Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP)

ERAMMP Report-57: Image Resolution Testing for Soil Erosion and Damage Features

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Abbreviations Used in this Report

AI	Artificial Intelligence
ALOS PaLSAR	Advanced Land Observing Satellite Phased Array type L-band Synthetic Aperture Radar
AOI	Area of Interest
APGB	Aerial Photography for Great Britain
AWEI	Automated Water Extraction Index
AWS	Amazon Web Services
BGS	British Geological Survey
BOA	Bottom of Atmosphere
CE	Coastal Erosion
CEDA/PML	Centre for Environmental Data Analysis / Plymouth Marine Laboratory
CNN	Convolutional Neural Nets
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
EO	Earth Observation
ERAMMP	Environment and Rural Affairs Monitoring & Modelling Programme
ERS-1/ESR-2	Earth Remote Sensing Satellite Mission-1 and -2
ESA	European Space Agency
GAEC	Good Agricultural and Environmental Conditions
GCPs	Ground Control Points
GHG	Greenhouse gas
GIS	Geographic Information System
GMEP	Glastir Monitoring and Evaluation Programme
GNDVI	Green Normalized Difference Vegetation Index
HWM	High Water Mark
InSAR	Interferometric Synthetic Aperture Radar
LIDAR	Light detection and ranging
LWM	Low Water Mark
MIR	Mid infrared
MNDWI	Modified Normalized Difference Water Index
Multi-GPU	Multple-Graphics Processing Units
N_2O	Nitrous Oxide
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NIR	Near Infrared
NRW	Natural Resources Wales
OS	Ordnance Survey
OSGB36	British National Grid 1936 coordinate reference system
OSM	Ordnance Survey Mastermap
PGA	Pan-Government Agreement
PL	Public Library [image repository]
PSO	PlanetScope Ortho-photo
QGIS	Quantum GIS, an open source geographic information system
RGB	Red, Green, Blue
S1 / S2	Sentinel-1 / Sentinel-2
SAR	Synthetic Aperture Radar
SED	Soil Erosion and Damage
SFS	Sustainable Farming Scheme

SFS	Safe for Shore
SNAP	Sentinel Application Programme
SoNaRR	State of Natural Resources Reports
SPOT	Satellite pour l'Observation de la Terre
SWIR	Short Wave Infra-Red
TIR	Thermal Infrared
TOA	Top of Atmosphere
UAV	Unmanned Aerial Vehicle
UKCEH	UK Centre for Ecology & Hydrology
UTM	Universal Transverse Mercator
VHR	Very High Resolution
VNIR	Visible Near Infrared
WG	Welsh Government
WGS84	World Geodetic System 1984

Abbreviations and some of the technical terms used in this report are expanded on in the programme glossaries: https://erammp.wales/en/glossary (English) and https://erammp.cymru/geirfa (Welsh)

Contents

1 SUMMARY

Maintaining healthy soils in Wales is important in order to ensure the sustainable management of natural resources under the environment act. Monitoring of soils in Wales is conducted in order to assess the state and change of soils and forms part of the state of natural resources reporting cycle (SoNaRR), quantify the impact of Glastir on soil health and contribute to a range of other reporting requirements.

Soil monitoring by ERAMMP is primarily based on structured sampling of topsoil but has also used aerial photography for peat condition and modelling. This report details work that examines the potential use of remote sensing for assessing the extent of soil erosion and damage (SED), and landsliding from space. The objective was to test different remote sensing imagery data sources, e.g. sentinel (~10m) and planet data (~3m) against high resolution APGB aerial imagery (~0.25m, by Bluesky International Limited), to determine if the resolution of the imagery is acceptable to replace aerial photographs for identifying features. The report summarises two tests of the data, one on the extent of soil erosion and damage and the other on coastal erosion and landslides.

For the soil erosion data, we found that the approximate relationship between the number of features that can be identified and the image resolution follows a non-linear, power law model. The reason why this emerges is because as image quality improves (e.g. from 10m to 3m spatial resolution), a greater number of smaller features become clearly visible. We should caution however, that we do not know if this relationship breaks down beyond the coarsest (10m) or the finest (0.25m) image resolutions tested here. However, we demonstrate that this power law relationship enables us to predict the approximate number of features we might expect to observe at different product resolutions between 0.25m and 10m.

Sentinel-2 imagery (~10m) is only suitable for identifying large scale features such as scree slopes, poaching, gate damage and areas of bare soil. The 3m (Planet) imagery is needed to identify finer features such as damage around feeders, while the finest-scale features such as terracettes are only picked up with 0.25m resolution imagery. The difference between the maximum number of features identified in a 1km square increased from 10 at low resolution (10m) to over 50 features at 0.25m resolution. For practical purposes, identifying bare soil and gate damage, the 3m resolution may be adequate.

With regard to the landslide event, this was a sizeable area (>800m^2) and both Sentinel (10m) and Planet (3m) data were able to identify the change through the use of time-lapse imagery. For events that cause features of this size there is no major advantage of using paid for data over the free Sentinel data. However, the work demonstrates a proof of concept that as the quality and resolution of imagery improves, so our capability to characterise both changes in soil volumes due to erosion or landslides will increase. This has other applications such as identifying areas and volumes that have been excavated or filled.

While soil damage and erosion features identify direct impacts on soil structure at a fixed location, additional work is needed to be able to translate this into the quantity of soil exported, especially to water courses.

2 INTRODUCTION AND PURPOSE OF THE WORK

Earth Observation (EO) offers an important monitoring platform for detecting soil erosion and damage (SED).

The quality and resolution of imagery is constantly improving and new data streams continue to become available. The purpose of this report is to determine how much value is added, or rather how many more features can be detected, using increasingly high resolution imagery. For SED the report compares 10m data from the EU's Sentinel-2 satellite which is free and the 3m Planet Labs data which is a paid for product. These are compared to very high resolution APGB aerial imagery 0.25m which is set as the benchmark.

Two case studies are presented. The first compares imagery of different resolutions and its ability to detect SED features. While the second, compares time-lapse images for assessing changes in a landslide.

A final section describes some of the challenges and opportunities for using EO to detect soil characteristics and their change.

3 EROSION & SOIL DAMAGE FEATURE RECOGNITION TEST

Farmers and land managers need to be aware of the risks of land degradation under certain practices, particularly when conditions are unsuitable (e.g. cultivating soils when they are heavily waterlogged). SED are indicators of land degradation and could trigger breaches of the Welsh Government's Good Agricultural and Environmental Conditions (GAEC)[1] regulations. For instance, too much bare soil area on farm would represent a failure to maintain a minimum soil cover (e.g. crops, stubbles, residues or other vegetation) under GAEC 4.0, and can be hotspots of nitrous oxide (N_2O) emissions – a potent greenhouse gas (Matthews et al., 2010). Earth Observation (EO) offers a powerful tool with which to detect SED features (de Jong et al., 2011).

A satellite-based monitoring system, which uses daily, or near-daily, EO information, including true-colour images, combined with modelling for prediction, could generate alerts for stakeholders to avoid possible GAEC breaches and provide additional soil health datastreams for national, Glastir/Sustainable Farm Scheme (SFS) reporting and other reporting requirements. These data could also support research and modelling needs which have requirements for soil health data.

Good optical imagery is required in order for such an alert system to work. While some EO systems like Sentinel-2 offer images at 10m resolution or coarser for free, Planet Labs offer images at finer resolution (3m and 0.5m) with potentially enough detail to detect erosion or damage at a commercial price.

3.1 Approach

In this work we select a total of 10 Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP) squares that have previously been analysed for SED features (Tye & Robinson, 2020) and conduct an independent analysis comparing 3 different image resolutions. A qualitative approach is adopted, whereby the locations and types of SED features are recorded without attempting to calculate their spatial extents. The aim here is to test how well SED features can be detected from different images at different resolutions. This inter-image comparison proceeds by identifying individual SED features, initially using the 10 m Sentinel-2 data, then the 3m Planet data, and lastly very high resolution 0.25m aerial images. Whilst we would ideally like to test a sub-metre resolution (e.g. Planet Labs product at 0.5m), these images are only freely available for select locations. A survey of a specified location has to be "tasked", which can be expensive. Therefore, we focus on just the 3m product from Planet.

All features are identified and recorded by the same trained analyst throughout to minimise inconsistencies. ERAMMP squares tested are selected based on the range of erosion features found from the 0.25m aerial imagery by a different analyst for Phase-1 of the *Soil Degradation, Erosion & Compaction* project (Tye & Robinson, 2020) within ERAMMP. Training was provided by the initial analyst in Tye & Robinson (2020) to the analyst undertaking the current assessment.

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[1] Welsh Government **Good Agricultural and Environmental Conditions** (GAEC) regulations – see https://gov.wales/sites/default/files/publications/2020-01/cross-compliance-verifiable-standards-2020.pdf

3.2 Materials and methods

Ortho-rectified, true-colour satellite and aerial imagery are derived from 3 different sources, including Sentinel-2, Planet Labs and from APGB (0.25m) and have been collected for 10 1km^2 ERAMMP survey squares. The details of these are summarised in Table 3.1.

Sentinel-2 and Planet images were re-projected from the World Geodetic System 1984 (WGS84) to the British National Grid (OSGB36) coordinate reference system and clipped to the extents of each of the 10 ERAMMP squares. Figure 3.1 illustrates the differences in detail that are discernible at different spatial resolutions within the same ERAMMP square.

Table 3.1: *Details of images for the 10 ERAMMP squares focussed on for resolution testing.*

ERAMMP Square ID	**Imagery dates**		
	Sentinel-2*	**Planet**	**BGS aerial**
	10m	**3m**	**0.25m**
6489	29-05-2020	19-05-2018	May 2018
9784	29-05-2020	23-05-2018	May 2018
11277	29-05-2020	23-05-2018	May 2018
16333	29-05-2020	23-05-2018	May 2018
16909	29-05-2020	23-05-2018	May 2018
17522	29-05-2020	23-05-2018	May 2018
18859	29-05-2020	23-05-2018	May 2018
37532	20-06-2020	23-05-2018	May 2018
38172	20-06-2020	23-05-2018	May 2018
43807	20-06-2020	19-05-2018	May 2018

**Sentinel-2 data for spring 2018 were either unavailable to download or obscured by clouds.*

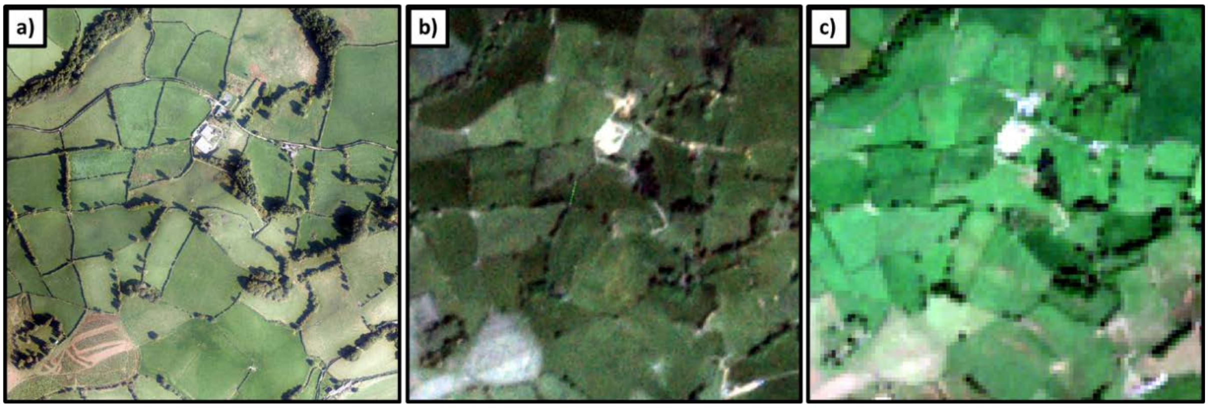

Figure 3.1: *Different image resolutions from the same location: a) 0.25m BGS aerial; b) 3m Planet; c) 10m Sentinel-2.*

