Satellite Applications

Satellite Earth Observation

Services for Ecosystem valuation

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Head of the CEO’s Office
Satellite Applications Catapult

17 March 2017

Innovate UK
Technology Strategy Board

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Outline

- **Introduction to Earth observation and ecosystem services valuation**
- **Example: The SENCE and Milton Keynes approaches**
- **MK broad-scale habitat map & ecosystem service layers**
- **Taking it further…**

Do not cut down the tree that gives you shade

- Arabian proverb

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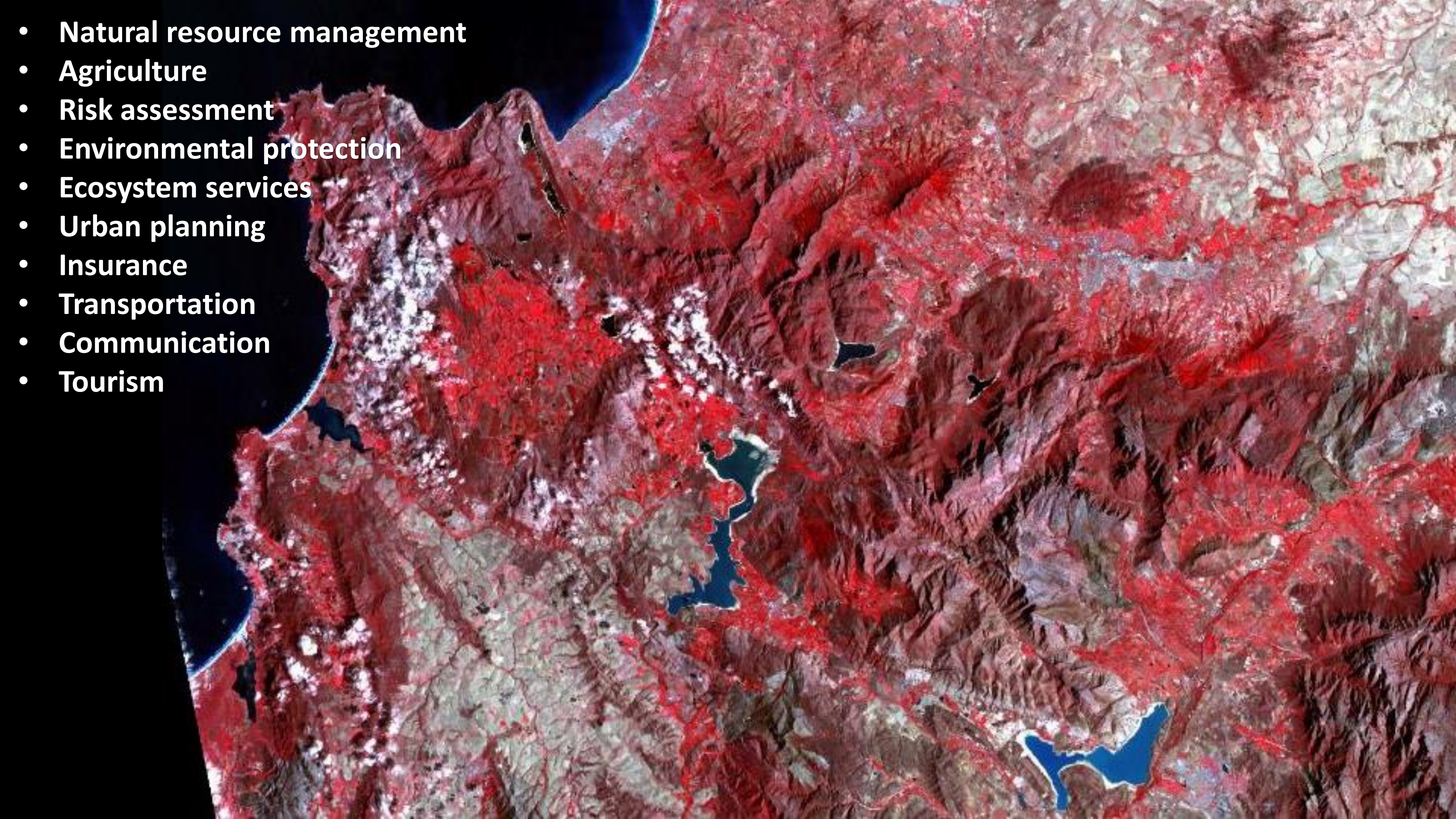
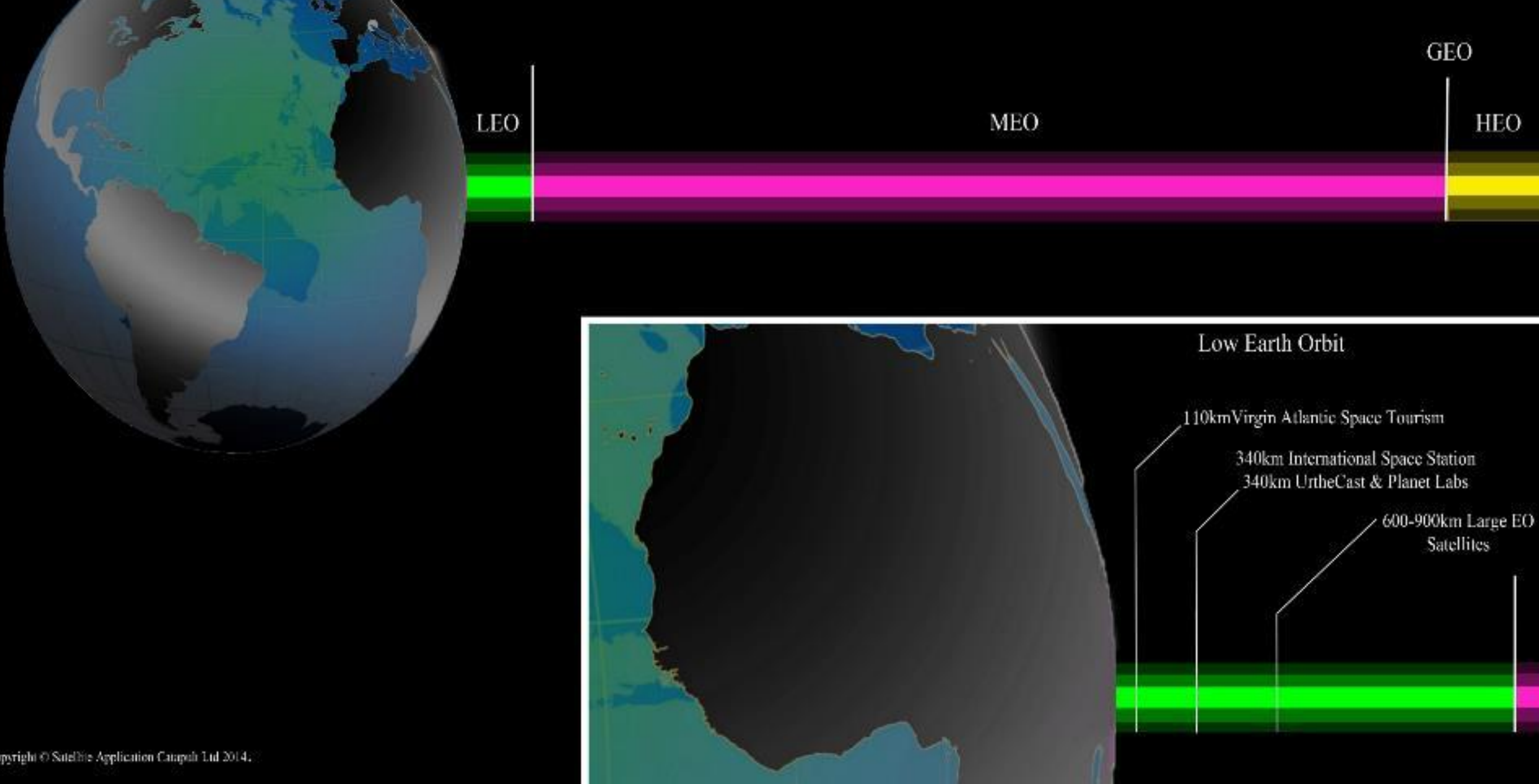
Earth observation is the gathering of information about the Earth's physical, chemical and biological systems



- Natural resource management
- Agriculture
- Risk assessment
- Environmental protection
- Ecosystem services
- Urban planning
- Insurance
- Transportation
- Communication
- Tourism

Where are the Satellites?

