Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP)

ERAMMP Report-70:
The use of remote sensing to assess soil erosion, poaching and disturbance features

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Abbreviations Used in this Report

AG	Acid Grassland
AH	Arable and Horticulture
ALC	Agricultural Land Classification
BGS	British Geological Survey
Bo	Bog
BW	Broadleaved Woodland
CDF	Cumulative Distribution Functions
CDF	Cumulative Distribution Function
CG	Calcareous Grassland
CW	Coniferous Woodland
Defra	Department for Environment, Food & Rural Affairs
DPSIR	Driver-Pressure-State-Impact-Response
DTM	Digital Terrain Model
ERAMMP	Environment and Rural Affairs Monitoring & Modelling Programme
ESB	European Soil Bureau
ET	Evapotranspiration
FM	Fen, Marsh & Swamp
GIS	Geographical Information System
GMEP	Glastir Monitoring & Evaluation Programme
HE	Heather
HG	Heather Grassland
IG	Improved Grassland
IR	Inland Rock
LCM	Land Cover Map
NG	Neutral Grassland
NSI	National Soil Inventory
NSRI	National Soil Resources Institute
SL	Supra Littoral
SM	Salt Marsh
SoNaRR	State of the Natural Resources Reporting
SPM	Soil Parent Material
SU	Suburban
UKCEH	UK Centre for Ecology & Hydrology
UR	Urban

Contents

1 Executive Summary

Soil is a finite resource. Within the concepts of natural capital and ecosystem services, the erosion and compaction of soil are considered to be major threats to both 'soil stock' and 'soil function'. Principal drivers of erosion include slope angle and length, precipitation quantity and intensity and vegetation coverage. Soil compaction (primarily caused by repeated movements by vehicles or poaching by animals leading to exposed soils) may reduce soil function in terms of water and gaseous movement and exacerbate N_2O emission, as well as potentially creating pathways for erosion to occur. However, producing national scale assessments of soil erosion is expensive and difficult, whilst soil compaction, or disturbance remains largely unconsidered in assessments.

Soil erosion is a compliance issue, however, the work outlined in this report is not aligned with any regulatory or compliance process such as outlined in Good Agriculture and Environmental Conditions 5 (Welsh Govt, 2022); it is purely a research project for the monitoring and assessment of soils.

Many methods for measuring soil erosion exist and are used over a range of different spatial scales. These include plot experiments, field or catchment studies. However, widespread quantification of erosion rates are time consuming and still remain spatially restricted. Other approaches are more suited to national scale assessments.

Modelling approaches, usually based on the 'Universal Soil Loss Equation' or its variants can provide an indication as to where long-term erosion is most likely to occur under certain land-use and climatic conditions and are useful for looking at potential change. Walk-over-surveys have the potential to measure area and sometimes volumes of soil erosion, but are also time consuming to undertake. However, they do provide the most repeatable basis for widespread or national scale monitoring.

The use of earth observation presented here, combined with field survey, may be an effective and less time-consuming approach for the assessment of national scale soil erosion, but its benefits and limitations need to be explored. This study reports on

(i) a desk-based soil erosion and disturbance survey undertaken using high resolution aerial images (0.25 m); and

(ii) a subsequent ground survey of the aerial photo survey undertaken as part of the 2021 ERAMMP field survey.

For the desk-based study the use of high definition (true orthorectified 0.25 m resolution) aerial photography was used to produce a dataset based on 261 squares of the ERAMMP (Environment and Rural Affairs Monitoring & Modelling Programme) survey of Wales. Soil erosion or disturbance polygons were marked within each selected 1 km x 1 km survey square. Polygons were linked within the GIS to data relating to land management or cover (Agricultural Land Classification, UKCEH Land cover map 2015), landscape properties (slope, altitude, geology, soil parent material) and other erosion-influencing properties (soil texture, annual precipitation). This allowed exploration of the aerial photography data in relation to the properties influencing soil erosion and disturbance.

Soil erosion and disturbance polygons were recorded under four main headings, these being 'Peat Erosion', 'Soil Disturbance', 'Mineral Soil Erosion' and 'Mass Movement' events. These accounted for 9%, 76%, 4% and 11% of the total identified polygons (n= 2580) respectively. The high percentage of 'Soil Disturbance' events identified demonstrates the influence of land use across Wales (predominantly grazing) on soil status, whilst the low incidence of 'Mineral Soil Erosion' potentially reflects the low acreage of arable agriculture in Wales. Due to Welsh agriculture being largely grass based, it offers a high coverage of vegetated landscapes all year long. The absence of vegetation is a key factor exacerbating erosion, because vegetation and roots bind the soil surface, increasing infiltration and decreasing pore water pressure through evapotranspiration. It is however evident that whilst recorded 'Mineral Soil Erosion' events were lowest in number, they were recorded in both arable and improved grass land uses, suggesting that agriculture in general leads to soil disturbance that may allow for erosion initiation. 'Peat Erosion' was associated with the identification of peaty hags and where surface vegetation had been removed, whilst 'Mass Movement' events were dominated by (i) soil scars or slips and also (ii) soil creep and terracette formation.

The largest categories of erosion found under 'Mineral Soil Erosion were (i) general soil erosion (evidence of erosion by water), (ii) riverbank erosion and (iii) erosion around drainage ditches. 'Soil Disturbance' events were largely concerned with poaching associated with livestock farming, and reflected livestock behaviour (feeding, sheltering, movements) and agricultural transport in support of livestock husbandry. The frequency of these events showed highest levels on Agricultural Land Classification classes ACL3b and ACL4 and on 'Improved Grassland'.

These factors suggest that an increase in the intensity of livestock farming (animal stocking rates) may drive soil disturbance. Influences of the other landscape and other soil erosion and disturbance producing factors were analysed including slope, altitude, precipitation and landcover. These generally conform to expected outcomes for the four main classes of erosion or disturbance examined and the land use or cover.