SED features can typically be picked out from the surrounding landscape on the basis of colour (e.g. small, bright brown or white patches in fields), and location (e.g. potential gateway damage along field boundaries or potential peat erosion evidenced by black / dark brown patches in uplands). Table 3.2 describes the types of features that were identified and were recorded as the 30 images were reviewed. It is important to note that not all types of soil damage / erosion are considered here, only those which can be detected from aerial and satellite imagery. Further, while some features such as riverbank erosion are detectable from aerial imagery, examples of these features were not found in the 10 survey squares analysed here. Therefore, the list in Table 3.2 is restricted to just 8 common features: "Gateway damage", "Feeder damage", "Poaching", "Bare soil", "Vehicle damage", "Terracettes", "Exposed peats" and "Mass movements". Erosion under vegetation cover cannot be detected from the air, and features such as rills are too small to be detected from even the highest resolution imagery tested here. Consequently, the analysis presented here is expected to be a lower bound in terms of the number of features identified.

Table 3.2: *Soil damage / erosion features identified from the imagery and their characteristics.*

Feature	Environment	Description	Example from 0.25-metre aerial imagery
Gateway damage	Lowland farms	Small brown features straddling field boundaries. Very common in agricultural settings, but their small size may make them hard to identify at the coarser image resolutions.	
Feeder damage	Lowland farms	Small circular light brown features in fields – often surrounding a circular or rectangular feeder – which may be part of a larger cluster of brown circles associated with earlier feeder positions.	
Poaching	Lowland farms	Trampling by animals. Often large dark brown areas in green fields. The presence of sheep may be a useful indicator of possible poaching in a field. If large enough, these should be identifiable from all the image resolutions tested here.	

Feature	Environment	Description	Example from 0.25-metre aerial imagery
Bare soil	Lowland farms; Uplands	Brown patches in the landscape of various sizes & shapes, with no obvious origin that can be explained from the images alone. Due to the comparatively limited detail of coarser imagery, features that are classed as e.g. gateway damage or feeder damage from 0.25m images may be classified as bare soil patches at 3 or 10m resolutions.	
Vehicle tracks* **only examples where erosion appears to be very pronounced*	Lowland farms; Uplands	Thin, incised white / light brown lineations in fields (lowlands); Thin, incised black / dark brown lineations in fields (uplands).	
Terracettes	Lowland farms	Ridges on hillslopes caused by soil wetting and drying. Shows up as several very thin lines bunched together, usually sloping down towards a stream. Highly unlikely to be identifiable from 3 and 10m images due to their subtle appearance in 0.25m imagery.	
Exposed peat	Uplands	Large dark brown or black areas contrasting with the lighter vegetated surrounding land areas. They should be large enough to spot at all image resolutions, but are not common features.	

Feature	Environment	Description	Example from 0.25-metre aerial imagery
Mass movements	Uplands	Clear scars on valley slopes, often grey in colour. Depending on their size, they may be discernible from all image resolutions, but are uncommon outside of steep, upland environments.	

The locations of suspected SED features were each marked with a single point in a GIS, not with a polygon or lines digitised around the extents of the features. Features were identified from the coarsest image resolutions first before moving onto the finest – i.e. the Sentinel-2 images first, and once all 10 of these images had been surveyed, features were identified from the 10 Planet images, and finally from the 10 BGS images.

The justification here is to guard against the bias that could arise if working from finest to coarsest. For instance, were small-scale features to be identified from 0.25m imagery first, there may be a temptation to record from the coarser imagery an otherwise non-descript pixel as an SED feature, simply because a feature was identified from the higher resolution imagery at the same location. All features were identified and marked by the same analyst (Chris Feeney) throughout to minimise error.

Features were typically recorded at 1:1,250 scale (i.e. 1cm on a screen equals 1,250cm on the ground) as this was usually sufficient to discern soil erosion or damage based on a combination of location and colour contrasts with surrounding areas. Identified features were recorded in a separate point shapefile for each image dataset with the following attributes:

1. Image – the name of the image dataset (e.g. "Sentinel") [STRING]
2. Resolution – the spatial resolution of the image in metres [DOUBLE]
3. FID – individual feature ID number [OBJECT_ID]
4. SQ_ID – the ERAMMP square number [LONG]
5. Feature – feature type as listed in Table 3.2 (e.g. "Gateway damage") [STRING]
6. X – Easting [FLOAT]
7. Y – Northing [FLOAT]

By recording the point locations, the number of co-located features identified between different images could be determined, as well as whether their classifications matched or not (e.g. whether a point identified as "Bare soil" at 10m was classified the same way for the other image resolutions).

After all 30 images were surveyed, summary statistics were calculated, including:

- The number of features identified at each spatial resolution of imagery;
- Different types of features as a proportion of the total identified at each resolution (e.g. *x* % of Sentinel features are exposed peat versus *y* % of BGS features);

- The false-positive rates for Planet and Sentinel when compared with each other and with the BGS imagery (which implies that features identified from the higher-resolution imagery in each comparison are all true positives).

3.3 Results

A total of 461 suspected SED features were identified across the 30 images, including 85 from Sentinel (10m), 107 from Planet (3m), and 269 from the 0.25m resolution aerial images (Figure 3.2). If we fit a model to these data, the number of features identified (*N*) from an image decays as a power law function of coarsening spatial resolution (*s*):

$$N = 167.18s^{-0.321} \; (R^2 = 0.98)$$

Assuming this relationship holds (especially as it is fitted using only 3 data points!), we would estimate that just over 200 features would have been identified from 0.5m resolution images had we been able to survey these as originally planned. It's possible this relationship could break down beyond the minimum and maximum image resolutions tested here, hence we would advise to use this model only to predict how many features might be identified at an intermediate image resolution (e.g. between 0.25 and 3m resolution; not 0.1m resolution).

The types of features also varied widely between the different images (Figure 3.2). Relatively common and large features, including poaching of fields and bare soil, make up the bulk of the features identified from the 10m and 3m resolution imagery. As these became easier to spot, smaller-scale feeder damage and gateway damage constitute the bulk of features that were identified from 0.25m imagery. Vehicle tracks and feeder damage could be identified from all images, but only the 0.25m imagery provided enough detail to spot terracettes.

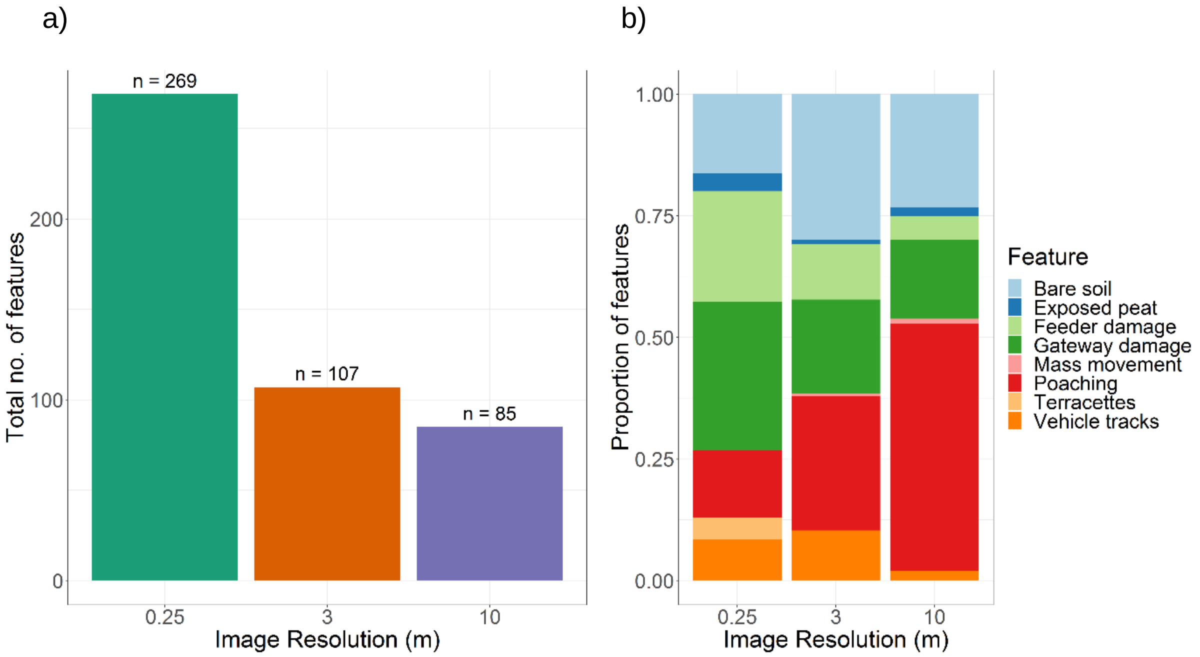

Figure 3.2: *a) Total numbers of features identified across all 10 squares at each image resolution; b) Different types of features recorded as a proportion of the total number of features identified at each image resolution.*

Comparing results across each ERAMMP square (Figure 3.3) reveals several patterns:

1. The number of features identified in a square increases as the image resolution gets finer. In the most extreme example, the number of features identified in square 6489 more than quadruples from 12 at 10m resolution, to 50 at 0.25m resolution.
2. The diversity of features increases from coarse to fine resolution, with the number of different types of feature found in a square increasing from 2 to 3 on average (with as many as 4 features in 1 square) at 10m and 3m resolution, up to 4 to 5 on average (with as many as 6 features in 2 squares) different types at 0.25m resolution. Further, the number of squares consisting of just 1 type of SED feature decrease from 3 at 10m resolution to 1 at 0.25m resolution.
3. Smaller scale features such as feeder damage, gateway damage and terracettes begin to dominate the taxonomy of features at 0.25m resolution, partly as these features become more visible; partly as bare soil identified at coarser resolution is reclassified as one of these types or discovered to not be SED at all.
4. The 3 squares, identified from the 10 m imagery as containing the most SED features (6489, 16333 & 38172), are also shown to contain the most features at both of the other resolutions. Likewise, the square with the fewest features identified from the 10m imagery (43807) contains the fewest features at the other resolutions too. Potentially, this demonstrates that even coarse imagery can identify “hot-spots” or “cold-spots” where many or few damage / erosion features occur, respectively.