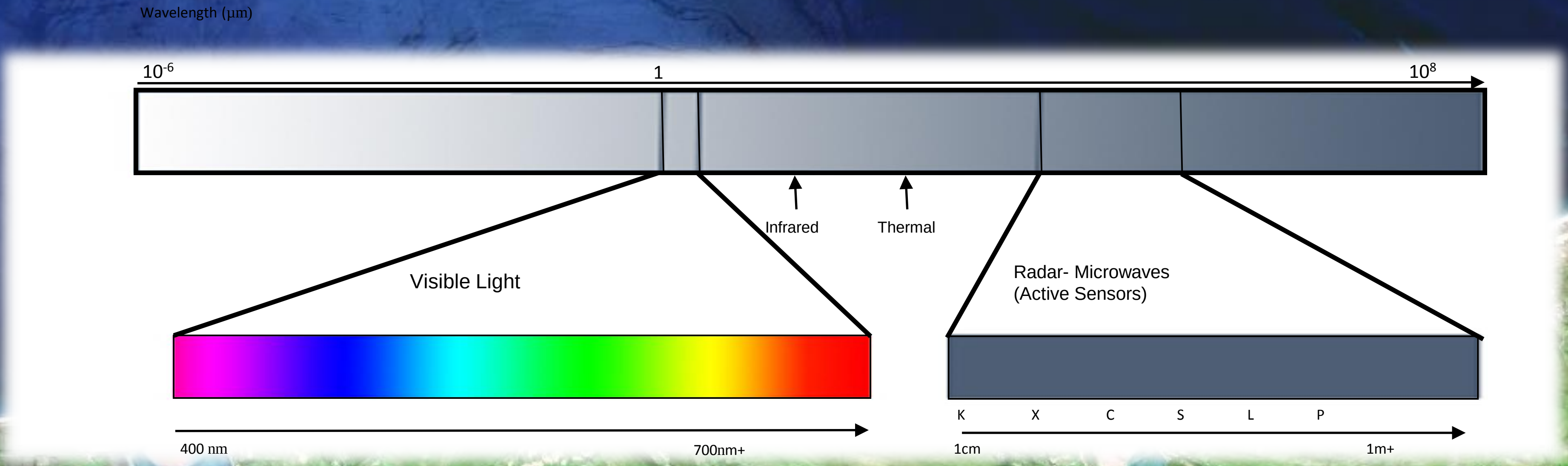



Worldview-1

Remote Sensing

Remote sensing systems make use of the electromagnetic spectrum in two ways:

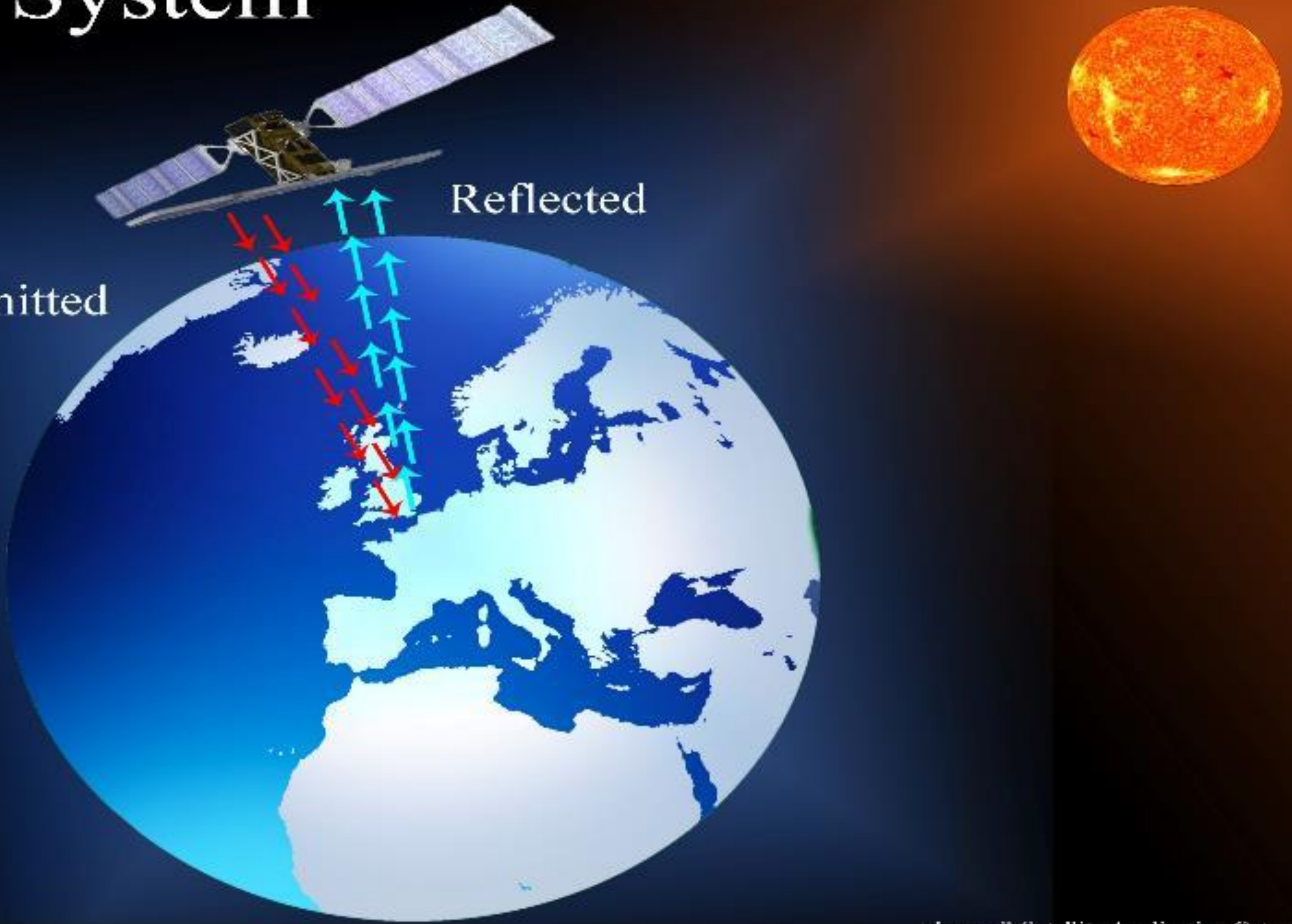
1. Collecting the radiation that is reflected, emitted or scattered by a target (**passive systems**)
2. Illuminating a target with a pulse or beam of radiation and collecting the signal that is reflected or refracted back to the sensor (**active systems**).



