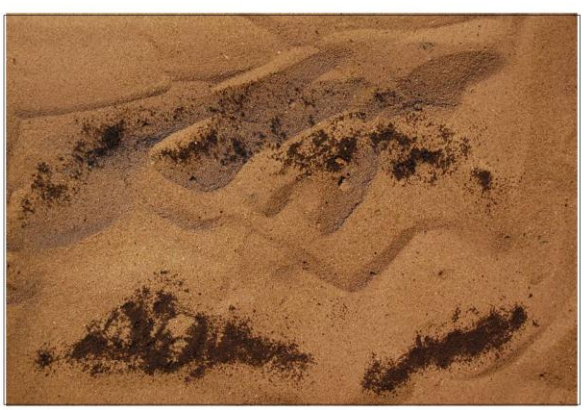


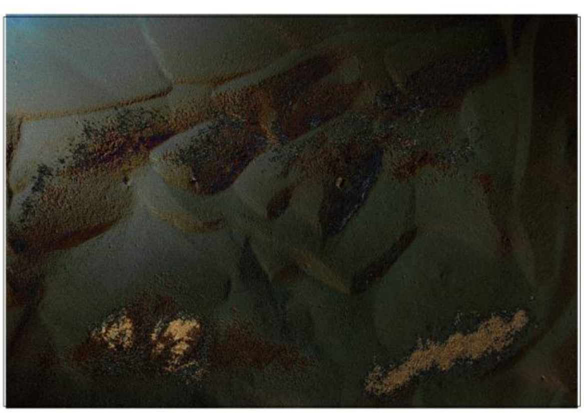
ANOMALOUS CHANGE DETECTION

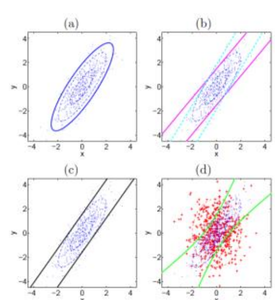
Changes and Differences

- Some differences on the imagery correspond with real changes on the ground
- Some differences are not change – for example cloud cover and mis-registration
- Many real changes on the ground will not show as differences on the imagery
- All matched pixels on the imagery are different – but some are more different than others









Anomaly detectors:

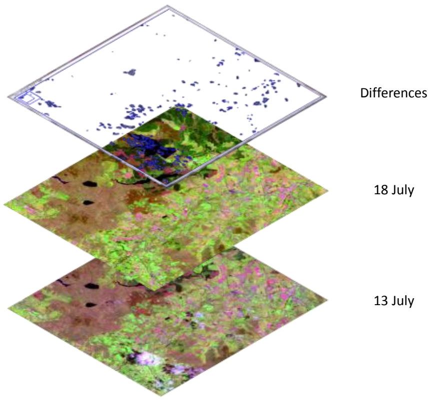
(a) Gaussian (two sigmas, 95%),

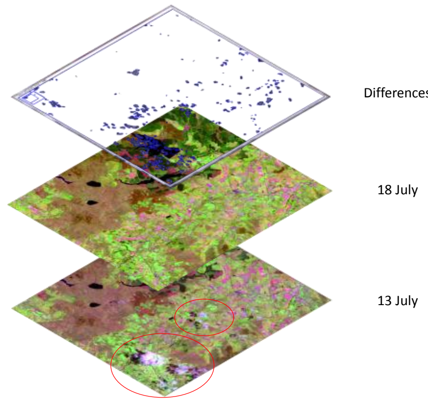
(b) chronochrome

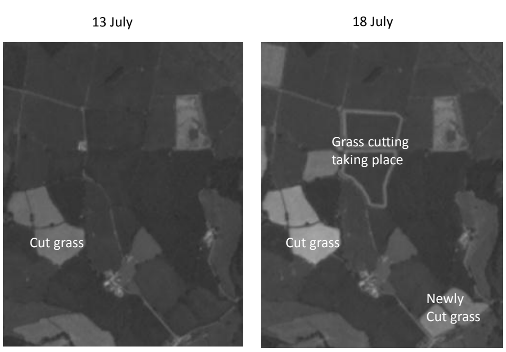
(c) covariance equalisation,

(d) hyperbolic.