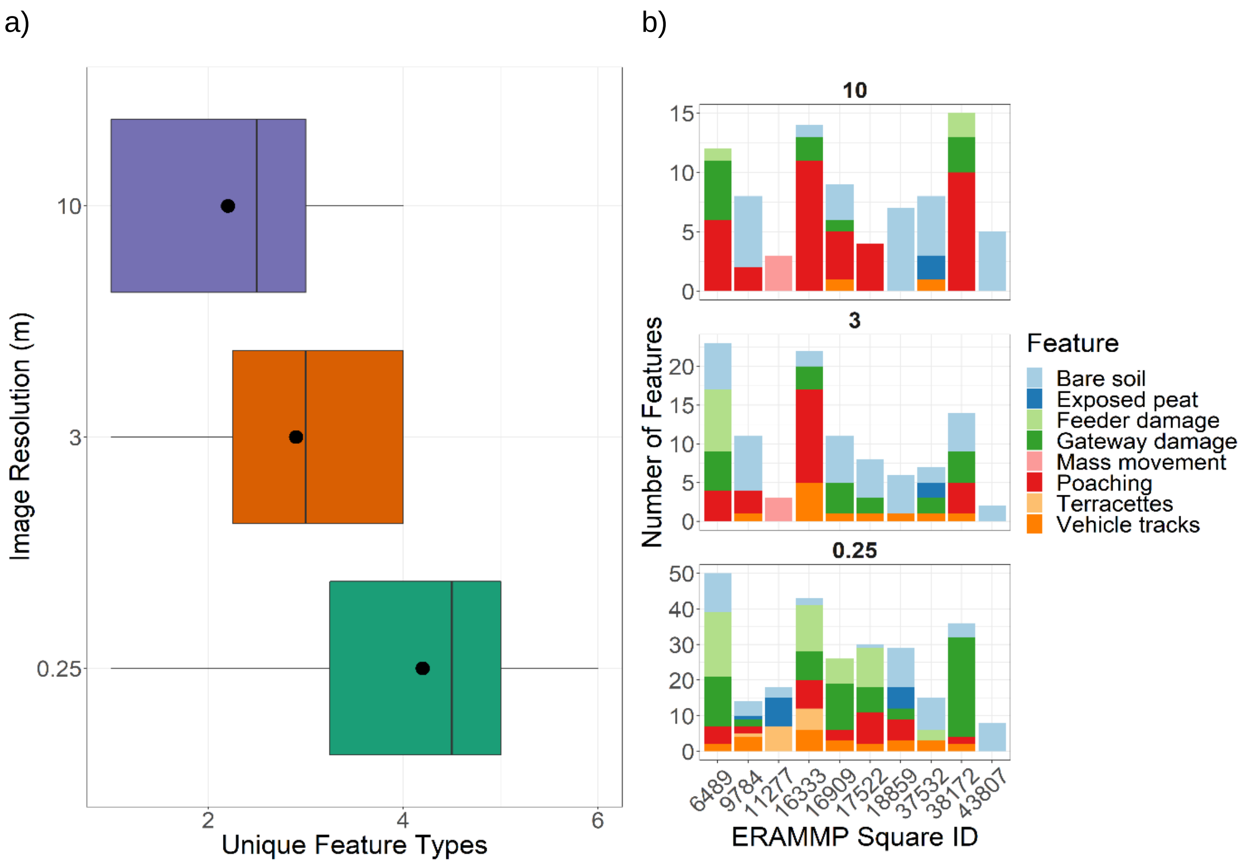

Figure 3.3: *a) Distributions of the number of unique erosion features identified at each image resolution. b) (Note the change of scale on the y axis) The total features recorded within each ERAMMP square with the breakdown of different feature types; plotted on separate graphs for each image resolution (10, 3 and 0.25m; note the different y axis ranges on each plot).*

The total number of features identified and their diversity change when comparing different image resolutions. This is also true however, of the error or disagreements between features identified at coarse versus fine image resolution. Table 3.3 presents a summary of the false-positive rates that result from comparing the locations ("Location") and the classifications ("Type") of features mapped at the different image resolutions. Here, the definition of false positive implies that features mapped at the finer image resolution in each comparison are all true positives.

Approximately two thirds of feature locations identified at 10m resolution did not match with those mapped at 3m resolution. A similar proportion of features mapped at 10m were also classified differently at 3m resolution (69.4 %). When comparing features mapped at either 10 or 3m with those mapped at 0.25m resolution, the false positive rates were even higher (approximately 76 % failing to match the locations, and about 85 % failing to match the types, recorded at 0.25m resolution).

False positive rates for feature locations vary widely, from 0 to 100 % for features mapped at 10m versus at 3m resolution (Figure 3.4). Taking square 11277 as an example, the same 3 features that were mapped at 10m were also mapped at 3m resolution. However, all of these were judged not to be SED features at all when looking at the 0.25m imagery, and so false positive rates became 100 % when compared with features mapped at 0.25m resolution.

For each inter-image resolution comparison, the false positive rates increase slightly further as a result of discrepancies in feature classifications. The 4.7 % difference in false positive rates of the 10m vs 3m comparison (Table 3.3) is a result of 4 features that were classified as "Gateway damage" from the 10m imagery, and then classified differently at 3m resolution. Eight features, mostly "Poaching", classified at 10m resolution were classified differently at 0.25m resolution. Nine features, including 4 "Bare soil", 3 "Poaching" and 2 "Gateway damage", identified at 3m were re-classified at 0.25m resolution.

Table 3.3: *False positive rates for each inter-image comparison (10 vs 3m; 10 vs 0.25m; 3 vs 0.25m). "Location" refers to whether a feature identified at the coarser image resolution was identified at the same location at the finer image resolution. "Type" refers to this as well, but includes whether the identified feature was classified identically between images. The "Difference" is calculated by subtracting values in the "Type" from the "Location" columns.*

Image comparison	**False positive rates (%)**		
	Location	**Type**	**Difference**
10m vs 3m	64.7	69.4	4.7
10m vs 0.25m	76.5	85.9	9.4
3m vs 0.25m	76.6	85.0	8.4

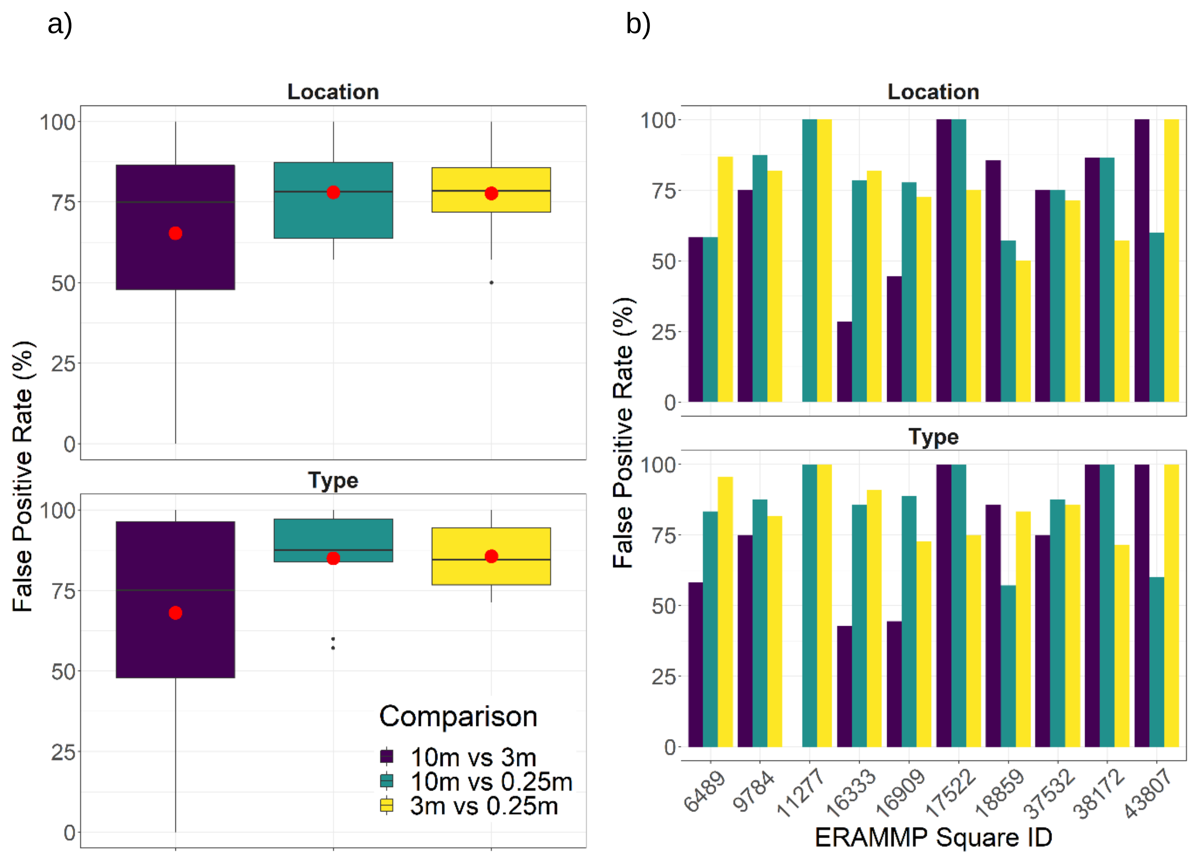

Figure 3.4: *a) Distributions of false positive rates (%) for each inter-image resolution comparison (10 vs 3m; 10 vs 0.25m; 3 vs 0.25m). b) False positive rates (%) of identified features for each inter-image resolution comparison at each ERAMMP square. "Location" and "Type" are the same as for Table 3.3.*

It is clear from the results that the resolution of the imagery can have a significant impact on both i) the number of features that can be identified and ii) how they are classified. While we can evaluate to some extent whether features identified at 10 or 3m resolution are "correct" (as an example, 2 locations in square 9784 were identified as "Bare soil" at 10 and 3m resolution, but were revealed to be wind turbines when analysing the 0.25m imagery), the surest way of validating features remotely sensed from imagery is for field surveyors to confirm this on the ground.

Several additional points need to be borne in mind with this analysis:

1. Our analysis would be more complete with testing on 0.5m – especially as this should provide levels of detail much closer to 0.25m resolution than 3m does.
2. Ambiguities: Some SED features may in fact be dead vegetation (e.g. white patches around darker exposed peats in uplands). As demonstrated in our analysis, this may be a more frequent problem with coarser than finer resolution imagery.
3. Different surveyors will disagree to an extent as to what is or isn't a feature and what type of feature it may be. They may have slightly different classification schemes and different sensitivities, including thresholds of spectral reflectance, when judging if a feature from an image is soil damage / erosion or not.
4. As stated previously, we need results validated by field surveyors to be sure if we've mapped features correctly. In addition, field surveyors may identify other features,

particularly those obscured by vegetation or difficult to see from the air such as terracettes.