Passive System

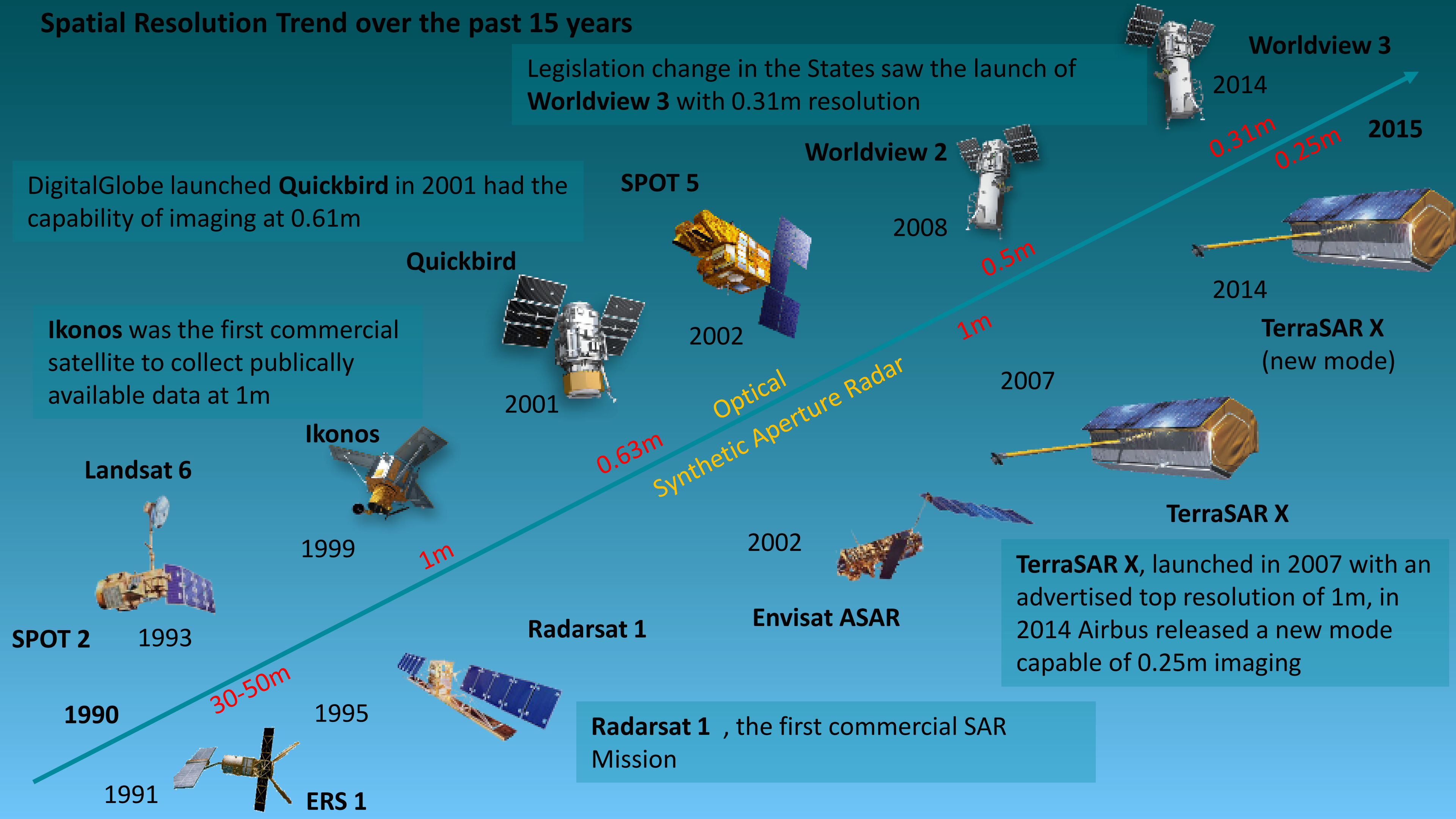
Optical Imagery at LEO

Active System



Radar Imagery

Resolution


Spatial Resolution Trend over the past 15 years
Legislation change in the States saw the launch of **Worldview 3** with 0.31m resolution
Worldview 3
2014
2015
0.31m
0.25m
DigitalGlobe launched **Quickbird** in 2001 had the capability of imaging at 0.61m
SPOT 5
Worldview 2
2008
0.5m
2014
Quickbird
2002
1m
TerraSAR X
(new mode)
Ikonos was the first commercial satellite to collect publically available data at 1m
2001
Optical
Synthetic Aperture Radar
2007
Ikonos
0.63m
Landsat 6
1999
1m
2002
TerraSAR X
TerraSAR X, launched in 2007 with an advertised top resolution of 1m, in 2014 Airbus released a new mode capable of 0.25m imaging
SPOT 2
1993
Radarsat 1
Envisat ASAR
1990
30-50m
1995
Radarsat 1 , the first commercial SAR Mission
1991
ERS 1

What are ecosystem services?

"a wide range of conditions and processes through which natural ecosystems, and the species that are part of them, help sustain and fulfill human life" (Daily et al. 1997)

- The environment is our life support system.
- Needs a healthy diversity of plants and animals to function.
- Ecosystem services are the benefits people obtain from ecosystems.

Environment Systems evidence and insight

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Progress in Physical Geography 33(4) (2009) pp. 528–546

Remote sensing and the future of landscape ecology

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Abstract: Landscape ecology focuses on the analysis of spatial pattern and its relationship to ecological processes. As a scientific discipline, landscape ecology has grown rapidly in recent years, supported by developments in GIS and spatial analysis techniques. Although remote sensing data are widely employed in landscape ecology research, their current and potential roles have not been evaluated critically. To provide an overview of current practice, 438 research papers published in the journal *Landscape Ecology* for the years 2004–2008 were examined for information about use of remote sensing. Results indicated that only 36% of studies explicitly mentioned remote sensing. Of those that did so, aerial photographs and Landsat satellite sensor images were most commonly used, accounting for 46% and 42% of studies, respectively. The predominant application of remote sensing data across these studies was for thematic mapping purposes. This suggests that landscape ecologists have been relatively slow to recognize the potential value of recent developments in remote sensing technologies and methods. The review also provided evidence of a frequent lack of key detail in studies recently published in *Landscape Ecology*, with 75% failing to provide any assessment of uncertainty or error relating to image classification and mapping. It is suggested that the role of remote sensing in landscape ecology might be strengthened by closer collaboration

2009 review of use of RS data in landscape ecology (habitat assessment)

Conclusion: an overwhelming use of RS as a source of land cover information, with other possible RS data products rarely used.

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journal homepage: www.elsevier.com/locate/ecolind

ELSEVIER

Review

Remote sensing of ecosystem services: A systematic review

CrossMark

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ABSTRACT

Appropriate integration of remote sensing technologies into ecosystem services concepts and practices leads to potential practical benefits for the protection of biodiversity and the promotion of sustainable use of Earth's natural assets. The last decade has seen the rapid development of research efforts on the topic of ecosystem services, which has led to a significant increase in the number of scientific publications. This systematic review aims to identify, evaluate and synthesise the evidence provided in published peer reviewed studies framing their work in the context of spatially explicit remote sensing assessment and valuation of ecosystem services. Initially, a search through indexed scientific databases found 5920 papers making direct and/or indirect reference to the topic of "ecosystem services" between the years of 1960 and 2013. Among these papers, 211 make direct reference to the use of remote sensing. During the search we aimed at selecting papers that were peer-reviewed publications available through indexed bibliographic databases. For this reason, our literature search did not include books, grey literature, extended abstracts and presentations. We quantitatively present the growth of remote sensing applications in ecosystem services' research, reviewing the literature to produce a summary of the state of available and feasible remote sensing variables used in the assessment and valuation of ecosystem services. The results provide valuable information on how remotely sensed Earth observation data are used currently to produce spatially-explicit assessments and valuation of ecosystem services. Using examples from the literature we produce a concise summary of what has been done, what can be done and what can be improved upon in the future to integrate remote sensing into ecosystem services research. The reason for doing so is to motivate discussion about methodological challenges, solutions and to encourage an uptake of remote sensing technology and data where it has potential practical applications.

May 2015

bess biodiversity & ecosystem service sustainability

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Article

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Potential contributions of remote sensing to ecosystem service assessments

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Abstract
Ecological and conservation research has provided a strong scientific underpinning to the modeling of ecosystem services (ESs) over space and time, by identifying the ecological processes and components of biodiversity (ecosystem service providers, functional traits) that drive ES supply. Despite this knowledge, efforts to map the distribution of ESs often rely on simple spatial surrogates that provide incomplete and non-mechanistic representations of the biophysical variables they are intended to proxy. However, alternative data sets are available that allow for more direct, spatially nuanced inputs to ES mapping efforts. Many spatially explicit, quantitative estimates of biophysical parameters are currently supported by remote sensing, with great relevance to ES mapping. Additional parameters that are not amenable to direct detection by remote sensing may be indirectly modeled with spatial environmental data layers. We review the capabilities of modern remote sensing for describing biodiversity, plant traits, vegetation condition, ecological processes, soil properties, and hydrological variables and highlight how these products may contribute to ES assessments. Because these products often provide more direct estimates of the ecological properties controlling ESs than the spatial proxies currently in use, they can support greater mechanistic realism in models of ESs. By drawing on the increasing range of remote sensing instruments and measurements, data sets appropriate to the estimation of a given ES can be selected or developed. In so doing, we anticipate rapid progress to the spatial characterization of ecosystem services, in turn supporting ecological conservation, management, and integrated land use planning.

June 2014

August 2012

Environmental Science & Technology
Critical Review
pubs.acs.org/est

Quantifying and Mapping Ecosystem Services Supplies and Demands: A Review of Remote Sensing Applications