The aerial photo GIS survey was ground-truthed by field surveyors as part of the 2021 ERAMMP field survey. In this survey, the number of events in up to 5 x 200 m circles located within each 1 km x 1 km square were used as comparisons. In the first comparison the surveyors recorded around 20% more samples in the selected 5 x 200 m circles than the aerial survey recorded. This may be due to the field surveyors being able to identify smaller areas of soil erosion and disturbance than the aerial photo survey, due to image resolution issues. In particular, areas <100 m^2 became more difficult to identify from the aerial photos. In a second analysis around 60% of the aerial survey polygons in the 200 m circles were ground-truthed by the surveyors.

These results were considered good as there was likely to be some mismatch between the age of the aerial photos used in the GIS survey and the field survey, and that not all selected circles could be accessed. The results also reflect the nature of erosion and disturbance events in a heavily vegetated (non-arable) environment in that (i) erosion processes will occur in vulnerable parts of the landscape and may be relatively long term, and (ii) animal behaviour leading to poaching will be fairly consistent in fields (e.g. sheltering spots, gates, and farmer feeding areas).

The area of erosion and soil disturbance was calculated for each square by combining the areas of polygons from the aerial photo survey only. Recorded soil disturbance or erosion per 1 km x 1 km square gave a median value of ~6000 m^2 or 0.6% of soil. A mean figure of 4.06% was recorded as disturbed or eroded. These figures are likely a conservative estimate as due to staff time and image resolution some disturbance events such as thin animal and vehicle tracks were either too time consuming or difficult to identify.

When these figures are compared to previous field or walk over surveys in the UK they are of a similar magnitude. However, no two previous walk-over surveys have been identical in their area examined or land use (e.g. arable or upland) making like for like comparisons difficult, and suggesting the need for a more standardised approach which aerial imagery could offer.

Results from this work have demonstrated the potential to use high resolution aerial imagery as a basis for long term comparable surveys to monitoring this aspect of soil health. There are limitations particularly with respect to identifying smaller areas of erosion and also in being able to identify some erosion processes such as rill erosion. However, future work should consider the use of satellite data at a similar resolution (0.25 m) as this would provide greater temporal accuracy as high-resolution aerial surveys are undertaken infrequently. There is also potential for developing computer learning techniques to identify eroded or disturbed areas which may increase the potential for increased monitoring.

2 Introduction

In Wales, the Environment (Wales) Act (2016) ensures that the goals laid out in, 'The Wellbeing of Future Generations Act' (2015) are achieved. Together they promote the sustainable management of natural resources in Wales. The 'State of the Natural Resources Reporting (SoNaRR)' procedure, published on a 5-year cycle, captures information regarding the state and change of natural resources. It uses a five-step method that incorporates the Driver-Pressure-State-Impact-Response (DPSIR) framework and four measures of sustainable management of natural resources, including:

1. Natural resources are safeguarded and enhanced
2. Ecosystems are resilient to expected and unforeseen change
3. Wales has healthy places for people, protected from environmental risks
4. Contributions to a circular economy with more efficient use of natural resources

Soils are one of the natural resources that must be reported on. The use of SoNaRR identifies gaps in knowledge and evidence requirements. One of these evidence gaps concerns the extent of soil erosion and disturbance within Wales. Further understanding is necessary to determine the sustainability of soil use across a range of land use activities, soil types and climatic ranges. This project reports on an investigation in assessing the applicability of remote sensing techniques (high resolution aerial photos) as a means to understanding the extent of national soil erosion and disturbance in Wales, and how these may fit into a field monitoring program. Limitations are discussed.

2.1 Background to the study

One of the major threats to the long-term sustainability and function of soils comes from soil erosion and disturbance caused by 'agriculture, forestry and other human impacts'. This can reduce the soil's ability to contribute to the ecosystem services that society often relies on them performing (Robinson et al. 2013; Steinhoff-Knopp et al. 2021). The loss of soil can lead to the eutrophication of surface waters, reduce soil volume and structure that allows carbon, nutrient and water storage. In addition, the life cycle of soils can be reduced when erosion is faster than soil formation (Evans et al. 2020). Soil formation and soil profile development are processes that take thousands of years (Evans et al. 2019; Tye et al. 2021).

The key drivers that determine the extent of water and wind soil erosion are vegetation coverage, precipitation quantity and intensity, soil texture and slope characteristics including angle and length. These are typically encapsulated in models such as the Universal Soil loss equation (Renard et al. 1997; Fullen, 1985). Typical water erosion processes include soil splash, sheet, rill or gully erosion. Assessments of soils in GB most at risk have been made (Brazier, 2004; Evans, 1990; Evans, 2002). Other forms of soil erosion may occur and are linked to natural geomorphological processes (but sometimes triggered by human impacts) involving slopes, soil matrix interactions under pore water pressure and vegetation. These may include soil creep, the formation of terracettes, landslides and soil slips.

Other forms of soil disturbance are possibly less well studied, but can be a precursor in many cases, to later erosion processes. Disturbance usually occurs as a result of repetitious interactions of humans and animals with the soil. Animal interactions with soil are often referred to as poaching (Carroll et al. 2004; Mullholland & Fullen, 1991; Timble and Mendel, 1995), whilst humans can leave both paths, vehicles tracks or tramlines in fields. Cattle are also responsible for other disturbance such as eroding riverbanks (Timble and Mendel, 1995). In many cases several processes interact. The result is bare and compacted soils, that slow water infiltration, increase runoff which can lead to increased sediment and nutrients in rivers (Deasy et al. 2009). Thus, soil disturbance can cause the long-term decline or even loss of soil function including drainage and induce negative changes in biogeochemical cycling including that of greenhouse gas emissions (Ball, 2013).

Quantifying the spatial extent of soil erosion and disturbance, to present a national baseline, so that improved policy and advice for land managers can be formulated is difficult. Soil erosion and disturbance occurs on a range of scales (e.g. from landslides to soil splash), with different combinations of the key erosion driving variables causing different spatial and volumetric extent. Some forms of erosion such as gulley erosion and muddy floods are highly visible (Boardman, 1988; Evans & Linsay, 2010) and their impact is evident. However, sheet erosion on slopes is harder to recognise but often occurs freely on slopes with light textured soils (Fullen & Reed, 1986).