5. Image dates for each resolution don't quite match. The Sentinel data is from 2 years after the 3m and 0.25m imagery were taken, due to a lack of available cloud-free Sentinel imagery from the same time. It is possible that within the Sentinel images, some new SED features have occurred in some places, and been ameliorated in other areas.
6. Incorporating other spectral bands (e.g. near-infrared), and topographic data (e.g. elevation and slope), could help distinguish erosion from the surrounding landscape. Other spatial datasets, such as the locations of buildings and energy infrastructure like wind turbines and electricity pylons, could also be incorporated to rule out some locations as displaying evidence of soil damage / erosion. Time lapse imagery may also help.
7. It is important that we classify SED features accurately as the threats they pose may differ substantially. For example, riverbank erosion or a mass movement event may threaten assets located nearby, whereas a field that has been badly degraded by livestock poaching may be a source of N_2O emissions.
8. If we can accurately record the spatial extents of damage / erosion features and their evolution over time (including inception), we can begin to estimate SED rates and potentially provide predicted timings of likely GAEC breaches and provide additional information for other soil health reporting requirements.

4 COASTAL EROSION AND LANDSLIDE TEST

A common challenge facing coastal communities in Wales is the risk of coastal change defined here as the physical change to the shoreline, for example, coastal erosion, coastal landslips, permanent inundation and coastal accretion. The removal of material from the coast by wave and tidal action, amongst other factors, can cause flooding, rock falls, landslips, loss of land and damage to infrastructure and coastal communities. Earth Observation (EO) from space is becoming sufficiently mature to provide valuable information services for coastal surveyors with an interest in improved management of coastal erosion risks to communities and assets.

The European Space Agency (ESA) have recently completed two projects (https://coastalerosion.argans.co.uk/ & http://spaceforshore.eu/), the scope of which was the development and demonstration of innovative EO products that can be used by user communities responsible for monitoring and controlling coastal erosion. These two projects, Coastal Erosion (CE) and Space For Shore (SFS) have identical aims but followed different approaches and were sited in different environments. The CE project was demonstrated in the UK with case studies in the East and South of England. These studies resemble the atmospheric and coastal environments that can be found along the Welsh coastline. The scope of these two ESA funded projects was limited to open EO data from Sentinel 1 and Sentinel 2 missions of the European Copernicus[2] initiative combined with the ERS-1[3], ERS-2, Envisat[4] and SPOT[5] archives. The aim of the current work is to test the quality of pay-per-use PlanetScope Ortho-photos (PSO) from Planet Labs imagery for assessing the before and after effects of one major coastal landslide event and to assess the added value of PSO imagery to monitor coastal erosion when compared with openly accessible EO.

4.1 Approach

In this work we have selected the landslide that occurred on the 4th March 2020 when a 17th century property at Porth Neigwl near Abersoch was left on the brink of disaster as reported by the press[6]. This landslide event has been checked by the BGS landslide team and included into the national landslide database (LandslideID: 20822) and is accessible via GeoIndex Onshore data portal[7] (Figure 4.1). Our approach to assess the suitability of the PSO imagery for manually observing the event, and then attempting to quantify the area change and amount of material moved is to first estimate the size and volume of the landslide event using third party data and secondly assess if the landslide event can be detected using different normalized EO indexes. To assess the added value of using PSO imagery to monitor coastal erosion we have compared what can be observed using Sentinel-2 openly accessible EO data for the same event.

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[2] https://www.copernicus.eu/en

[3] https://earth.esa.int/eogateway/missions/ers

[4] https://earth.esa.int/eogateway/missions/envisat

[5] https://earth.esa.int/eogateway/missions/spot

[6] https://www.dailymail.co.uk/news/article-8118239/Holiday-cottage-North-Wales-just-yards-away-falling-sea.html?ito=social-twitter_dailymailUK

[7] https://mapapps2.bgs.ac.uk/geoindex/home.html

***Figure 4.1**.- Front view and aerial view of the selected landslide event for this study. Pictures from Daily Mail, published 16 March 2020.*

4.2 Materials and methods

The Planet Lab and Sentinel-2 (S2) data archives were explored using the dedicated EO browser[8],[9] to find cloud free images before and after the selected landslide event. Table 4.1 shows the main characteristics of both PSO and S2 images used in this study. Both products used are in cartographic geometry (UTM/WGS84 projection) and have the same radiometric resolution. Radiometric resolution is the capacity of the instrument to distinguish differences in light intensity or reflectance. The greater the radiometric resolution, the more accurate the sensed image will be.

Radiometric resolution is routinely expressed as a bit number of DN, typically in the range of 8 to 16 bits. The instrument used in this study acquires measurements at 12 bits. These measurements are converted to reflectances and stored as 16 bit integers in the final (PSO-3B or S2-L2A) product.

From Planet Labs we have used the PlanetScope 4 bands Ortho Scene Product Level 3B which are orthorectified, scaled Top of Atmosphere radiance (at sensor) image product suitable for analytic and visual applications. This product has scene based framing and projected to a cartographic projection. The product was designed for a wide variety of applications that require imagery with an accurate geolocation and cartographic projection. It has been processed to remove distortions caused by terrain and can be used for cartographic purposes. They are delivered as visual (RGB) and analytic (RGB+NIR) products. Ortho Scenes are radiometrically-, sensor-, and geometrically-corrected products that are projected to a cartographic map projection. The geometric correction uses fine Digital Elevation Models (DEMs) with a post spacing of between 30 and 90 meters. Ground Control Points (GCPs) are used in the creation of every image and the accuracy of the product will vary from region to region based on available GCPs. From Sentinel 2 we have used the S2 Level-2A product

[8] https://www.planet.com/explorer

[9] https://apps.sentinel-hub.com/eo-browser

which provides Bottom Of Atmosphere (BOA) reflectance images derived from the associated Level-1C products. The 13 spectral bands of Sentinel-2 range from the Visible (VNIR) and Near Infra-Red (NIR) to the Short Wave Infra-Red (SWIR). We have only used two bands (B4: red ~665nm and B8: NIR ~833nm) which have 10 m ground resolution[10] which are the bands required for the NDVI index.

***Table 4.1**: Characteristics of optical satellite instruments compared in this study.*

Criteria	**Planet Labs (PSO)**	**Sentinel 2**
Bands (wave length)	4–5 (440–900 nm)	13 (497–2190 nm)
Night-time imagery	No	No
TIR/SWIR	No	Yes
Ground Sample distance	3.7 m*	10 m**
Pixel Size (orthorectified)	3 m	10 m
Cadence	< 1-72h	5-10d
Product Level	3B	L2A

*at reference altitude 475 km
** we have used only B4 (red) and B8 (NIR) which both has 10m ground sampling distance

To estimate the size and volume of the landslide event we have used the 2 metre LIDAR Digital Surface Model (DSM) for 2015 provided freely by Natural Resources Wales[11] and the 2009 high resolution (0.25m) PGA[12] Red, Green and Blue (RGB) aerial imagery. The Aerial Photography RGB PGA data product is a digital orthophoto mosaic and true colour representation of the real world, showing all ground features visible at a viewing scale of 1:1000.

Light Detection and Ranging (LIDAR) is an airborne mapping technique, which uses a laser to measure the distance between the aircraft and the ground. Up to 100,000 measurements per second are made of the ground, allowing highly detailed terrain models to be generated at spatial resolutions of between 25cm and 2 metres.

The Natural Resources Wales (NRW) composite dataset contains digital elevation data derived from surveys carried out over several years and covers approximately 70% of Wales. NRW are making available 25cm, 50cm, 1m and 2m datasets, supplied as terrain models (a representation of the ground level) or surface models (a representation of object heights such as vehicles, buildings and vegetation). We have used the latest 2 metre DSM, with a temporal extent of 2015-01-01 / 2015-12-31 and therefore before the landslide event occurred. There is no LIDAR DSM after the landslide event available. The landslide volume is estimated by extracting elevation profiles from the DSM that represent the before and after profile elevation.

To delineate the approximate location of the landslide we have geo-referenced the aerial image shown in Figure 4.1 using QGIS v3.12.0-București and the Freehand raster geo-referencer plugin (Free v0.8.3). Once geolocated we have created a polygon shape that delineates the edge of the landslide. This polygon is later used to extract the zonal statistics

[10] https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi/resolutions/radiometric

[11] https://libcat.naturalresources.wales/folio/

[12] http://www.geostore.com/geostore4/WebStore?xml=geostore4/xml/productsAPRGB.xml

for the different EO index extracted from the PSO images. Exploring the full list of EO index with the potential to be used to detect landslides is too large[13] to be explored in this work. We have selected the three listed in *Table 4.2*;

- The Normalized Difference Water Index (NDWI) is one of the most widely used indices. Other indices such as the Modified Normalized Difference Water Index (MNDWI) and Automated Water Extraction Index (AWEI) required MIR and SWIR bands. As the Planet Lab PSO imagery used here did not contain MIR/SWIR bands the use of MNDWI or AWEI was not possible. For shoreline extraction, the NDWI makes use of the green and near-infrared (NIR) bands. NDWI values can range from -1 to 1, with water pixels typically being greater than zero and approaching 1 for clear open water.
- The Normalized Difference Vegetation Index (NDVI) is the most common in agriculture to quantify vegetation greenness and is useful in understanding vegetation density and assessing changes in plant health. NDVI is calculated as a ratio between the red (R) and near infrared (NIR) values in traditional fashion.
- The Green Normalized Difference Vegetation Index (GNDVI) is similar to NDVI except that instead of the red spectrum it measures the green spectrum in the range from 0.54 to 0.57 microns. This is an indicator of the photosynthetic activity of the vegetation cover; it is most often used in assessing the moisture content and nitrogen concentration in plant leaves according to multispectral data which do not have an extreme red channel. Compared to the NDVI index, it is more sensitive to chlorophyll concentration. It is used in assessing depressed and aged vegetation.

Table 4.2.- EO index used in this study

EO Index	Name	Formula
NDVI	Normalized Difference Vegetation Index	$\frac{\boldsymbol{Near\_Infrared - Red}}{\boldsymbol{Near\_Infrared + Red}}$
GNDVI	Green Normalized Difference Vegetation Index	$\frac{\boldsymbol{Near\_Infrared - Green}}{\boldsymbol{Near\_Infrared + Green}}$
NDWI	Normalized Difference Water Index	$\frac{\boldsymbol{Green - Near\_Infrared}}{\boldsymbol{Green + Near\_Infrared}}$

The NDVI and GNDVI can have any value between -1 and 1, from completely unvegetated (or bare soil) to completely vegetated. By subtracting the NDVI values in the pre-landslide images

[13] https://www.indexdatabase.de/

from the post-landslide NDVIs, for spatially collocated pixels, we obtain a raster dataset of pre/post-landslide NDVI differences. A negative NDVI difference thus indicated areas where vegetation has been damaged and/or covered by landslide deposits.

To assess if this landslide event could have induced a shoreline change we have used the Ordnance Survey (OS) Vectormap District tidal boundary lines[14]. In England and Wales these tide lines will be the levels of mean tides, for example, of a tide between a spring and neap tide. In Scotland the tide lines are those of mean spring tides. In places where there is no Foreshore (for example vertical cliffs), the TidalBoundary is classified as 'High Water Mark' (HWM). The nominal viewing scale is 1:25 000, with a recommended viewing scale range of 1:10 000 to 1:25 000.

4.3 Results

Figure 4.2 shows the before and after aerial view of the landslide event.

According to BGS's landslide classification convention[15] this event was a rotational slide: a down-slope movement of material that occurs along a distinctive rupture or slip surface. As the slip surface is listric (curved or spoon-shaped) the slide is said to be rotational. These landslides are characterised by a prominent main scarp and back-tilted bench or block at the top with limited internal deformation.