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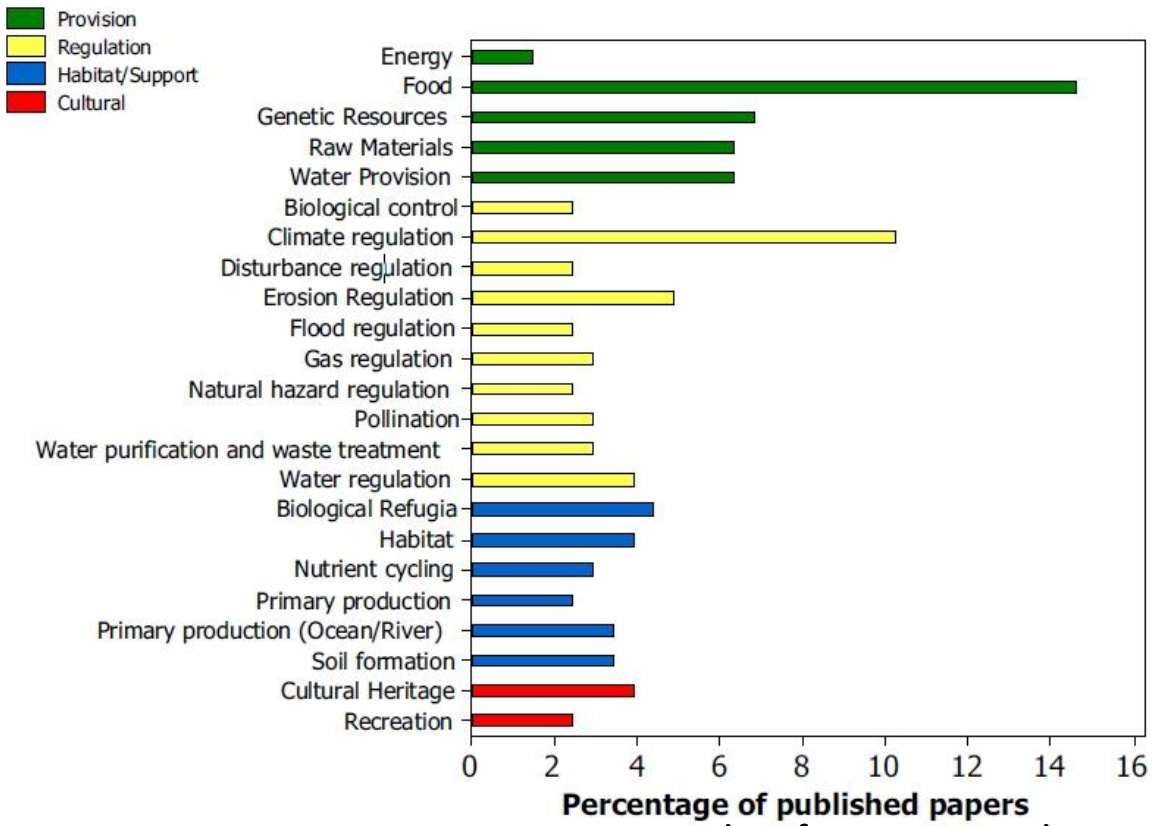
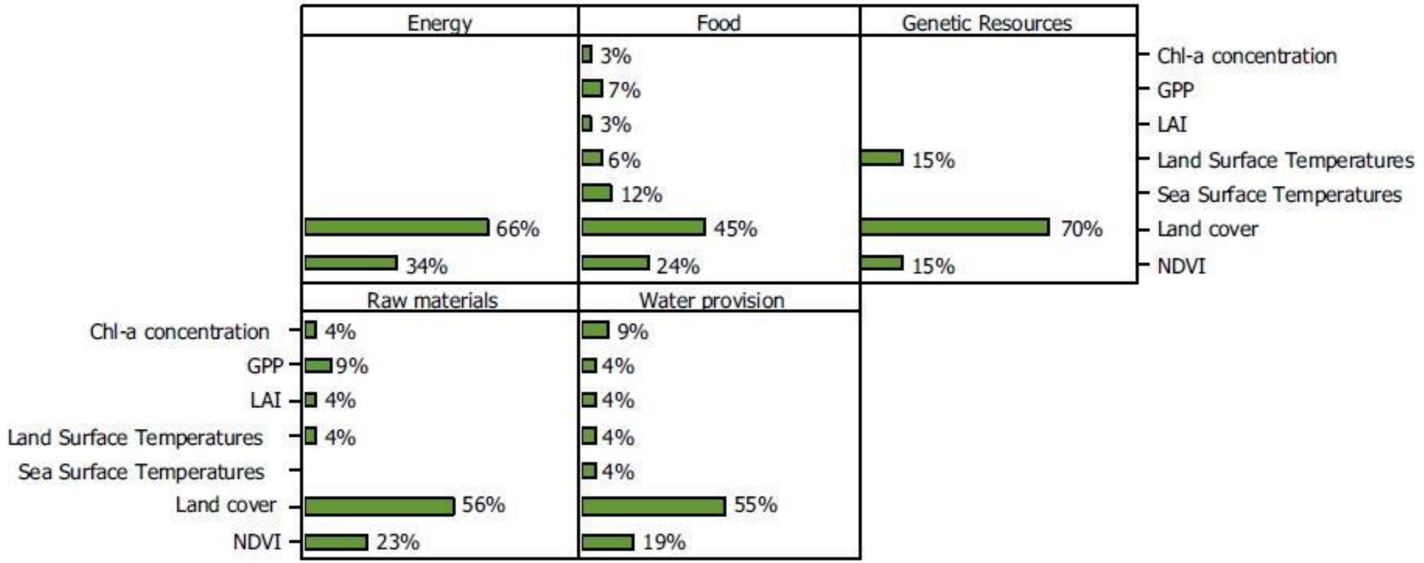
Supporting Information

ABSTRACT: Ecosystems provide services necessary for the livelihoods and well-being of people. Quantifying and mapping supplies and demands of ecosystem services is essential for continuous monitoring of such services to support decision-making. Area-wide and spatially explicit mapping of ecosystem services based on extensive ground surveys is restricted to local scales and limited due to high costs. In contrast, remote sensing provides reliable area-wide data for quantifying and mapping ecosystem services at comparatively low costs, and with the option of fast, frequent, and continuous observations for monitoring. In this paper, we review relevant remote sensing systems, sensor types, and methods applicable in quantifying selected provisioning and regulatory services. Furthermore, opportunities, challenges, and future prospects in using remote sensing for supporting ecosystem services' quantification and mapping are discussed.



on remote sensing of ecosystem services

Provisioning services



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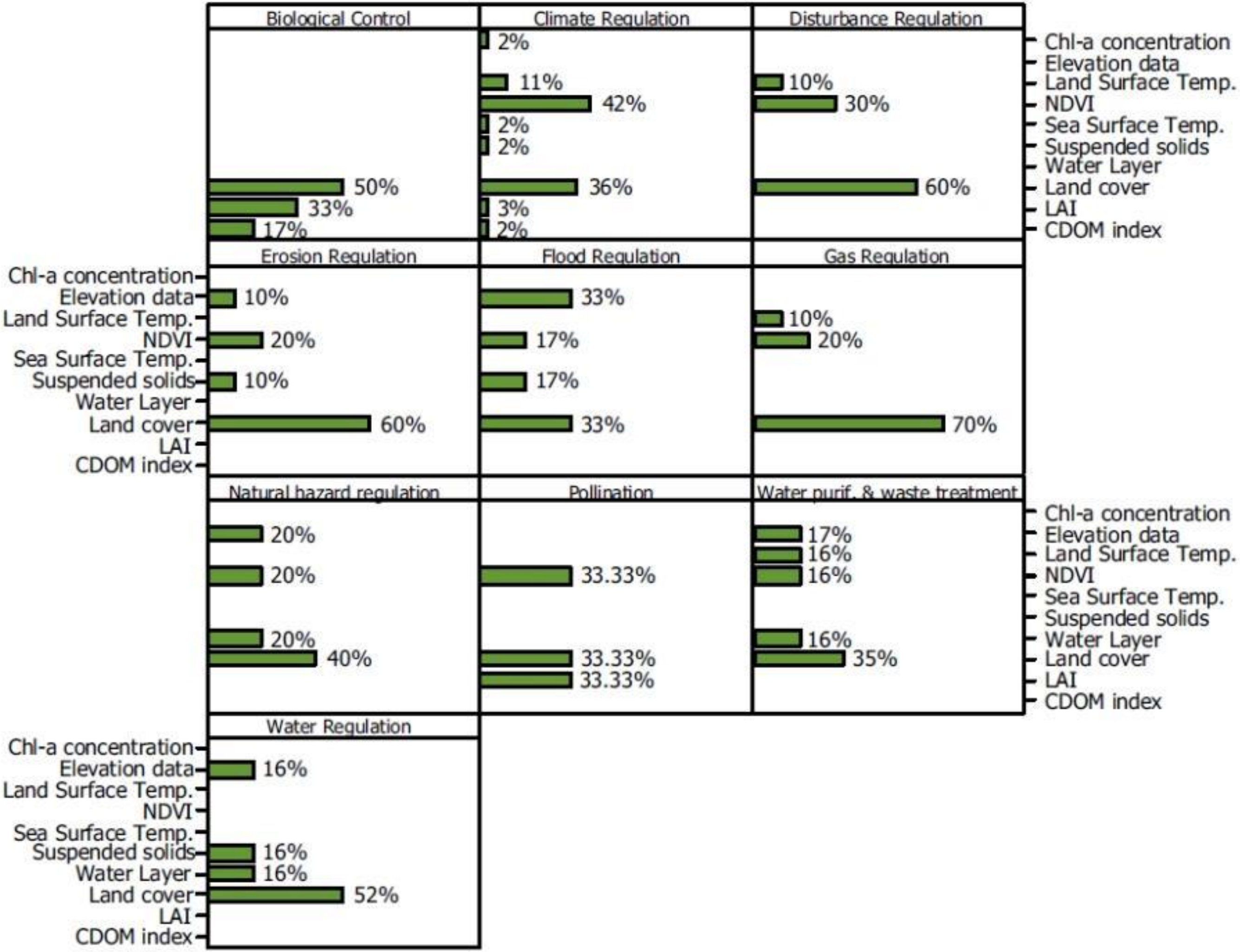
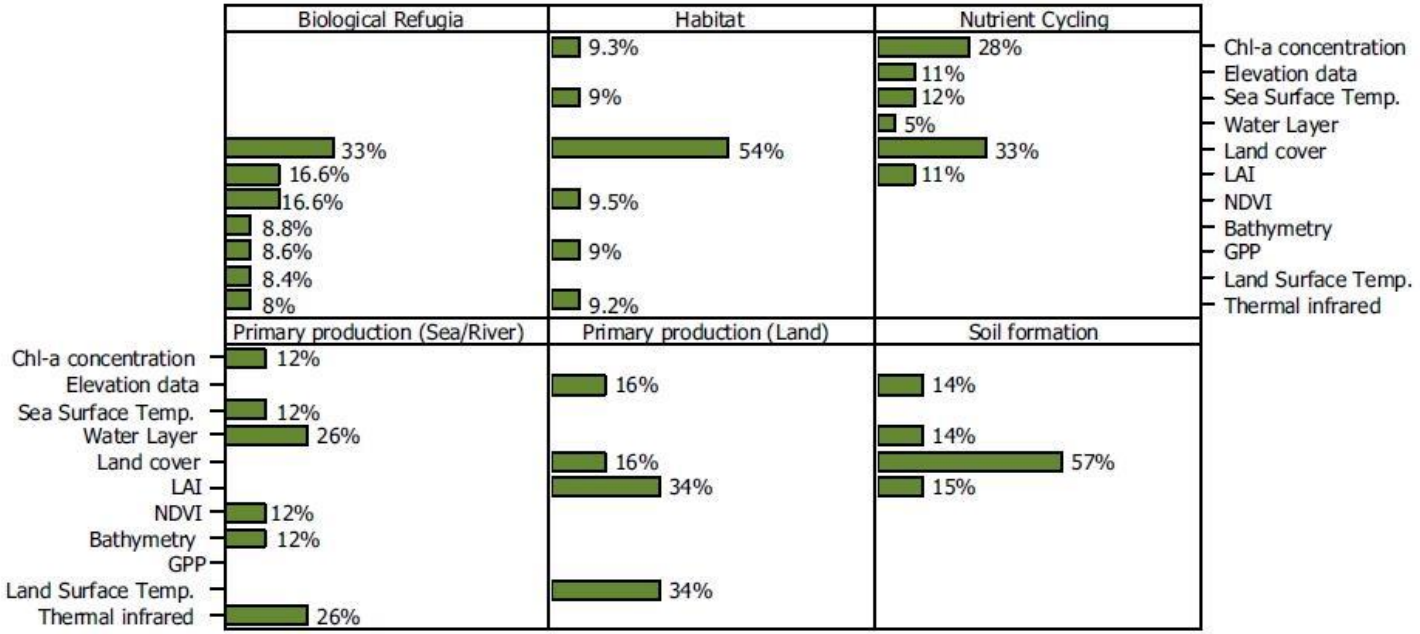
Regulatory services