This has led to many techniques being developed to measure erosion rates experimentally. These include soil erosion plots which provide detail on the soil and slope variables that contribute towards erosion (Fullen et al. 2006), field scale assessments, which include tillage erosion, through the redistribution of radio-nuclides such as ^{137}Cs and ^{210}Pb (Quine and Walling, 1991), estimated catchment losses by measuring suspended sediment (Collins & Walling, 2004; Wass & Leeks, 1999; Heywood & Walling, 2003), whilst the volume of soil loss in large events can be undertaken using Terrestrial Lidar Scanning (DeRose & Basher, 2010; Li et al. 2019). Whilst these techniques focus on the field-scale they are limited in helping to determine the baseline over regional areas or for national assessments. Many are expensive to undertake, limiting their more widespread use. Costs for national or widespread erosion monitoring surveys were reviewed in a Defra report (Defra, 2016), and for the Welsh Government (Tye & Robinson, 2018).

One way in which the extent of soil erosion over large areas has been studied is the use of walk –over-surveys (e.g. Boardman, 1990; McHugh et al. 2002). These surveys focus on manual examination of features across a range of designated fields or survey area, often complementing an existing environmental monitoring programme (e.g. Countryside Survey, National Soil Inventory (NSI)). A complementary approach to this may be the assessment of soil erosion through aerial imagery. The use of aerial photographs in assessing soil erosion has been regularly considered. Early attempts were made by Vandaele et al. (1996) using stereoscopic aerial photography and by Evans (1988) and Chambers et al. (1992) in England and Wales. However, recent advances in digital imaging have allowed increasingly high-resolution aerial photos to be produced and introduced into GIS systems. Routine high-resolution photography by satellites allows regular images to be captured which may allow greater temporal and spatial assessments to be made (Robinson et al. 2021).

The work outlined in this report is not aligned with any regulatory or compliance process such as outlined in Good Agriculture and Environmental Conditions 5 (Welsh Govt, 2022). The definitions and assessment of severity of erosion and disturbance used are specific to this study, and are based and adopted from previous walk-over surveys of Wales (e.g. McHugh et al. 2002). The work also differs from GAEC assessments as it identifies poached areas which are not part of GAEC requirements as vegetation is likely to recover rapidly to protect soils. However, from a scientific point of view interest exists in the change in soil processes that may occur after such soil disturbance (e.g. compaction, greenhouse gas emissions). Thus, the objectives of this work are to understand what soil erosion and disturbance features aerial photography can identify, and whether it is a technique that can be used to understand trends in soil disturbance and erosion, particularly in changing climates and agricultural practice at a national scale. This follows on from many surveys with a similar purpose that have been undertaken in England and Wales over the last 40 years, including walk over surveys which this survey based on aerial photography most closely resembles.

2.2 Aims of the study

In this study we report on the use of existing high-resolution aerial photography and validation through field survey as a basis for assessing the extent of soil erosion and disturbance across Wales. The work was undertaken by the British Geological Survey and UKCEH.

The work involved:

An assessment of the frequency and spatial extent of soil disturbance and erosion features that could be identified using high resolution aerial photography in 261 1 km x 1 km survey squares of the Welsh Glastir Monitoring and Evaluation Programme. Polygons of soil erosion and disturbance were produced within a GIS system. This dataset was used as a basis for a field surveying campaign where features were ground-truthed and additional features added in a subset of 105 out of 130 1 km x 1 km squares surveyed during the ERAMMP field season in 2021.

Both datasets were linked to a wide selection of environmental variables known to influence soil erosion and disturbance to produce a dataset which forms the basis of a statistical assessment of the extent of the vulnerability of the Welsh soils to erosion and physical disturbance or degradation.

3 Material and Methods

3.1 Assessment of aerial photographs

The aim of the GIS based aerial imagery survey was to identify the extent of soil erosion and disturbance across 261 1 km x 1 km areas of Wales. These squares form part of the wider GMEP survey. The first stage of the process was to set up a GIS with the ERAMMP squares to be surveyed. These were selected as part of the planning process for the next stage of the ERAMMP field survey (initially planned for 2020 but postponed to the 2021 field season due to the Covid-19 pandemic).

Aerial photos were cut for the selected 1 km x 1 km squares. The aerial images used were the APGB high resolution aerial imagery licensed to BGS from Bluesky International Limited. The photos were the 'True Orthorectified 25cm National Resolution' dataset. Other datasets loaded into the GIS to help interpret the potential areas of erosion identified from the aerial imagery included OS maps and DTM derived landscape characteristics. Google Earth images were additionally used to help analysis potential erosion areas in squares where the resolution of the Bluesky aerial imagery was not sufficiently clear. An important further factor in the interpretation of potential features was the analyst's knowledge of landscape features and agricultural practice. This expert knowledge is important in asking whether 'would this process be likely here?' and in classifying the nature of the soil erosion feature. Using these datasets, areas of soil erosion and disturbance were marked as polygons on the GIS which had their spatial extent calculated.

A couple of practical issues associated with the analysis are worth reporting at this stage. The time required for the photo analysis was approximately 2 to 2.5 hours for five 1 km x 1 km squares. However, squares with a large number of features, particularly those in this survey associated with lowland dairy farming, could take 40 minutes or more. When examining the aerial imagery, it was found that a good image resolution to use was obtained at 1:1250 (i.e. 1 cm on the screen represents 1250 cm in real life). When increasing resolution on the GIS beyond 1:1250, there was a tendency for the landscape to become a pixelated blur. With respect to the aerial imagery the dates of the photography were not easily identified so there may be questions of relevance if an up-to-date survey based on aerial images is required. However, for the purposes of this study, the time period of the photos was not considered a large negative, as it is not expected that large changes in the spatial land use and agricultural practice would take place. Thus, soil erosion and disturbance features are likely to be fairly consistent as arable and grassland will have similar practice and the landscape features such as slope will be constant.

3.2 Classifying features

Figure 3.1 shows some of the types of soil erosion likely to be found within the Welsh landscape. These represent the types of features that were originally looked for.