The landslide affected an area of approximately 2,063 m^2 as indicated by the red polygon in Figure 4.2. From the high resolution aerial image of 2009 (pre-event) we have been able to manually delineate the vegetated area of 807 m^2 within the affected area (indicated by a green polygon). The cliff has a maximum elevation of ca. 35m and the landslide eroded about 15m of cliff top line and deposited it as a wider depositional fan of ca. 50 m width on the upper beach.

From the extracted elevation profiles shown in *Figure 4.2* ,we can see that about the same volume of soil per unit cliff length has been eroded from the cliff face (-155 m^3) and deposited on the upper beach (238 m^3) at this particular transect. On the eroded section, the profile elevation has decreased ca. 5m and on the depositional section the elevation has increased by ca. 9.5 m. The total volume of eroded material can be estimated by multiplying the 15 m of eroded cliff top line by the eroded volume per unit cliff top length to obtain a total of 2,325 m^3 of material that has been eroded from the cliff face. From the aerial image right after the event we can see that the majority of the sediment was deposited as a fan which is likely to be washed away by the tides and waves reaching the fan toe.

The location of the OS HWM is shown in Figure 4.2. It can be seen that only waves coinciding with high tides will be likely to erode the toe of the material deposited on the upper beach.

[14] https://www.os.uk/business-and-government/products/vectormap-district.html

[15] https://www.bgs.ac.uk/discovering-geology/earth-hazards/landslides/how-to-classify-a-landslide/

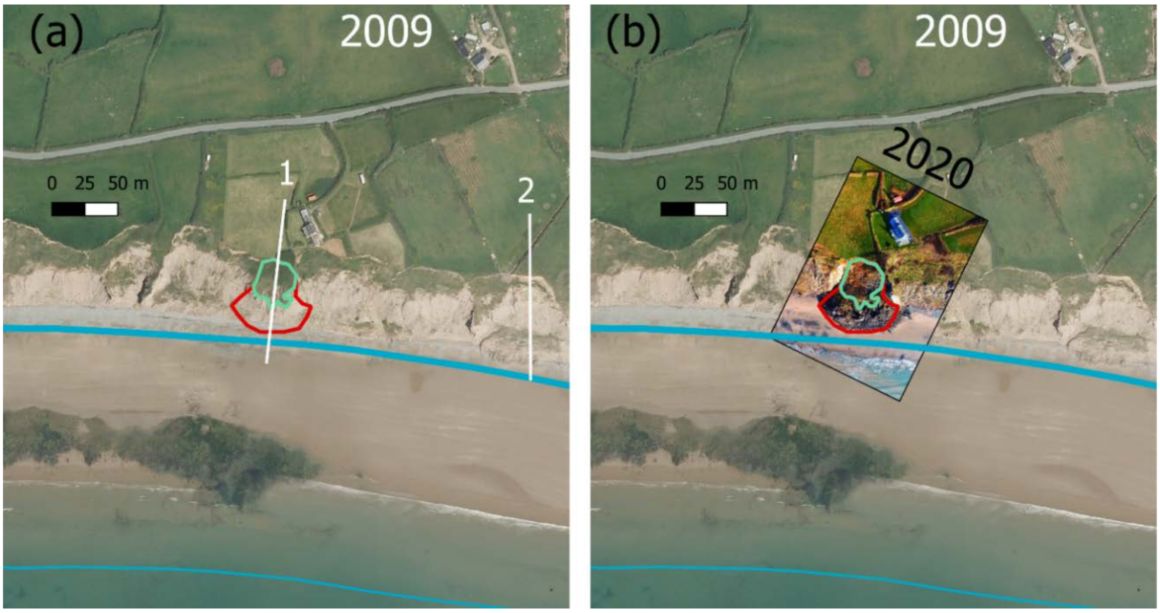

***Figure 4.2**.- Before and after aerial view of the landslide event than occurred on the 4th March 2020: (a) The approximate area within the landslide area that has vegetation is indicated in green overlying the 2009 aerial imagery from PGA data product. The white line segments indicates the location of a transect that represent the initial (1) and final (2) cliff elevation profiles. The blue lines represent the OS Tidal Boundary lines, HWM (thick) and LWM (thin); (b) the approximate landslide area indicated by a red polygon and the geolocated aerial image of the 2020 event over the 2009 aerial image.*

Using a nominal pixel size we can estimate the number of pixels that a PSO image will likely have within the landslide affected area (e.g. pixels that will be used to detect the change). As the PSO images have about 9 m^2 area (i.e. assuming a nominal square pixel size of 3m), the number of pixels within the landslide affected area was approximately ~ 230 pixels and only ~87 pixels of the affected area were covered by vegetation.

We expect to see a decrease of the vegetated area after the landslide event as some of the vegetation, initially on the top surface has been remobilized and might have been covered by the deposited material. We also expect to see changes in the colour of the vegetation that has not been covered, but is likely to suffer from the more harsh environmental conditions at elevations closer to the mean sea level (i.e. salt spray) and therefore a reduction of vegetation health is expected over time.

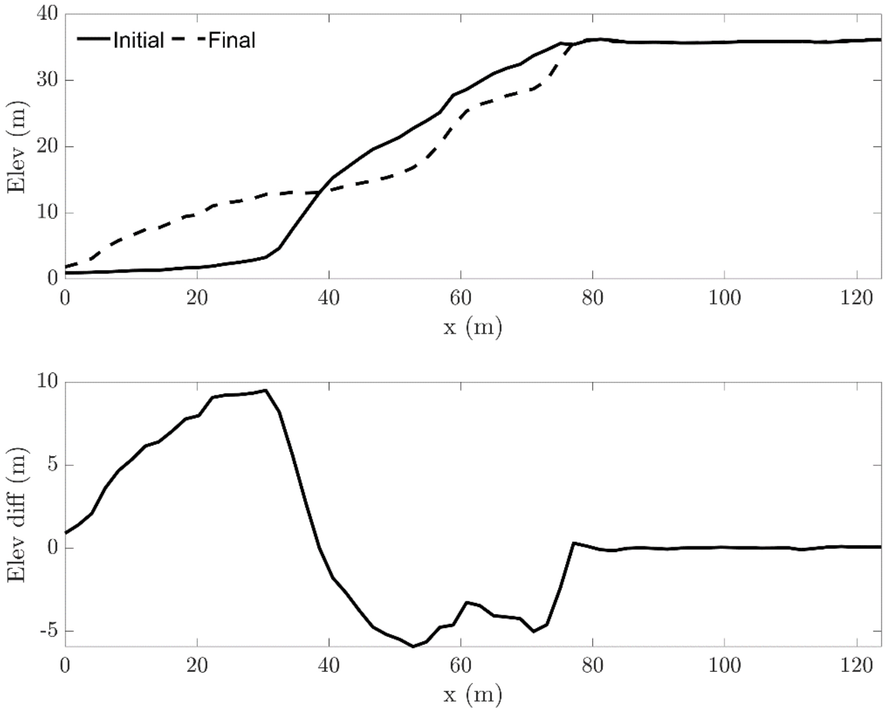

***Figure 4.3**: Elevation profiles along the lines 1 and 2 shown in Figure 4.2. Elevation values extracted from the 2015 LIDAR DSM.*

Figure 4.4 shows the two PSO images that we have selected (2nd and 25th March 2020) as suitable images for this analysis. We have searched PL image repository to identify images before and after the event for which the Area of Interest (AOI) was not covered by clouds. The selected images are the ones closest to the time with a clear view of the AOI and also happen to have 0% cloud coverage (This is an issue in Wales as discussed in section 5). Despite the differences in colour intensities between the true colour images, the slide is still somehow visible on the true colour image.

The location of the landslide is more evident when looking at the differences between the EO index before and after the event (Figure 4.4). As expected, we see a decrease in the vegetation index (NDVI and GNDVI) at the cliff area were vegetation coverage and health has decreased and the NDWI values (i.e. a proxy for water content) increases. For plotting purposes we have coloured the pixels for which the differences on the NDVI, GNDVI were smaller than a threshold of -0.08, -0.07 respectively and for the NDWI bigger than 0.01.

We have manually tried different threshold values until we found values that approximately match the area that we were able to characterize as vegetated area before the event and more clearly isolate the affected area. The threshold NDVI values was able to clearly map an area of 740 m^2 within the landslide area without marking other nearby pixels while the threshold GNDVI and NDWI maps occurred at places not affected by the landslide.

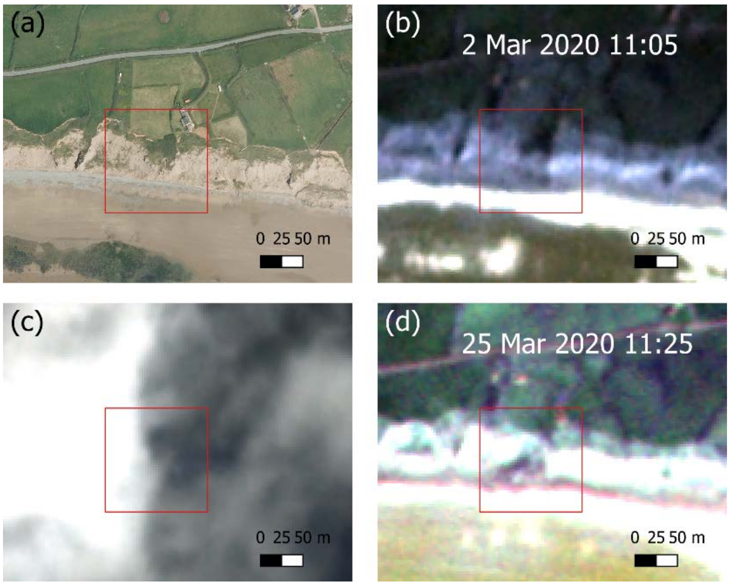

***Figure 4.4**: Aerial and view from the space of the area of interest (red square): (a) on the 2009 PGA aerial image; (b) selected PSO image before the event on the 2nd March 2020; (c) example of an non suitable PSO image due to cloud coverage on the 6th March 2020; (d) selected PSO image after the event on the 25th March 2020.*