Support services



Satellite Applications

Cultural services

Satellite Applications

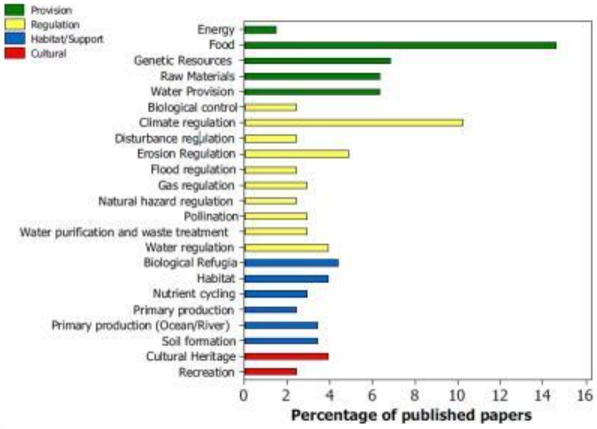
Average RS variable use per ecosystem service category

Provisioning services	
%	RS variable
58.4	Land cover
23.0	NDVI
5.8	Land surface temp
4.0	GPP
3.2	Sea surface temp
3.2	Chl-a concentration
2.2	LAI

Regulating services	
%	RS variable
46.9	Land cover
19.8	NDVI
9.6	Elevation data
6.9	LAI
4.7	Land surface temp
5.2	Water layer
4.5	Suspended solids
1.9	CDOM Index
0.2	Chl-a concentration
0.2	Sea surface temp

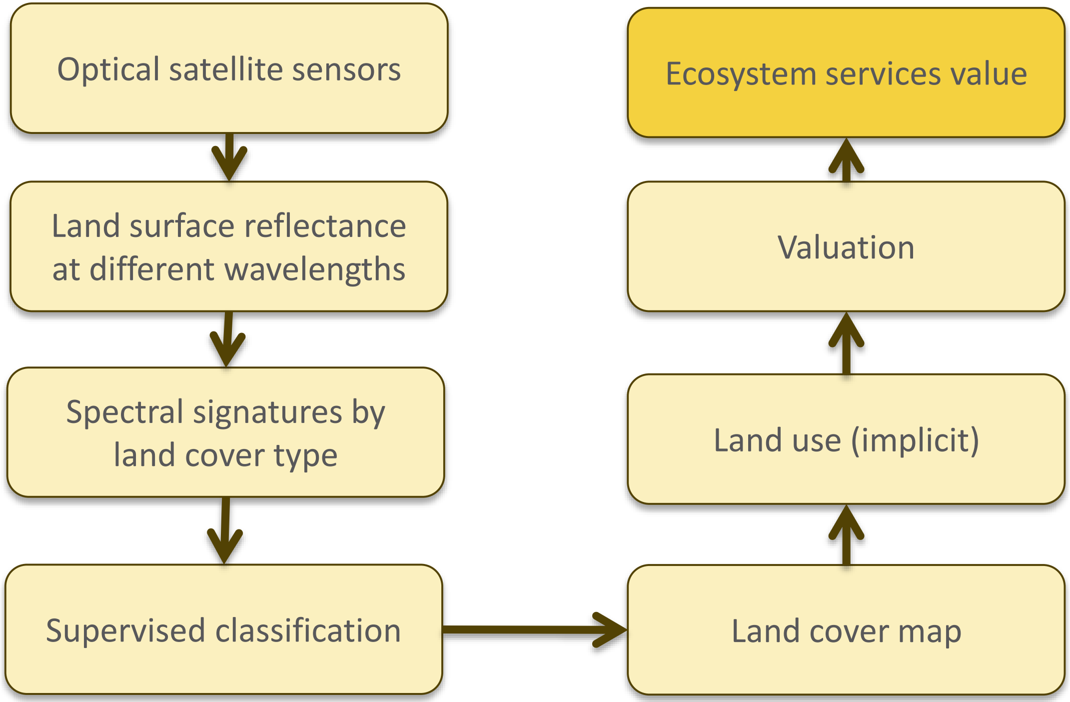
Supporting services	
%	RS variable
32.2	Land cover
12.8	LAI
8.2	Chl-a concentration
7.5	Water layer
7.2	Thermal infrared
7.0	Land surface temp
6.8	Elevation data
6.5	NDVI
5.5	Sea surface temp
3.5	Bathymetry
3.0	GPP

Cultural services	
%	RS variable
55.0	Land cover
28.5	NDVI
16.5	Land surface temp

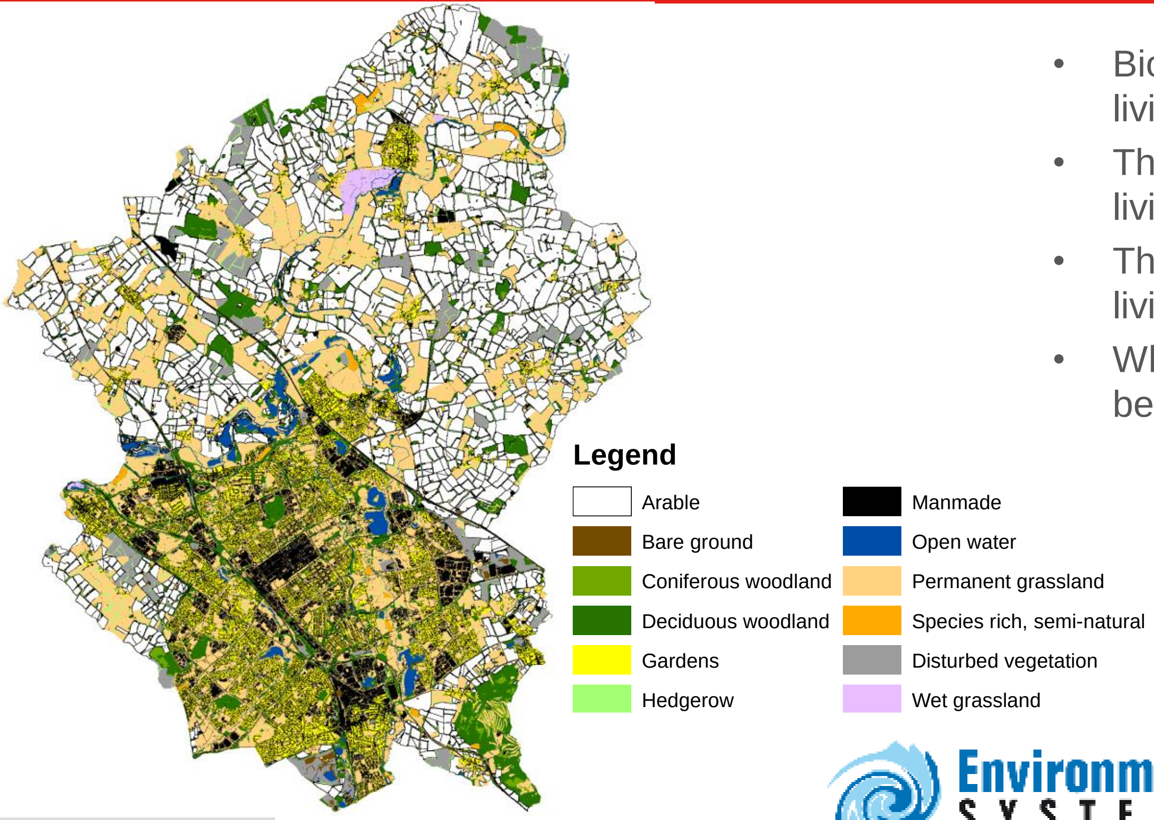


Land cover
NDVI and/or LAI
Land surface temperature
(Elevation data)
(Chlorophyll-a)

Most common approach: land cover



Understanding living systems that provide Ecosystem Services



- Biophysical characteristics of a living system
- The natural processes of that living system
- The benefits we gain from the living system
- What is the value of those benefits?