Peat hags

Path erosion in the uplands

Examples of poaching by animals

Mass movement, landscape scars

Example of terracetes, from the LUCAS survey

Landslides

Coastal erosion

Riverbank erosion

Figure 3.1: Images of erosion and disturbance features.
Photos: David Robinson (UKCEH) and Chris Feeney (UKCEH)

3.3 Surveyor ground-truthing survey

The purpose of the field survey was to assess how accurate the aerial survey was by identifying whether the features found in the initial desk-based survey could be identified in the field. This task was undertaken by field surveyors, who assessed soil erosion and disturbance along with the ERAMMP assessment of woody features. A sample of 130 squares was selected for re-survey in ERAMMP (from the original 300 in GMEP), of which 105 were re-surveyed in 2021. Within each survey square there are up to 5 plots (so called X-plots) where soils are sampled and vegetation is assessed. Circles of 200 m are drawn around the X-plots and soil erosion features marked within these zones were re-located by the field surveyors. This generates a subset of soil erosion features that the field surveyors located, confirmed presence or absence, recorded what these features and photographed. Additionally, surveyors were asked to add missing soil erosion features to the dataset which occurred within the 200 m diameter of the X-Plot. Soil erosion features were only verified and identified in access permitted land. An example of the design is shown in Figure 3.2.

ArcGIS Collector

ERAMMP_Squares

4 features

▨ 9: Peat Erosion (area)
Area: 6.11 Acres

Square

Feature ID
9

Description
Peat Erosion (area)

Land use
Rough Grazing

Slope
Slope

Figure 3.2 An example of the style of map that the surveyors used to validate and record soil erosion features detected by aerial survey. The 200 m circles were checked and features recorded within. X marks the X-plots at the centre of those circles. Each hashed feature was checked and recorded with its British Geological Survey (BGS) number. Clicking on the feature gave information of the expected soil erosion feature – in the shown case – Peat Erosion.
Contains OS data © Crown copyright and database rights 2022

These records will allow us to:

I. Obtain an initial measure of the area of soil disturbance that can be obtained from air photos and validated on the ground by surveyors;
II. Identify false positives from the aerial survey and the number of missing features, and hence, determine the reliability of an earth observation approach;

The BGS aerial survey data was loaded onto field survey tablets that each surveyor carried. This allowed the surveyors to see the polygons identified by the aerial photo surveys (as above). The surveyors were asked to identify the presence of any features within the 200 m circle that had been marked in the BGS aerial survey. Those features present from the aerial survey were numbered, in accordance with the order they were identified in the aerial survey. The continued presence of the BGS feature from the aerial survey was marked as a Yes/No in the tablet worksheet, with additional notes. First-order estimates of the area of the eroded or disturbed soil event were made by marking the feature on the map on the tablet. New erosion or disturbance plots were classified as per Table 4.1 with a Primary classification, followed by the sub-classification. Analysis of the field data took the form of (i) identifying the number of BGS aerial survey polygons were still present, (ii) an analysis of new features.

3.4 Environmental variables for dataset understanding

Polygon features were joined to a range of landscape variables and soil parent material characteristics within the GIS. These features were selected based on their known influence on soil erosion (Table 3.1). Altitude was selected as a proxy for the difference in upland and lowland landscapes within Wales, and this would also reflect the temperature and precipitation variation that may occur. The difference in altitude within a polygon is a proxy for the slope angles that may occur, whilst mean slope within a polygon will also provide a measure of the role of slope on erosive features. Erosion in Wales is likely driven by precipitation, so its inclusion was essential. Vegetation and its cover and type are covered by the Dominant Land-use cover within a square whilst Dominant Predicted Agricultural Land Class is an example of potential land use intensity within agriculture. The bedrock and superficial geology were included as variables relating to soil parent material and hence soil properties, such as texture and drainage. The European Soil Bureau Soil parent material class from the BGS SPM dataset was selected. The use of the ESB Soil parent Material code was used in a recent report on soil formation for the Welsh Government (Tye et al., 2021) so this adds consistency with a complementary topic when assessing soil life spans. Soil texture is an important variable in relation to erosion with sandy and silty soils being prone to both wind and water erosion. These variables are outlined in Table 3.1 along with the data source.

Table 3.1: Environmental and geomorphological characteristics that polygons were joined to.

Category / Feature	**Calculated**	**Source**
Mean Altitude within Polygon	Z (masl)	Bluesky 5 m LIDAR DTM (data collected 2003-2020)
Difference in Altitude within Polygon	Zmax – Zmin (m)	Bluesky 5 m LIDAR DTM (data collected 2003-2020)
Mean Slope within Polygon	%	Bluesky 5 m LIDAR DTM (data collected 2003-2020)
Annual Precipitation	Converted to mm yr^{-1}	CHESS precipitation
Land cover within 1 km^2 square	Dominant land cover within 1 km^2 square	LCM 2015
Dominant Agricultural Land Classification	Dominant ALC within 1 km^2 square	ALC 2020 (Predictive)
Dominant Bedrock Geology	Dominant Bedrock Geology within 1 km^2 square	BGS DigMapGB-50 v8
Dominant Superficial Geology	Dominant Superficial Geology within 1 km^2 square	BGS DigMapGB-50 v8
Dominant Soil Parent Material	Dominant soil parent material classification within 1 km^2 square	BGS PMM v6.1
Dominant Soil Parent Material texture group	Dominant Soil Parent Material texture within 1 km^2 square	BGS PMM v6.1
Dominant	Dominant Soil Parent Material Estimated texture within 1 km^2 square	BGS PMM v6.1
European Soil Bureau (ESB) Parent Material Code	Dominant ESB code within 1 km^2 square	BGS PMM v6.1

4 Results

4.1 Aerial survey - What features could be identified

A total of 2580 soil erosion events were recorded from the analysis of 261 1 km x 1 km survey squares. Figure 4.1 shows examples of features found with corresponding GIS polygons marked. Not all soil erosion and disturbance features (e.g. rills, erosion under vegetation) can be identified from the analysis of aerial photographs. There is also a likely limit on the size of feature found because of pixel resolution. Types of soil erosion disturbance were limited to a number of features such as erosion scars, gullies, animal and vehicle compaction around gateways or livestock poaching features. These represent areas of at least several square meters and therefore provide a good contrast with surrounding vegetation. Sets of tram lines or animal tracks were not included in the analysis as these would have been extremely time expensive to record, and in many cases difficult to map effectively with the resolution available. As such, due to resolution issues the results may be considered a lower bound estimate with respect to the extent of disturbance within a 1 km x 1 km survey square. However, the following features were identified quite easily from the aerial photographs:

- Gateway disturbance – this includes both the gateway itself and the associated fan shape of compaction produced as animals or vehicles approach to the point of egress
- Hedge gap /wall gap disturbance – similar to above but through field hedges and walls
- Poaching around feeding areas
- Poaching where animals congregate for shelter or socializing (e.g. behind hedges or walls)
- Poaching in fields, particularly around farmyard access (e.g. where animals are congregated prior or after milking or for animal maintenance)
- General field poaching
- Terracettes
- Areas of soil / peat erosion or where bare peat is evident
- Riverbank erosion
- Silage or straw clamps with associated compaction
- Erosion - deposition fans indicating erosion in peat or soil

Figure 4.1: Examples of features recorded using polygons and aerial data. a) gateway soil disturbance from machinery and livestock and poaching around feeder; b) poaching in fields where livestock access to farmyards is required; c) gateway soil disturbance; d) area of soil erosion on very steep slope; e) area of terracettes.
Derived in part from DTM of Great Britain at 5m resolution © Bluesky International Limited

4.2 Producing a Classification Scheme

After the aerial photo survey, a defined erosion/ disturbance event classification was produced which was used as a basis for the 2021 field survey and for statistical analysis (Table 4.1). Soil erosion or disturbance events were placed in one of four major categories, these being (i) Peat Erosion Features, (ii) Soil Disturbance Features, (iii) Soil Scars or Slips and (iv) Mineral Soil features. Within these major categories a number of erosion and disturbance sub-categories were included. However, within the ‘Mineral Soil Features’ category a number of smaller scale erosion processes (e.g. rain splash or sheet erosion) were included which could be identified by field surveyors but unlikely through aerial photography. Therefore, an additional feature was included for the aerial analysis and where the erosion process could not be specifically identified called ‘Soil Erosion General’.

Table 4.1: The four major categories of erosion and their sub-groupings derived from the aerial photo survey and used in the field survey.

Peat Soil Erosion Features	**Soil Disturbance Features**	**Soil Scar or Slip**	**Mineral Soil Erosion Features**
Peat hags or peat erosion	Poaching or compaction by animals in fields or around feeders	Soil scar or slip	Rain Splash
Peat drainage Ditch erosion	Poaching or compaction around gates	Soil creep / Terracettes	Sheet erosion
Peat pipes or tunnels present	Footpath disturbance or erosion	Scree	Rill
	Substantial wheel ruts / machinery disturbance	Landslides or other mass movements	Gully
	Tree root scars		Tillage
			Riverbank erosion
			Drainage Ditch
			Coastal
			Soil pipes
			Muddy outwash onto roads
			Soil Erosion General

4.3 Analysis of soil erosion features – frequency of recorded soil erosion events in the 4 major categories

This analysis is a high-level analysis of the number of events in each major soil erosion / disturbance category as laid out in Table 4.1. The data is visualised in Figure 4.2 and summarised in Table 4.2. Events relating to processes in the 'Soil Disturbance' class were the dominant events recorded from the aerial survey. These accounted for 76 % of the recorded events, whilst those for 'Peat Erosion', 'Mass Movement' and 'Mineral Soil Erosion' accounted for 9.3%, 10.3% and 4.3% respectively.

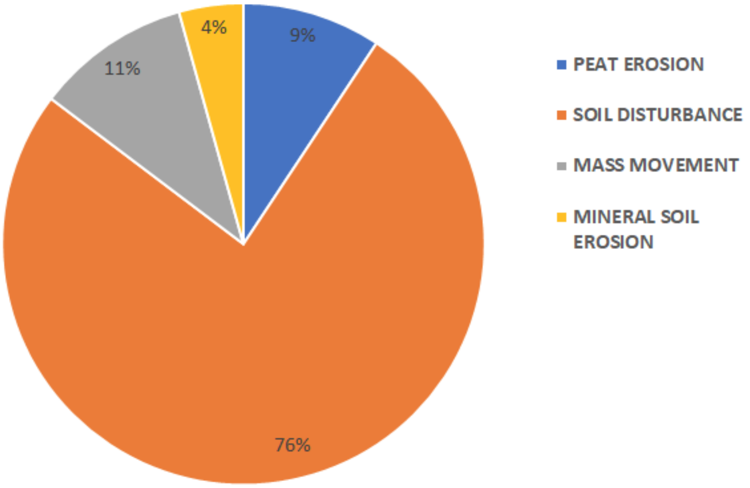


Figure 4.2: Numbers of soil erosion or disturbance events recorded in the aerial survey under the four major erosion categories

Table 4.2: Number of events and percentages of the total number of events of soil erosion or disturbance recorded in the aerial photographs for the 4 top level categories

	Aerial Survey			
	Mineral	Mass	Peat	Disturbance
N = 2580	111	268	240	1961
% events	4	11	9	76

4.4 Numbers of soil erosion events recorded for each process occurring in each of the 4 major categories

The next level of analysis breaks down each of the four major soil erosion/ disturbance groups into their sub-categories (Table 4.1). For 'Peat Erosion' (Figure 4.3) which accounted for 240 soil erosion events, the vast majority (213) were identified as peat hags or peat erosion. A smaller number of events (27) occurred around peat drainage areas, drains or ditches. In Figure 4.4 the number of events associated with each sub-category of 'Soil disturbance' are reported. Two sub-categories accounted for 91% of the total events recorded, these being (i) poaching or compaction around gates (48%) and (ii) poaching or compaction around field feeders (43%). For the 'Mass Movement' category the number of events are dominated by 'soil scarring and slips' and 'soil creep and terracettes' sub-categories (Figure 4.5). For the 'Mineral Soil Erosion' category the major sub-category is 'General Soil Erosion' which accounted for 57% of events. This reflects the inability of the aerial survey to identify the cause of erosion although identification was made often through identifying the variation in soil colouring within deposition zones. Tables 4.3-4.6 summarise the number of events and their percentage values.