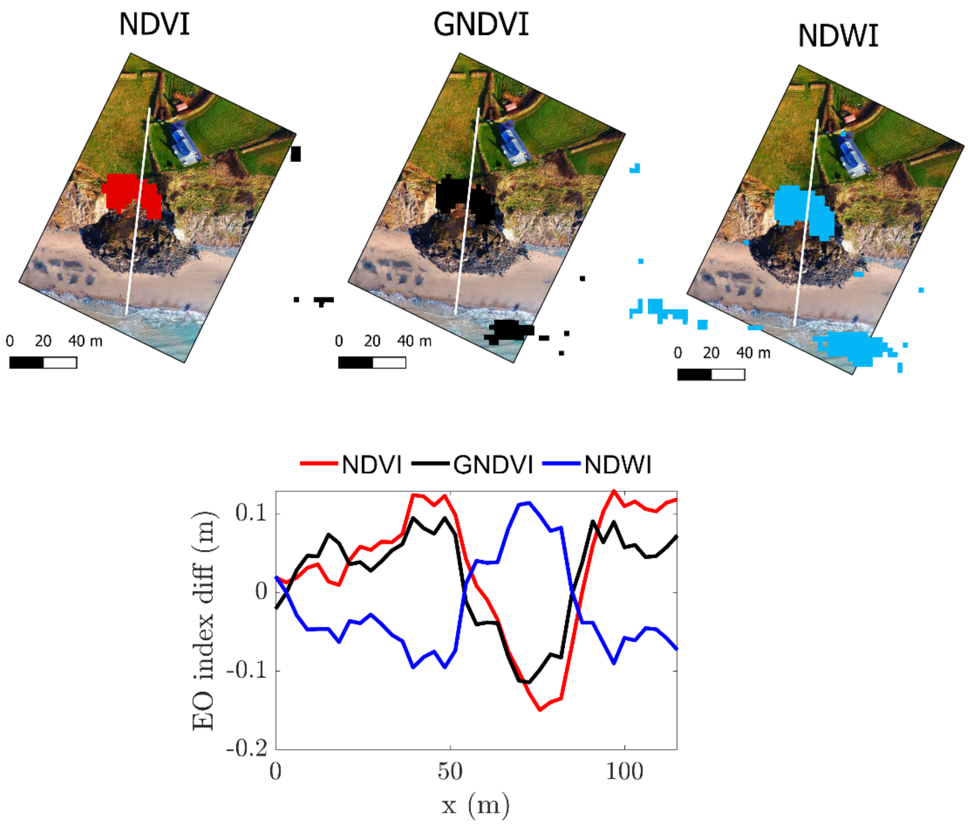

***Figure 4.5**: Differences of EO index (NDVI, GNDVI, NDWI) values resulting from subtracting the index value for the selected PSO image after the event (25th March 2020) the index values before the event (2nd March 2020). Top panels shows the pixels for which the differences were below (NDVI = red and GNDVI = black) and above (NDWI = blue) the thresholds (NDVI≤-0.08; GNDVI≤-0.07; NDWI ≥ 0.05). Bottom panel shows the variation along one transect that starts at the beach (Change = 0) and ends at the cliff top (Change = 125) (indicated white line).*

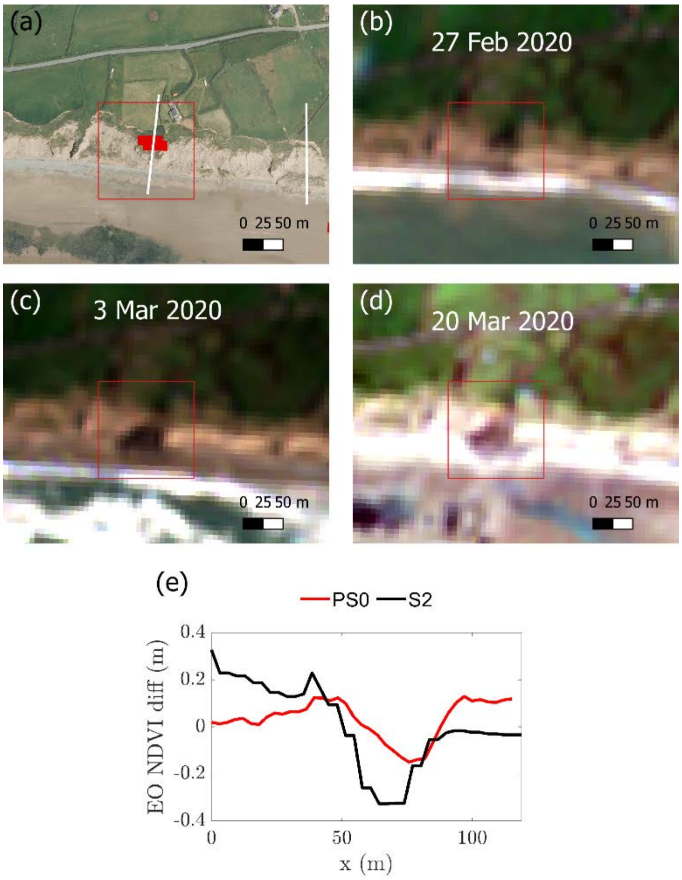

***Figure 4.6**: Differences of NDVI index values resulting from subtracting the index value for the selected S2 image after the event (3rd March 2020) and the index values before the event (27th Feb 2020): (a) shows the pixels in red for which the differences were below the threshold of -0.02; (b) selected S2 image before the event on the 27th Feb 2020; (c) selected S2 image after the event on the 2nd March 2020; (e) the variation along one transect that starts at the beach (Change = 0) and ends at the cliff top (Change = 120) (indicated white line) for both S2 and PSO NDVI differences.*

Figure 4.6 shows the NDVI change obtained from open Sentinel-2 (S2) optical data. We found suitable images for three dates (27th Feb, 3rd and 20th March 2020) for this study. We have calculated the NDVI for all three images and calculate the differences between the March images (as post event images) and the February image (as pre event image) and found that the landslide was already visible on the 3rd of March 2020 (one day earlier than the date reported in the Daily Mail).

The NDVI change along the beach to cliff transect shows the expected decrease on the NDVI values. For comparison purposes, we have also plotted the NDVI change obtained from the PSO imagery and noticed that the maximum change observed with S2 is about twice the change observed with PSO. As we are using different radiance values (BOA and TOA) and different days, it is not possible to attribute the cause of these large apparent differences. We found that using a threshold of -0.02 value, and colouring all pixels with a value smaller than this threshold we were able to approximately mark an area of 634 m^2 where the NDVI has significantly decreased. This area is close to the 807 m^2 that we were able to delineate as vegetated area affected by the landslide.

4.4 Summary & limitations of this scoping study

The main results of this study are summarized below:

1. The landslide event chosen for this study at Porth Neigwl near Abersoch was a rotational slide that occurred between the 2nd to 3rd of March 2020. This event did not cause a net loss of material from the area (i.e. eroded sediment from the cliff face were deposited in the upper beach) but increased the risk of damaging a nearby property that is now perilously close to the edge of the cliff.
2. As the eroded material remained on the upper beach and above the High Water Mark, the event did not cause a change in the shoreline (e.g. edge between water and land) and therefore NDWI index, often used to delineate the shoreline, is not suitable for this event.
3. As the top of the cliff was vegetated, the before and after images of the event show a decrease in the vegetation of 807 m^2 within the affected area cover that is suitable to be detected using EO index such as the NDVI or GNDVI:
    a. The size of the affected area is larger than the pixel resolution of the PSO (3 m) and S2 (10 m) images.
    b. By subtracting the EO index values in the pre-landslide images from the post-landslide values, for spatially collocated pixels, we obtain a raster dataset of pre/post-landslide NDVI differences.
    c. The NDVI and GNDVI can have any value between -1 and 1, from completely unvegetated (or bare soil) to completely vegetated. A negative NDVI or GNDVI difference thus indicated areas where vegetation has been damaged and/or covered by landslide deposits.
4. The before and after images that were closest in time to the event, were suitable for this analysis (i.e. cloud free) and were available are: the 2nd and 25th March 2020 for PSO and 27th Feb and 3rd March 2020 for S2.
5. The NDVI resulted in larger and sharper pre/post-landslide changes in the affected area.
6. Using a simple thresholding approach of the NDVI differences we were able to obtain estimates of the vegetated area affected of similar order than expected and of 740 m^2 for PSO images and 634 m^2 for S2 images. These areas are about 8% and 22% smaller than the vegetated area pre-landslide estimated from high resolution aerial imagery and is consistent with the fact that some vegetation is still present on the affected area on the post-landslide state.

Before we present our conclusions on the added value of PSO imagery compared with S2 openly accessible imagery we also acknowledge here the main limitations of this study. We have limited our study to only three bands (red, green and near infra-red) and not explored the added value of all bands available for S2 imagery. Changes on the cliff edge line due to the landslide could have also been detected from backshore classified images in two steps: 1st the EO image is classified and on 2nd the cliff edge line is extracted from the classified image. Figure 4.7 shows some littoral lines for different environments using a two steps sea front classification approach[16].

This sea front classification algorithm use EO indexes (NDVI and NDWI) that can be obtained from PSO imagery. If the areas of interest are expected to be covered by snow, then the Normalized Difference Snow Index (NDSI) will be required which uses, among other bands, the shortwave infrared (SWIR) band that is not included in the PSO imagery. For the two step approach, higher resolution PSO images are not necessarily better but to the contrary worse than coarser image resolution.

From VHR to low-resolution image the size of the smallest distinguishable unit increases. The influence of image resolution on the classification relies on spatial inter-class variability and intra-class variability. Thus, we may have an optimum resolution by land cover above and below which classification accuracies will decline (Townshend & Justice, 2007).

The optimum resolution for classification strongly depends on the landscape. The more fragmented and mixed the landscape, the finer the resolution should be chosen (Chen et al., 2004).