What can satellite data provide for Ecosystem Service Valuation?

SENCE
Spatial Evidence for Natural Capital Evaluation

– Data Information
– Habitat Information

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The SENSE approach: Data & ecological knowledge

It is important to consider all the information in any land-based decision…

SENCE

Spatial Evidence for Natural Capital Evaluation

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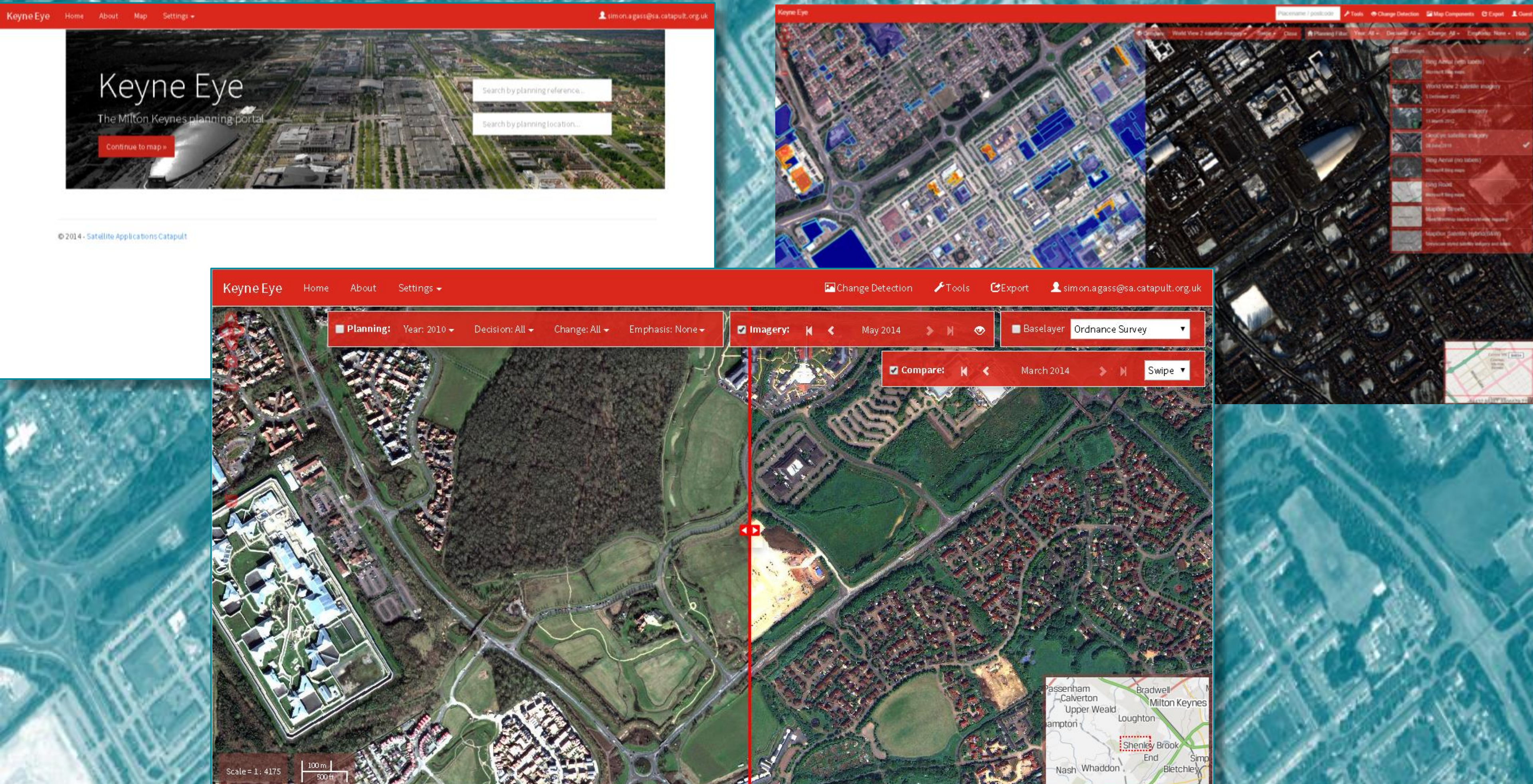
Working With Local Authorities



The Milton Keynes (MK) approach: Broad-scale habitat map

Imagery:

Landsat

Pleiades

SPOT 6

SRTM

WV 2

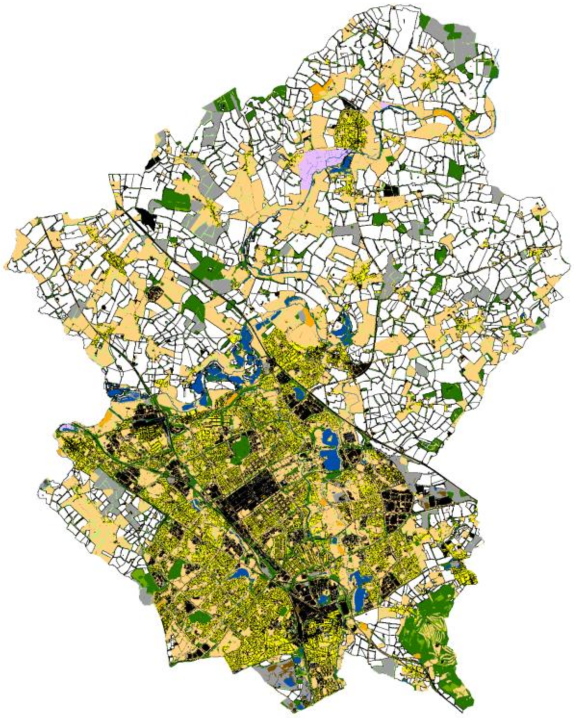
WV 3

Thematic layers:

OSMM

NE Priority habitats

Cloud cover



Legend

- Arable
- Bare ground
- Coniferous woodland
- Deciduous woodland
- Gardens
- Hedgerow
- Manmade
- Open water
- Permanent grassland
- Species rich, semi-natural
- Disturbed vegetation
- Wet grassland

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The MK approach: Knowledge-based ruleset

Each delineated habitat is given a score of importance, from a disbenefit to a high and positive affect, for each ecosystem service layer.

Habitat	Food Provision	Pollination	Air Quality	Soil Function	Water quality	Carbon storage
Agricultural	3	1	0	-1	-1	-1
Gardens	2	2	1	2	1	1
Heterogeneous grassland	1	3	1	3	2	1
Hedgerow	1	1	2	3	3	2
High intensity grassland	2	1	1	-1	0	-1
Permanent grassland	2	2	1	2	1	1
Species rich, semi-natural grassland	1	3	1	3	2	1
Urban	0	0	0	-1	-1	-1
Wet grassland	2	2	1	3	1	2
Woodland (broadleaf)	1	2	3	3	3	3
Woodland (coniferous)	0	0	2	1	2	3

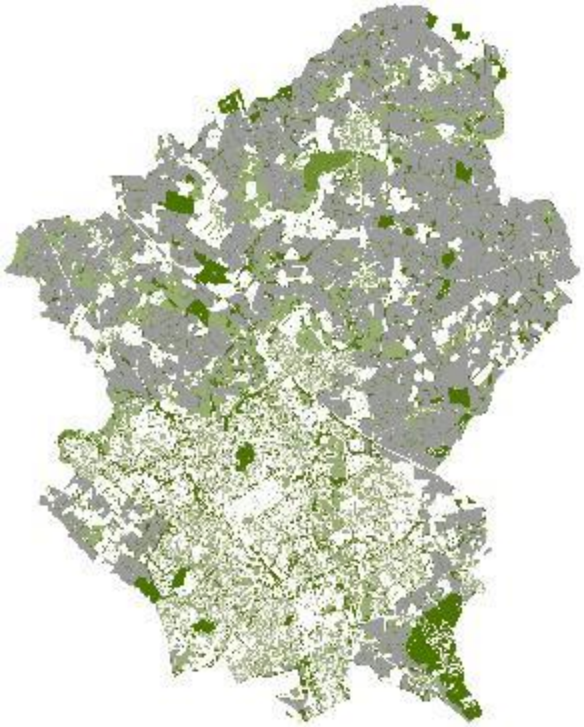
MK ecosystem services: Carbon storage

Legend

- High
- Moderate
- Low
- Disbenefit

9.2% High
3.8% Moderate
18.2% Low
19.1% None
37.0% Disbenefit *

*not including urban areas



Areas of land important for carbon storage in vegetation

How to interpret the map:
The darkest colours represent areas where there is more carbon storage in the vegetation, which include areas of woodland. Grey areas indicate a loss of carbon into the atmosphere.