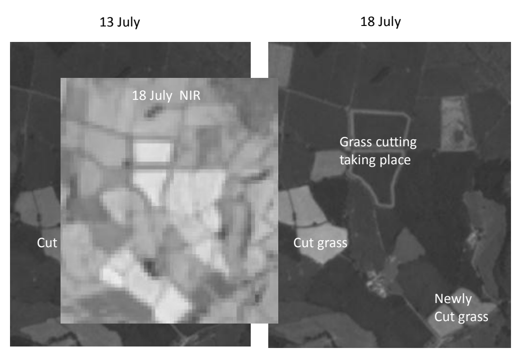
From Theiler and Perkins (2006): *Proposed Framework for Anomalous Change Detection*



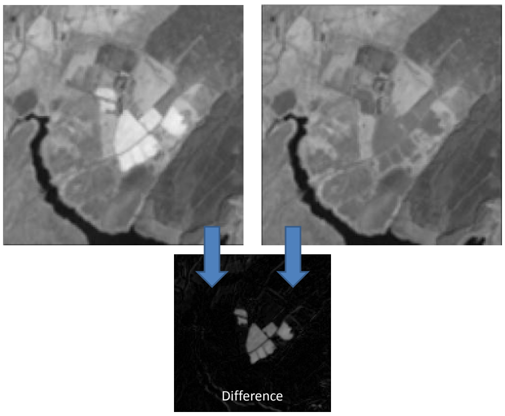


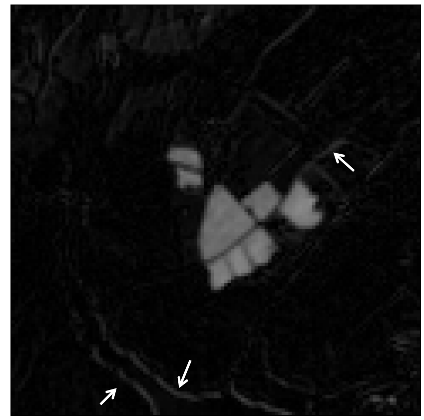


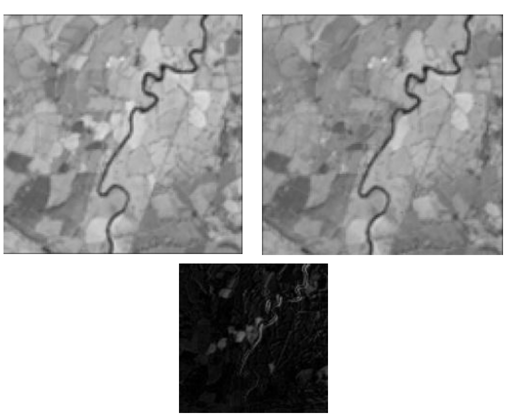
Red channel: dark shows surfaces absorbing red light (=vegetation), bright is reflecting red light. Bright areas show mown grass and lying hay

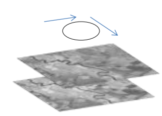


In the near Infra-red channel for 18 July, here at a coarser spatial resolution, actively Photosynthetic vegetation is highly reflective and appears bright in the image

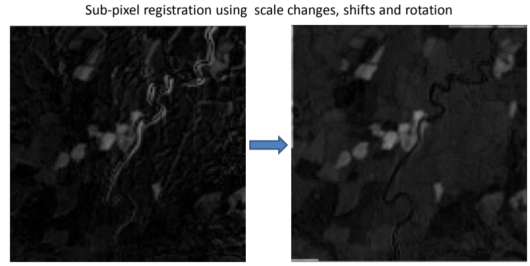






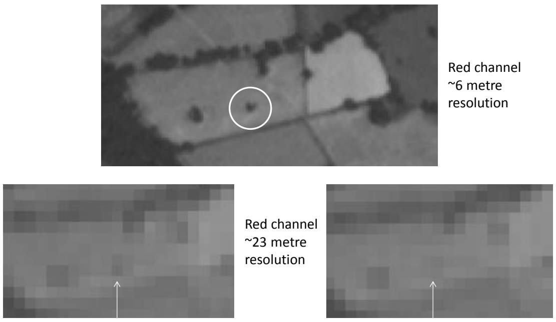


Sub-pixel registration using scale changes, shifts and rotation



Here mis-registration is mainly caused by a slight rotation between images

With local registration, the false differences are minimised, leaving the bigger true differences



The small tree causes a big change in the value of a single pixel on the left image (13 July), while the same difference is averaged across four pixels in the second image (18 July), making it seem to disappear. The next tree to the west is large enough to affect more than one pixel in both images.

New Software

New software includes:

- High quality open-source GIS, statistical software (e.g. R), image processing software
- Object-based methods (notably eCognition)
- Specialist software (e.g. image-image registration, hyperspectral analysis)
- Modelling packages

New types of Knowledge

New knowledge might include:

- The range, extent and distribution of broad habitat classes – and how it changes
- What types of land cover surround a protected site
- Habitat networks and connectivity
- The potential range of species restricted to some habitats, and where to look

Article 17 Reporting

- Range and Area covered within range:
  - Stable or increasing?
  - Greater than reference range / area?
  - Any significant changes in pattern (distribution)?
- Specific structures and functions:
  - Status of typical species?
  - Condition?
  - Any deteriorations / pressures?
- Future prospects