[16] https://coastalerosion.argans.co.uk/src/SO-TR-ARG-003-055-ATBD-SF.pdf

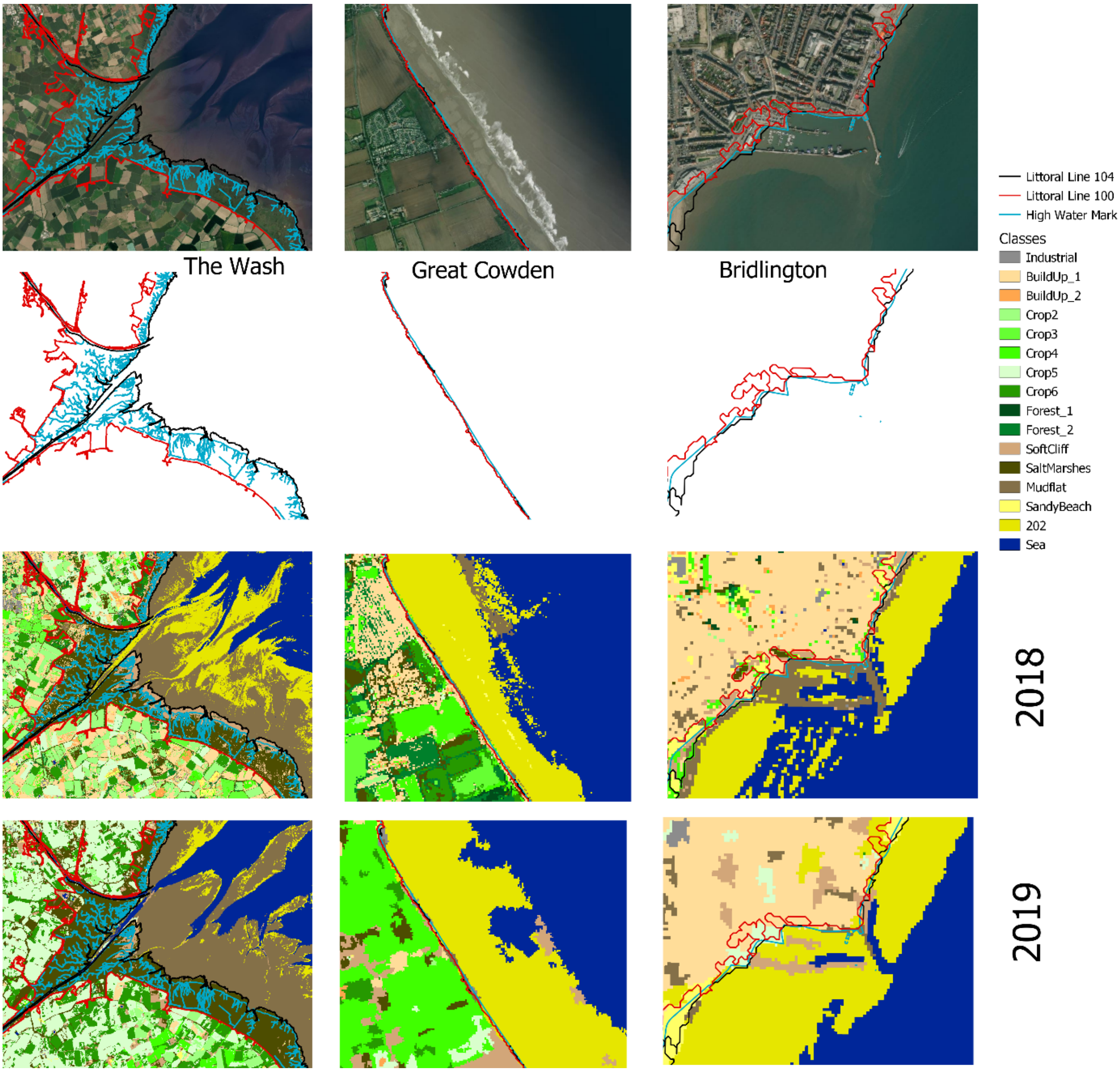

***Figure 4.7**: Details of littoral lines for year 2018 for three different environments: large intertidal areas (The Wash), beach backed by soft cliff (Great Cowden) and built environment (Bridlington). (Images from BGS OR/20/40[17]).*

[17] https://bgs.sharefile.eu/d-s0dfdc8ef25d64fb28342c4e635960dab

4.5 Conclusion

Regarding the quality of PlanetScope Ortho-photos (PSO) from Planet Labs imagery for assessing the before and after effects of one major coastal landslide we conclude that the vegetation change estimated from the PSO imagery is better than the results obtained from the S2 imagery. While both methods under-estimated the vegetated area lost, PSO under estimation is only 8% vs the 22% difference for the S2.

Table 4.3*: Estimated vegetated area change after the 3rd March landslide obtained from different images.*

	Aerial	PSO	S2
Resolution	0.25m	~3m	~10m
Estimate of vegetated area change (m^2)	807	740	634
Percentage difference aerial vs EO	---	-8%	-22%

5 OPTIONS FOR FUTURE EXTENSION OF SATELLITE BASED SOIL MONITORING

This section summarises the potential methods, data sources and requirements for an EO-based soil monitoring system to aid stakeholders in adhering to the Good Agricultural and Environmental Conditions (GAEC) guidelines and for other reporting purposes. Tye & Robinson (2020) proposed the ambition to develop a SOIL-ALERT monitoring system that uses daily, or near-daily, Earth Observation (EO) combined with modelling for prediction, to generate alerts for land-managers and other stakeholders. This could help land managers avoid land degradation when conditions are unsuitable for some practices. We propose a set of options in the following section that would begin to address the following avoidable activities:

- Leaving soil bare (GAEC 4.0)
- Erosion and soil damage (GAEC 5.3, 5.2, 1.3)
- Ploughing too close to boundary features (GAEC 7.6)
- Cultivating or trafficking soils that are water logged (GAEC 5.1)

A preliminary investigation of soil erosion feature properties followed by two simple trial detection applications are proposed as the next steps, based on the those covered in section 3 and limitations of available EO data.

5.1 Platforms and Imagery

The European Space Agency (ESA platforms (Sentinel 1&2 (S1 & S2) offer imagery at about 10m resolution. The platforms offer both optical and synthetic aperture radar (SAR) imagery where the radar can be used to assess moisture or movement. The Planet data is finer spatial resolution, 3-1m dependent on the platform, where each improvement in resolution enables more features to be determined. The EO platforms of potential use for mapping soil extent or erosion features are summarised in table 5.1.

***Table 5.1**: EO platforms for soil extent and erosion monitoring.*

Platform	Relevant Bands	Revist (days)	Pixel resolution/spacing
Sentinel 2	4, 7 (B, G, R, RE1, RE2, RE3, NiR)	5	10 m, 20m
Sentinel 1	NA – SAR	5	~10-20m*
Planet Scope	4 (B, G, R, NiR)	3	3m
Planet Skysat	5 (B, G, R, NiR, Pan)	5	0.5-0.75-1m**

* Pixel spacing dependent on mode etc. - see *here* for details.

** 0.5m Pan chromatic; 0.75 pan-sharpened; 1m multi-spectral.

Planet / Sentinel2 satellite revisit times generally range from 3-5 days (<10), but given the changeable nature of UK weather, the availability of cloud free, useable optical data will be more limited. The following plot depicts S2 scene cloud cover percentage over North Wales for 2019. As the data shows cloud free imagery is the exception not the norm.

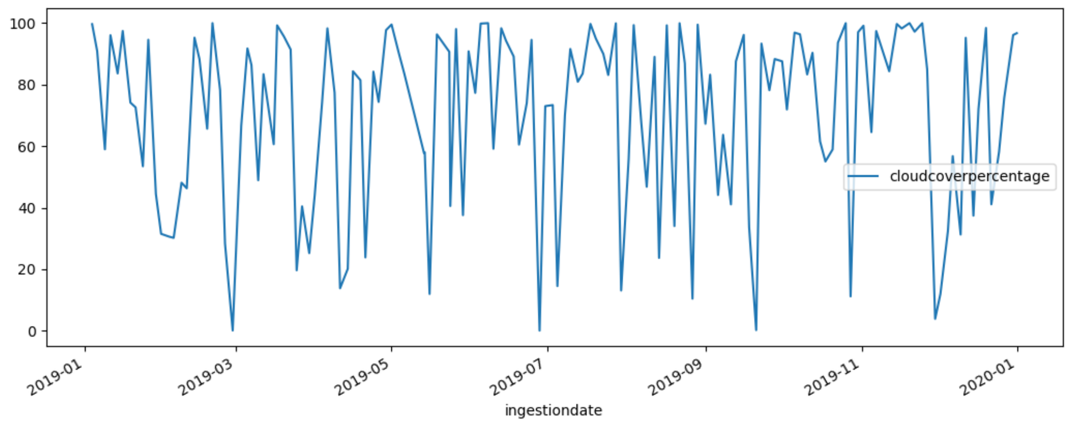

***Figure 5.1**: Cloud cover per S2 acquisition for 2019 over North Wales.*

Monthly composites of optical data may be the minimum viable solution, or next cloud free pixel updates if detections are to be more frequent.

The alternative is to rely upon Synthetic Aperture Radar which is unaffected by cloud cover due to its lower energy and higher wavelength. RADAR imaging from orbit would require impractically large antenna to produce fine spatial resolution data, hence SAR provides an alternative solution to this problem. SAR simulates a larger antenna through the along-track trajectory of the sensor meaning finer spatial resolution imagery may be obtained by a modestly-sized platform. Satellite-based SAR platforms tend to offer a specific subset of the microwave region which are classified which range from K (0.75cm) to P (30-100cm).

***Table 5.2**: SAR band designations and wavelengths.*

SAR Band designation	Wavelength (cm)
K (three subsets)	0.75 - 1.1
X	2.7 - 3.75
C	3.75 - 7.5
S	7.5 - 15
L	15-30
P	30-100

Most EO-based platforms use X (e.g. TerraSAR X), C (e.g. Sentinel 1) and L (e.g. ALOS PaLSAR). The wavelength of the band determines the scale of objects the pulse will interact most vigorously with. The key exploitable SAR signal properties are backscatter, polarisation and phase, from which a variety of imaging and mapping products can be derived from further processing, such as land cover, biomass, movement, moisture and surface reconstruction.

5.2 Bare soil assessment (spatial and temporal)

Sentinel 1 and 2 offer the greatest potential and utility for mapping large homogenous exposures of soil, this includes bare fields, scree or rock exposure or bogs, where the defining characteristic is spectral. This is potentially achievable via per-pixel mapping (>=100m^2) with S1, S2 (or a hybrid of both) or at a finer spatial resolution using Planet Scope (9m^2). Exact methods would need to be developed as there is a rapidly growing literature.

Activities:

- Training/calibration on optical historic time series using bands directly or ratios/indices
- Training/calibration on SAR backscatter or InSAR phase

Outputs:

- Thematic maps of bare soil extent updated on a monthly basis (see Frequency)
- Determination of some feature categories could be made via post-processing through association with known features (e.g. field boundaries, gates etc.) and/or feature geometric properties (e.g. moment-based properties)

5.3 Soil Erosion and Damage (SED) Features

Section 3 illustrated that Sentinel 1 and 2 are less suitable for finding smaller SED features. In order to assess the remaining SED features, the defining characteristic for most is likely a combination of spectral and spatial properties, for which the minimum viable resolution is <=3m. At 3m, Planet Scope data may be of limited use where there is adequate separation between features, with Planet Skysat (0.5-1m), manned-aerial imagery (<=0.5m) or UAV derived data (<0.2m) providing detail necessary to identify features clearly. Whilst Skysat data was not available for testing in section 3, a freely available image sample from Planet Labs clearly illustrates the differences in discernible detail ranging from Planet Scope at 3m, Skysat at 0.75m to a Google Basemap at <=0.3m (Fig 5.2).

***Figure 5.2**: Planet Scope, Skysat pan-sharpened and Google basemap imagery comparison. Please note that the Google basemap is not contemporaneous with the Planet imagery.*

5.3.1 Further investigation of the SED feature set

The initial stages of this program of work on SED features collected a set of 2500 SED features (Tye & Robinson, 2020) which were mapped from 0.25m metre aerial imagery. This is an excellent baseline product, but it is not repeated regularly. As proposed in Tye & Robinson (2020), this provides an ideal training dataset for investigating the efficacy of expert-based or machine learning techniques to map the SED features.

Further steps with this data set would be to investigate the pixel-based properties of mapped SED features, to determine whether there are distinctive properties for each feature type, which will in turn inform subsequent detection algorithms for automating detection. Editing or reworking of the manually derived polygons to represent the feature boundaries precisely is a prerequisite here.

- Investigate pixel spatial properties at different scales for the erosion types
- Investigate pixel temporal properties at different scales (of most use with S1, 2)

We would constrain mapping in the first instance to agricultural areas demarcated through the OS Mastermap (OSM) layer which has the potential to reduce error, data ingestion and processing time. OSM could also be used to mask urban and impervious structures e.g. infrastructure.

5.3.2 Erosion feature mapping using Convolutional Neural Nets

This is potentially achievable via Skysat or aerial imagery, with possible extension to Planet Scope. This application is best targeted on the small-scale features of Gateway damage, feeder damage, vehicle tracks and poaching.

Activities:

- Using the existing training set of polygons
- Applied to regional then Wales-wide Aerial imagery dataset
- Further extendable to sediment flows beyond farm boundaries
- Aerial imagery could be reduced in resolution as a surrogate indicator for Skysat
- Potential extension to currently available planet scope data, subject to access to WG holdings.