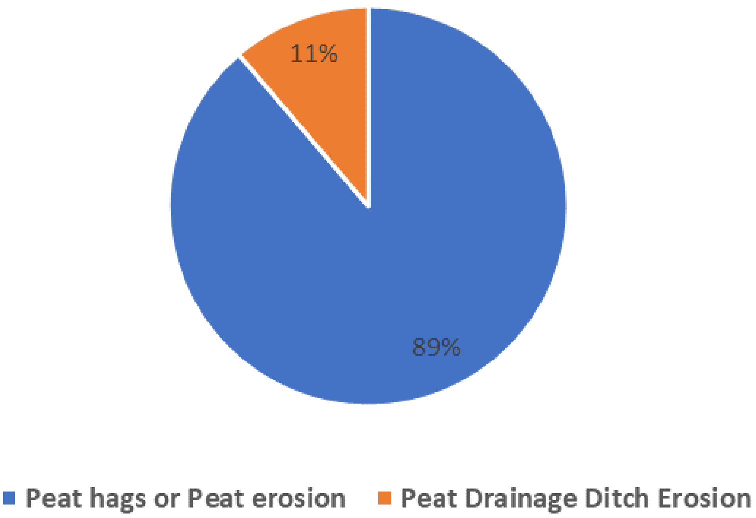


Figure 4.3: Numbers of events recorded in the sub-categories of 'Peat Erosion'

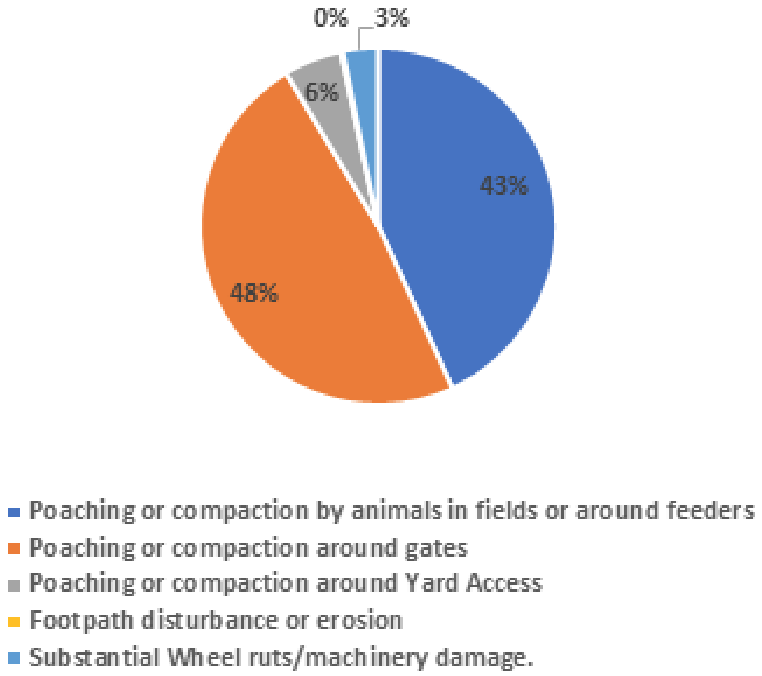


Figure 4.4: Numbers of events recorded in the sub-categories of 'Soil disturbance'

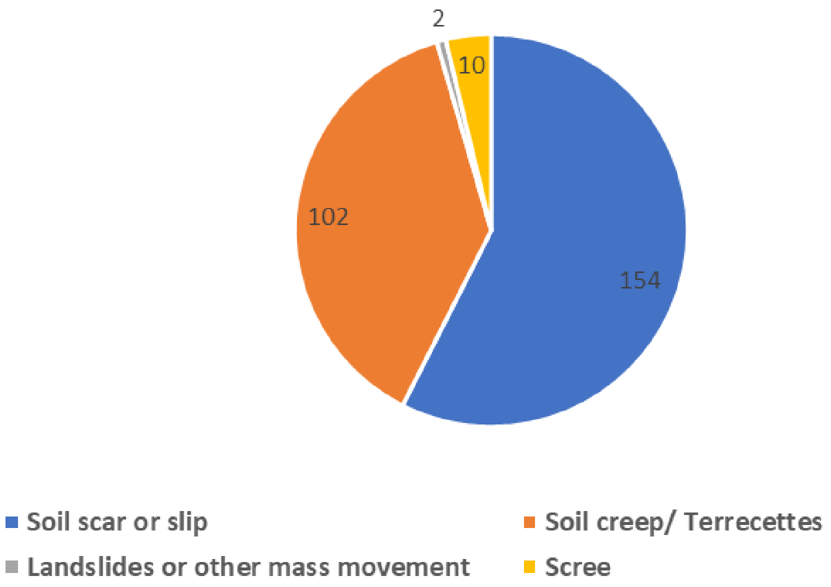


Figure 4.5: Numbers of events recorded in the sub-categories of 'Mass Movement'

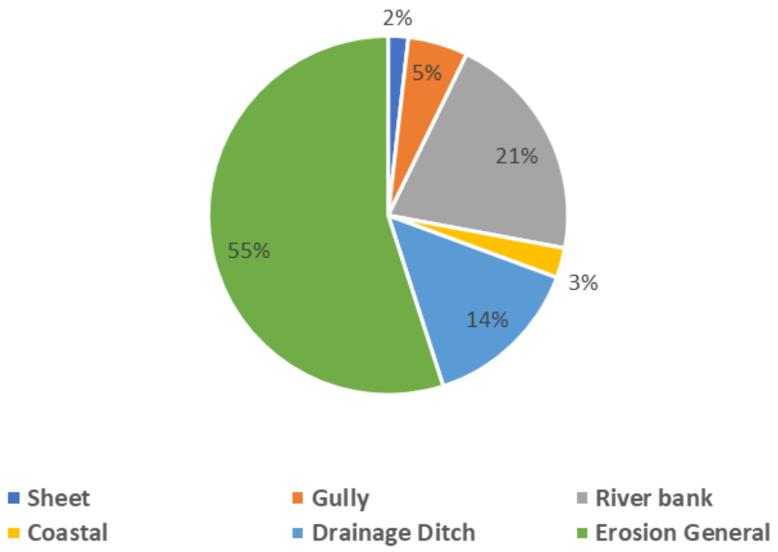


Figure 4.6: Numbers of events recorded in the sub-categories of 'Mineral Soil Erosion'