What the ecosystem service is:
This map shows where there is significant storage of carbon within the vegetation of the Milton Keynes county borough. Atmospheric carbon is sequestrated by and stored in vegetation through the process of photosynthesis, resulting in vegetative growth. The more biomass present in the vegetation the more carbon that is stored, with mature woodland at one end of the spectrum and grasslands at the other end. Carbon storage in the vegetation can help in mitigating climate change by binding up the carbon and preventing its release to the atmosphere.

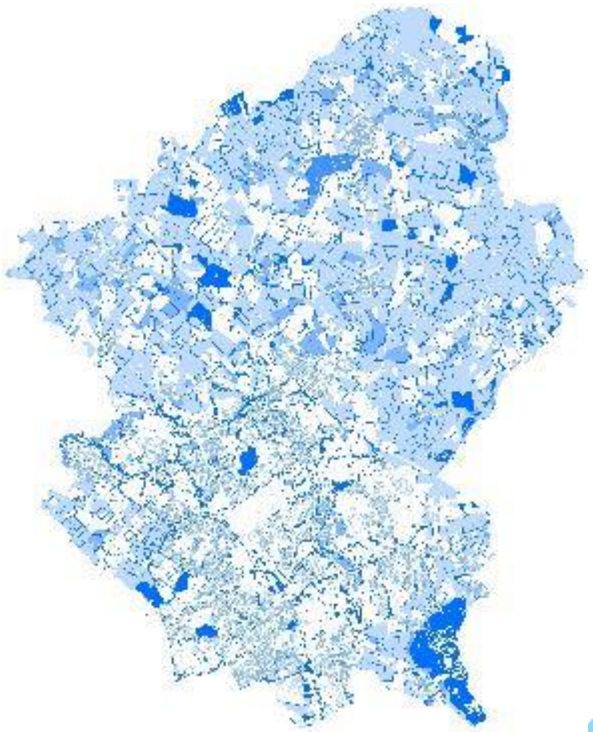
MK ecosystem services: Surface water

Legend

- High
- Moderate
- Low
- Disbenefit

12.6% High
0.4% Moderate
11.3% Low
29.7% None
33.4% Disbenefit *

*not including urban areas



Areas of land which help store water, helping to mitigate flood risk

How to interpret the map:
Darker colours represent areas that are helping to temporarily store water, slowing its passage throughout the environment. Areas of disbenefit represent those where water moves rapidly, increasing risk of flooding in heavy rainfall events.

What the ecosystem service is:
This map shows where the environment is helping to slow the movement of rainfall over the land into rivers (also known as overland flow).

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MK ecosystem services: Water quality

Legend

High

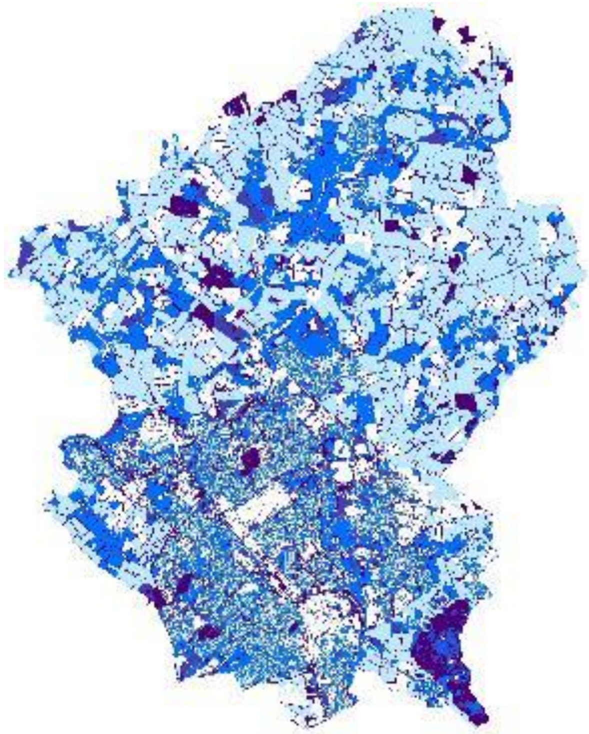
Moderate

Low

Disbenefit

11.4% High
6.5% Moderate
25.6% Low
10.6% None
33.4% Disbenefit*

*not including urban areas



Areas of land which help clean water by filtering out pollutants, providing pure drinking water

How to interpret the map:
The darkest colours represent land that contributes most to water filtration, and therefore 'better' water quality. Lighter colours represent land that may be inputting impurities into the water environment.

What the ecosystem service is:
Contribution of the land to the filtration and supply of fresh water. Pure clean water is essential for human health and underpins the whole environment.

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MK ecosystem services: Food provision

Legend

High
Moderate
Low

33.1% High
29.5% Moderate
18.7% Low
6.1% None *

*not including urban areas

Ability of the land to contribute towards food provision

How to interpret the map:
Dark brown colours show areas of higher value arable crops. Mid colours are likely to be grazing land supporting animal farming. Light yellow colours show areas where occasional wild food might be collected.

What the service is:
The map shows the land being used for cropping mainly based on multi-temporal data.
Food security is a significant issue with a growing world population; agricultural crops play an important role in this.

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MK ecosystem services: Pollination

Legend

High

Moderate

Low

5.3% High
27.2% Moderate
46.7% Low
8.2% None *

*not including urban areas

Areas of land likely to provide a source of food for pollinating insects

How to interpret the map:
The darkest colours represent where there are habitats most likely to support pollinators, such as bees. Lighter colours represent areas where there are few flowering plants and little support for insect pollinators.

What the ecosystem service is:
This map shows areas likely to contain pollen bearing plant species supporting a wide range of pollinating insects.
Insect pollination of our food and flower crops is an extremely important ecosystem service, for without it many of our crops would not effectively form.

Environment SYSTEMS evidence and insight

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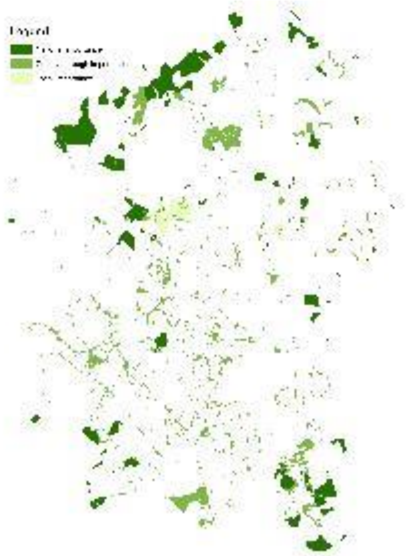
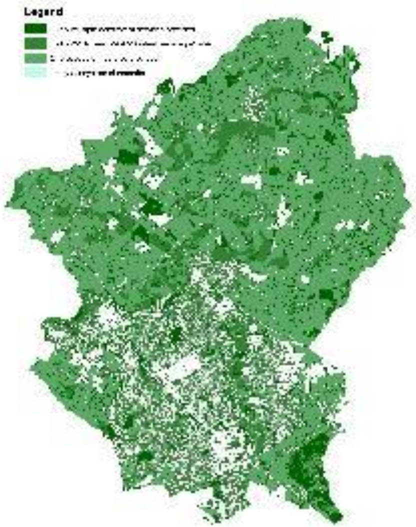
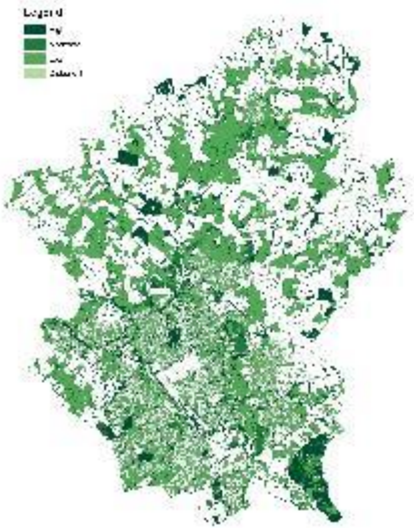
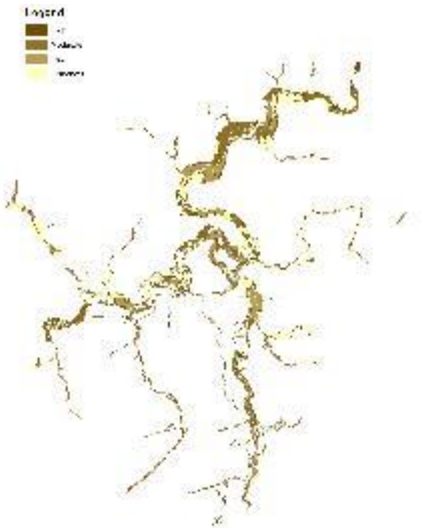
MK ecosystem services: Additional layers