CNNs (Convolutional Neural Nets) have emerged in the last 10 years as a cutting-edge technique in image labelling and semantic segmentation tasks. Broadly speaking, CNN's follow a neural net structure (a process inspired by, but not a model of, the biological counterpart), where feature extraction and classification are combined in one process. The process is loosely analogous to different parts of the network being devoted to different characteristics of the object/class of interest, the cumulative result being the recognition of a spatial pattern of pixels, as opposed to other machine learning methods, which focus on feature vectors of single values with no spatial component.

Potential outputs:

- Labelling of an image subset of specified size (e.g. 50m x 50m)
  e.g. "This area contains a poaching SED feature"
- Bounding box around the target SED feature
- Direct segmentation of the feature (based on a probability threshold), where the SED feature is extent delineated

5.4 Strip Width Detection at Field Boundaries

Where GAEC compliance is associated with habitat features (e.g. hedgerows/linear features, river banks), a combination of UKCEH land cover map and/or OS metadata could be used for their location. Where not available, it could be automatically mapped from LIDAR or Aerial imagery to provide a baseline dataset as in the example below. The Euclidean distance from soil erosion feature to habitat feature would then be derived via spatial analysis to determine compliance.

5.5 Soil Wetness

The ESA constellation of Sentinel 1A (launched in 2014) and Sentinel 1B (launched in 2016) satellites offer synthetic aperture radar (SAR) using the c-band (5.405 GHz). This is a frequency value which is a bit higher than common soil moisture sensors such at time domain reflectometry, but comparable.

The SAR data is often combined with the optical data from Sentinel 2 in order to determine soil moisture where vegetation is an issue; for bare soil it's not required. Sentinel 2 data is converted to a normalized difference vegetation index (NDVI) for this purpose. The SAR data can also be used to map land cover and derive a proxy indication of vegetation structure as well as soil moisture. ESA provides a range of tools for processing the data including the SNAP software. Pre-processing steps are required in order to use the data for soil moisture estimation.

We have not yet attempted to use SAR and soil moisture estimation in Wales but it has a clear potential for use for water logging detection. If used in such an application the imagery may not require the same amount of processing compared to us to estimate the actual soil moisture. At present soils are assigned a wetness class in the soil survey of England and Wales (Rudeforth et al., 1984). This value helps to guide appropriate practice for the soil. However, the values are generally static and don't change unless reassessed. Satellite monitoring offers the opportunity to develop a dynamic wetness class. This could be useful for several applications:

- Determining when soils are suitable or unsuitable for farm activities such as cultivation.
- Determining when a field has changed from one wetness class to another for example by the addition of drains. Conversely, it may be feasible to detect when drainage no longer works as soils are consistently wetter.
- Carbon content of soils is likely linked to soil wetness and so a combination of NDVI and soil wetness may help with the interpretation of soil carbon measurements.

5.6 Other methods

The use of earth observation to detect features relevant to GAEC was the focus of this section. However, other methods and techniques may also me of interest. In particular ground motion for soils in Wales, determined using interferometry (inSAR), was first tested in work under GMEP (Robinson et al., 2014). Imagery for the Migneint from between 1993 and 2000 was used to detect peat motion (Cigna et al., 2014). Researchers have now refined this technique with application to studying peat condition in the flow country in Scotland (Alshammari et al., 2020). Ground motion studies originate in California where the technique was used to study ground motion of fields prior and post irrigation (Gabriel et al., 1989). The ability to measure ground motion (mm – cm) at pixel resolutions of 10m offers interesting potential for assessment of erosion rates, landslide potential or subsidence especially around infrastructure (North et al., 2017).

5.7 Erosion rates and transport

SED features simply identify the location and extent of direct impacts detectable from EO. No soil erosion rate data or soil and sediment transport information is obtained, either on site or off site. Further work would be required in order to determine soil erosion rates. Furthermore, work would also be required to determine how much eroded soil ends up in water courses and is transported as sediment downstream. Work was undertaken on estimating sediment yield in England and Wales previously (Cooper et al., 2006) with the results presented in Figure 5.3 from that report. There may be opportunities to update that work for Wales and to link EO to identifying hotspots and locations that feed into the yield of river sediment and impact water quality.

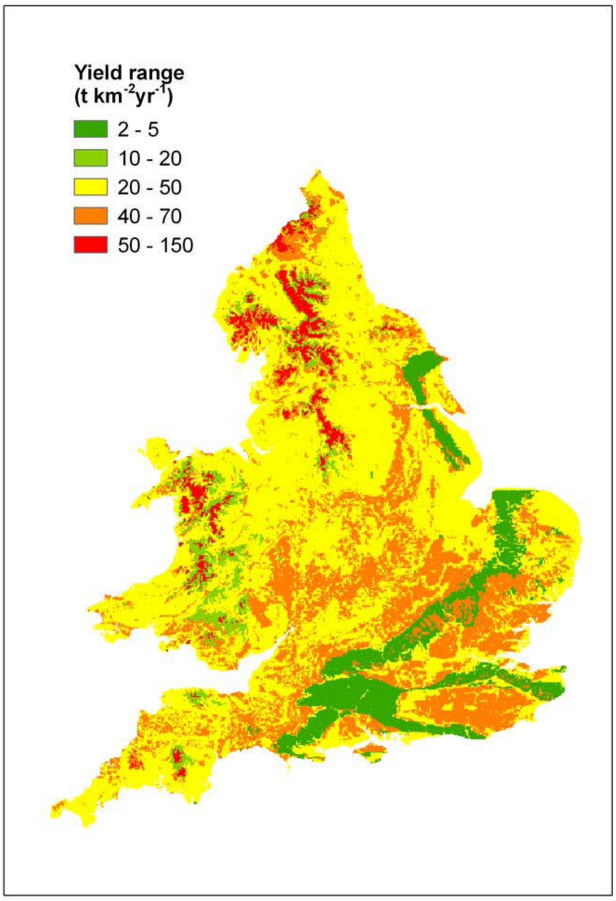

Figure 5.3. *Sediment yields for types, showing estimated interquartile ranges (From Cooper et al., 2006)*

5.8 Summary

A combination of EO products used in conjunction with ground based assessment offers great potential for soil monitoring and providing tools of value to stakeholders. A range of options are available for remote monitoring using EO which is becoming less expensive. At present the resolution of free imagery limits applications to detection of large features, such as bare fields, scree, or bogs. There is also potential to use this imagery for detecting water logged fields. Detection of smaller features such as soil damage around gates that may be ephemeral would require commercial imagery.

6 LOGISTICS & REQUIREMENTS

The processing of EO-imagery on a regional or national scale requires considerable computational resource, given the complexity and volume of the input data. The potential storage burden is now partially alleviated by publicly available data holdings provided by ESA, NASA and NERC as well as cloud-based platforms such as AWS and Google who also hold complete archives. The following provides an overview of the options for an EO-based monitoring system through acquisition, processing and storage.

6.1 Acquisition

Imagery access via web API:

- ESA servers (free - download limited- likely impractical for an operational system)
- NERC CEDA/PML (free for development - may lag behind ESA archive**)**
- AWS/Google (largely free with cost for mass transfers)
- Planet (at cost/WG)

6.2 Processing

- Processing will require a multi-core computational resource such as a powerful dedicated desktop, HPC/server allocation or cloud-hosted service (e.g. Google or AWS).
- Any web/mobile integration would ideally reside in the same resource, suggesting AWS may be the best candidate for an operational system.
- CNN training will require a multi-GPU resource, if it proves a viable method.

6.3 Storage

The permanent storage of the imagery itself is unnecessary, given the speed with which it may be retrieved from the above sources, should verification of results be required. The storage burden should be limited to the output mapping products derived from the imagery, which would be of single-band raster, vector or web-compatible display format.

7 REFERENCES

Alshammari, L., Boyd, D.S., Sowter, A., Marshall, C., Andersen, R., Gilbert, P., Marsh, S. and Large, D.J., 2020. Use of surface motion characteristics determined by InSAR to assess peatland condition. Journal of Geophysical Research: Biogeosciences, 125(1), p.e2018JG004953.

Chen, D., D. A. Stow & P. Gong. 2004. Examining the effect of spatial resolution and texture window size on classification accuracy: an urban environment case. International Journal of Remote Sensing 25, 2177–2192

Cigna, F., Sowter, A., Jordan, C.J. and Rawlins, B.G., 2014, October. Intermittent Small Baseline Subset (ISBAS) monitoring of land covers unfavourable for conventional C-band InSAR: proof-of-concept for peatland environments in North Wales, UK. In SAR Image Analysis, Modeling, and Techniques XIV (Vol. 9243, p. 924305). International Society for Optics and Photonics.

Cooper, D.M, P. Naden, G. Old and C. Laizé 2006. Development of sediment targets for short-term management of sediment inputs into aquatic systems. Final report, English Nature contract EIT36-05-020. CEH, Wallingford, UK

de Jong, R., de Bruin, S., Schaepman, M. & Dent, D., 2011. Quantitative mapping of global land degradation using Earth observations. International Journal of Remote Sensing, 32(21), 6823-6853.

Gabriel, A.K., Goldstein, R.M. and Zebker, H.A., 1989. Mapping small elevation changes over large areas: Differential radar interferometry. Journal of Geophysical Research: Solid Earth, 94(B7), pp.9183-9191.

North, M., Farewell, T., Hallett, S. and Bertelle, A., 2017. Monitoring the response of roads and railways to seasonal soil movement with Persistent Scatterers Interferometry over six UK sites. Remote sensing, 9(9), p.922.

Matthews, R.A., Chadwick, D.R., Retter, A.L., Blackwell, M.S.A. and Yamulki, S., 2010. Nitrous oxide emissions from small-scale farmland features of UK livestock farming systems. Agriculture, ecosystems & environment, 136(3-4), pp.192-198.

Robinson, D.A., Edwards, F ., Barrett, G., Bradley, D., Carter, H., Cigna, F., Creer, S., Emmett, B.A., Evans, C., Grebby, S., Greene, S., Hughes, S., Jones, D., Keith, A., Kelly, M., Lallias, D., Lebron, I.,McDonald, J., Pereira, MG. and Rawlins, B. 2014. Chapter 8 Soil natural capital and water flow and quality. In Emmett B.E. and the GMEP team (2014) Glastir Monitoring & Evaluation Programme. First Year Annual Report to Welsh Government (Contract reference: C147/2010/11). NERC/Centre for Ecology & Hydrology (CEH Project: NEC04780), pp. 442

Rudeforth, C.C., Hartnup, R., Lea, J.W., Thompson, T.R.E. and Wright, P.S., 1984. Soils and their use in Wales. Soils and their use in Wales., (Bulletin 11, Soil Survey of England and Wales).

Townshend, J. and Justice, C., 1981. Information extraction from remotely sensed data. A user view. Remote Sensing, 2(4), pp.313-329.

Tye, A.M. & Robinson, D.A., 2020. Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report-45: Soil Degradation: Erosion & Compaction Phase-1. Report to Welsh Government (Contract C210/2016/2017)(UK Centre for Ecology & Hydrology Projects 06297 & 06810).

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