Table 4.3: Percentages of soil erosion or disturbance for Peat

	Aerial Survey	
	Peat Drainage	**Peat hags or erosion**
n	27	213
% events	11	89

Table 4.4: Percentages of soil erosion or disturbance for Mass Movement

			Aerial Survey	
	Landslides	**Scree**	**Soil creep / Terracettes**	**Soil scar or slip**
n	2	10	102	154
% events	1	4	38	57

Table 4.5: Percentages of soil erosion or disturbance for Soil disturbance

			Aerial Survey		
	Footpath	**Poaching gates**	**Poaching Yard**	**Poaching Feeders**	**Substantial Vehicle**
n	4	945	103	847	62
% events	<1	48	6	43	3

Table 4.6: Percentages of soil erosion or disturbance for Mineral Soil Erosion

			Aerial Survey		
	Coastal	**Drainage Ditch Erosion**	**Gully**	**Riverbank**	**General soil erosion**
n	3	16	6	23	63
% events	3	14	5	21	57

4.4.1 Key analysis points

- The analysis showed that soil disturbance was far greater in prevalence than what is typically described as soil erosion. This reflects Welsh agriculture being largely animal based and that arable land only accounts for ~11% of the land.
- Poaching was the most frequent soil disturbance activity and was linked to feeding and shelter areas as well as activities involved in movement and grazing. Disturbance around gates was an issue but these also involve vehicular movements.

4.5 Drivers of soil erosion and disturbance and the number of events

Having summarised the number and type of events in each of the 4 categories of soil erosion and disturbance, we assess the data in terms of those variables typically considered to be drivers of soil erosion and disturbance. These include soil parent material and texture, precipitation, slope characteristics and vegetation coverage. The following section reviews the number of events in relation to these properties.

4.6 The role of soil parent material class on erosion events

The ESB soil parent material code allows us to consider the bedrock and superficial geology and its influence on erosion. It is a simplified indicator of soil parent material and is preferred to using separate geological classifications. The ESB definitions are presented in Table 4.7, along with the spatial extent each ESB class occupies in Wales (from Tye et al. 2021). Figure 4.7 shows a map of the distribution of ESB class taken from Tye et al. (2021). The dominant ESB types are class 100 (48%), those soils forming from consolidated clastic sedimentary rocks (e.g. sandstones and mudstones) and class 600 (31.7%) which are the soils formed from glacial deposits and drift. Soils formed from organic materials, Class 800 (Peat), occupy 1.1 %, but many organo-mineral soils exist in the classes 100 and 600 (See Tye et al. 2021).

Table 4.7: Classification of ESB classes and the extent of area they occupy in Wales

ESB Class	**Parent Material Major class**	Extent (%)
100	Consolidated clastic sedimentary rocks	48
200	Sedimentary rocks (chemically precipitated, evaporated, or of organo-genic or biogenic origin)	2.4
300	Igneous rocks	1.7
400	Metamorphic rocks	0.2
500	Unconsolidated deposits (alluvium, weathering residuum and slope deposits)	3.5
600	Unconsolidated glacial deposits / glacial drift	31.7
700	Aeolian deposits	0.1
800	Organic materials	1.1
900	Anthropogenic deposits	NA

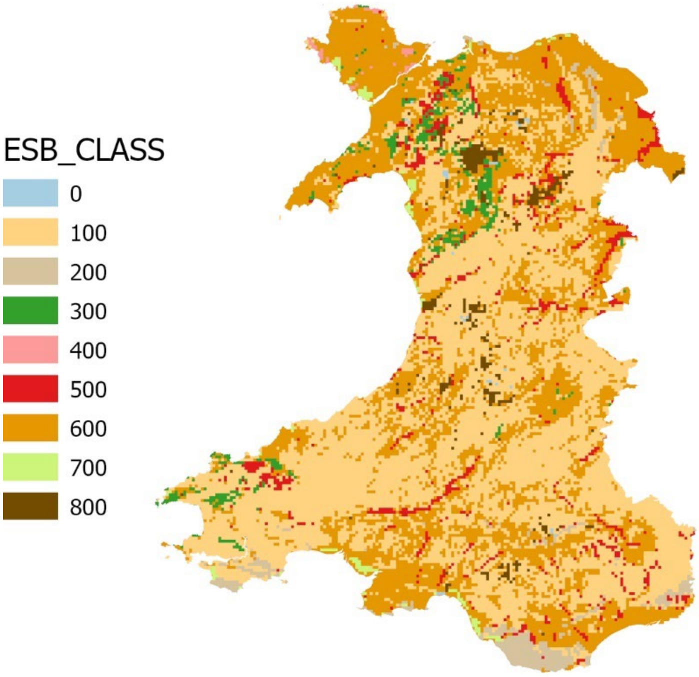


Figure 4.7: The distribution in Wales of Soil Parent Materials based on the classification by the European Bureau of Soils. See Table 4.7 for definitions.
Contains BGS Geology Data © UKRI

The following graphs examine the co-occurrence of soil parent material class (ESB) and the number of soil erosion events recorded under the 4 major erosion and disturbance classes. Figure 4.8 shows the results for the 'Peat Erosion' category and it is apparent that the aerial survey analysis was not restricted to Class 800, but also included contributions from the other ESB types. This suggests that when classifying the erosion types during the aerial photo survey, some organo-mineral soils were likely included as peat due to the colour (difficult to differentiate peat and a top of organo-mineral soil), or that the ESB classification mapping is of a lower resolution than the photos. For those designated as 'peat' soils (ESB 800) the majority of the events recorded were of peat hags or peat erosion. ESB classes 100, 600 and 800 all had some erosion around peat-based drainage channels, and these are also likely to include organo-mineral soils.