Importance to biodiversity


Multiple benefits

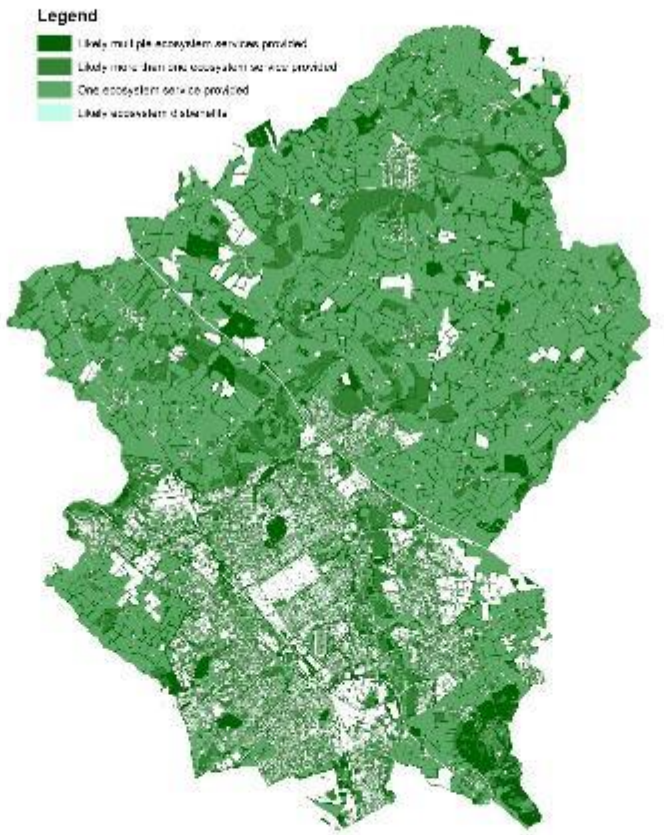

Air quality


Sedimentation

Taking it further…

- **Quality assure EO habitat map**
- **Working in partnership with local authority**
  - Natural flood management
  - Biodiversity conservation (resilience)
  - Spatial planning (housing)
- **Apply the SENCE approach**
- **Change detection**
- **Strategic environmental assessment & environmental impact assessment**
- **Scenario modelling**
  - Catchment management
  - Spatial planning

Multiple Benefits (bundles)



Earth Observation is more than Land Cover

Other data products include:

- Normalised Difference Vegetation Index (NDVI)
- Leaf area index (LAI)
- Fraction of absorbed photosynthetically active radiation (fAPAR)
- Land surface temperature (LST)
- Fire radiative power (FRP)
- Burned area
- Active fires
- Soil moisture index
- Digital terrain models

Derived data products:

- Habitat fragmentation
- Aboveground forest biomass
- River sinuosity
- and many others

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To boldly go…

State-of-the-art: Linking land cover and habitat maps to ecosystem services through empirical production functions

We aim to go beyond these approaches by incorporating novel EO developments:

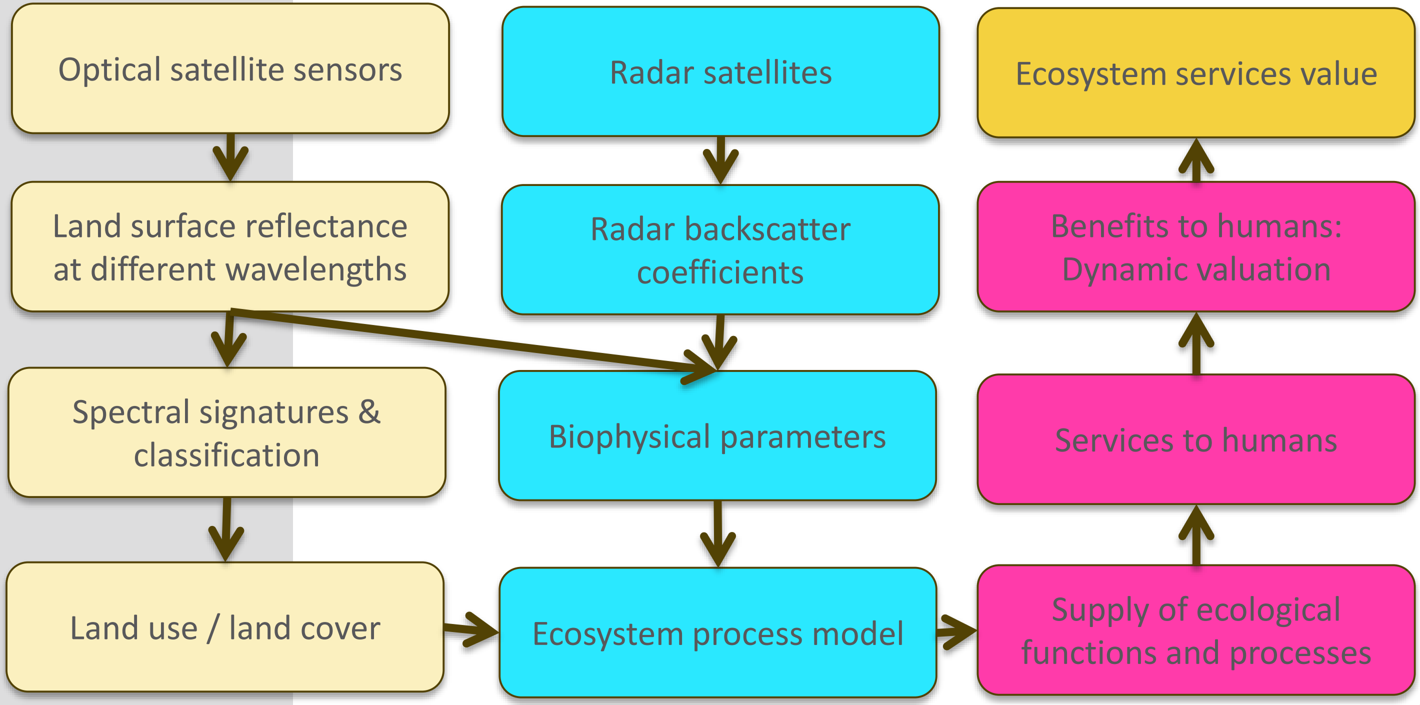
Time-series analysis of biophysical parameters (LAI, fAPAR, NDVI)

Assimilation of EO into models

Higher spatial resolution, better thematic content and greater data availability

Cloud processing capability and UK investment in CEDA / JASMIN

An EO framework for ecosystem service valuation



ESA Sentinel-1 data

C-band Synthetic Aperture Radar (SAR)

VV-VH polarisation

2 satellites

Modes:

- Interferometric wide-swath mode at 250 km and 5×20 m resolution
- Wave-mode images of 20×20 km and 5×5 m resolution (at 100 km intervals)
- Strip map mode at 80 km swath and 5×5 m resolution
- Extra wide-swath mode of 400 km and 20×40 m resolution

Revisit time: 1-12 days (1-6 days with two satellites)

Data volume: 2 GB per SLC image at dual-pol (170 km x 250 km)

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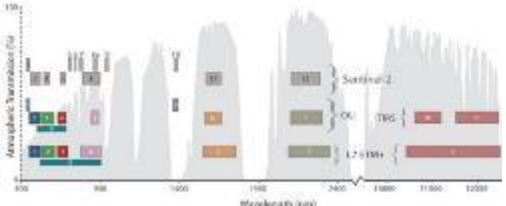
ESA Sentinel-2 data

Multispectral imager (MSI) covering
13 spectral bands (443 nm–2190 nm) with
a swath width of 290 km and spatial resolutions of
10 m (4 visible and near-infrared bands),
20 m (6 red-edge/shortwave-infrared bands) and
60 m (3 atmospheric correction bands)

Data size: 600 MB per granule of 100 km^2

Revisit time: 10 days (5 days with two satellites)

Systematic coverage of land between 84°N and 56°S



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Future Potential – 1m Video – Skybox Imaging

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samuel.pike@envsys.co.uk

And the NERC BESS EO working group

Innovate UK

Technology Strategy Board

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