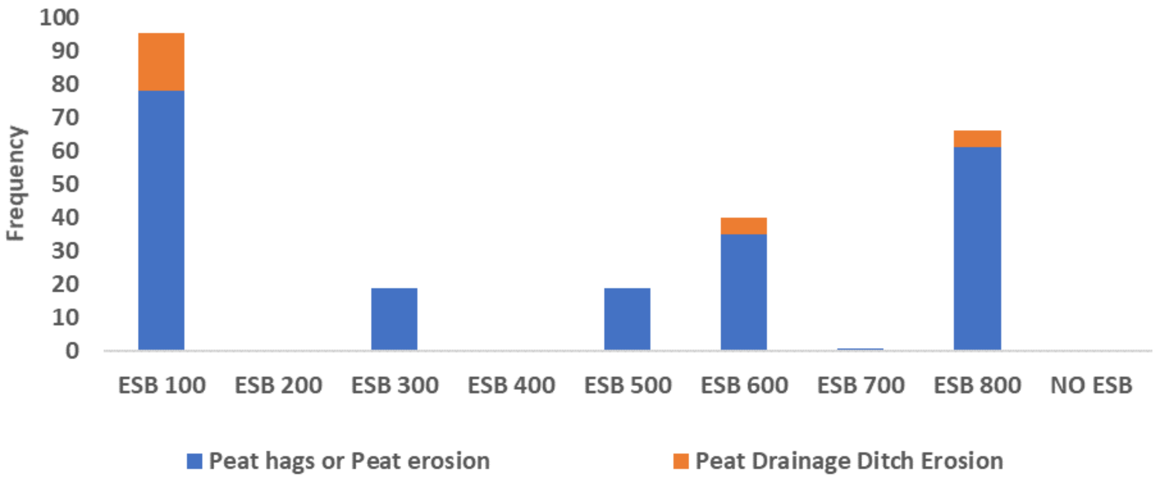


Figure 4.8: Number of events associated with ESB classification found for the Peat Erosion category, Frequency scale 0-100

For the ‘Soil Disturbance’ category, ESB groups 100 and 600 had the greatest frequency of events, reflecting the area they cover within Wales (Figure 4.9). Poaching around gates and feeders were by far the most common soil erosion events and were roughly equal between the two parent material types, with approximately 400 of each event type identified. Poaching was also identified on peat soils (ESB500) whilst it occurred with low frequency in the other, spatially restricted soil parent material types.

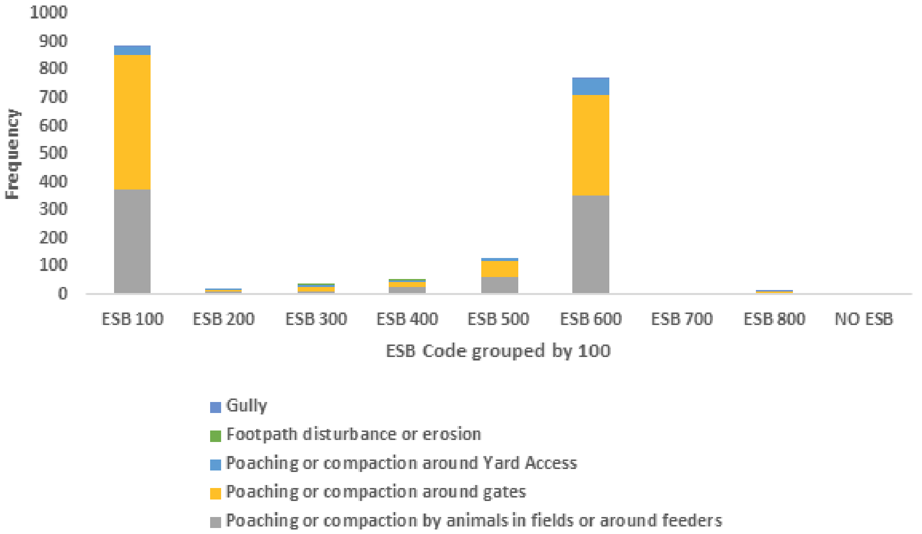


Figure 4.9: Number of events associated with ESB classification found for the Soil Disturbance category. Frequency scale 0-1000

For the ‘Mass Movement’ erosion category (Figure 4.10), ESB groups 100 and 600 dominated, although the ESB 100 class had almost double the number of events recorded (~160). This may indicate that the clastic sedimentary rocks may produce steeper slopes, producing greater soil scaring and soil creep/terracettes. This was investigated further and Figure 4.11 shows the distribution of events relating to ESB soil parent material type and slope (%). It can be seen that mass movement events occur at steeper angles and that events are dominated by ESB group 100.

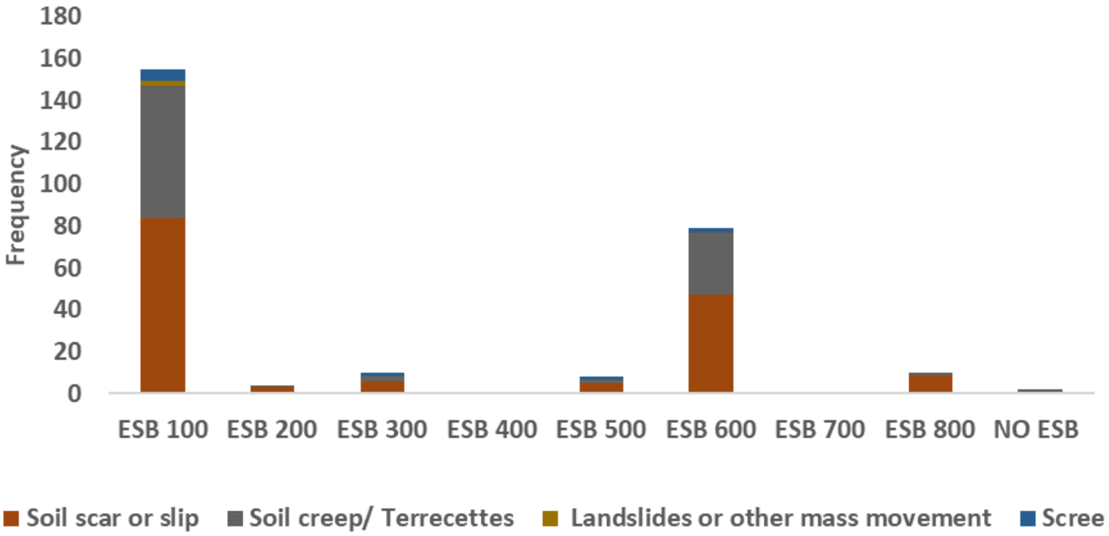


Figure 4.10: Number of events associated with ESB classification found for the Mass movement category; Frequency scale 0-180

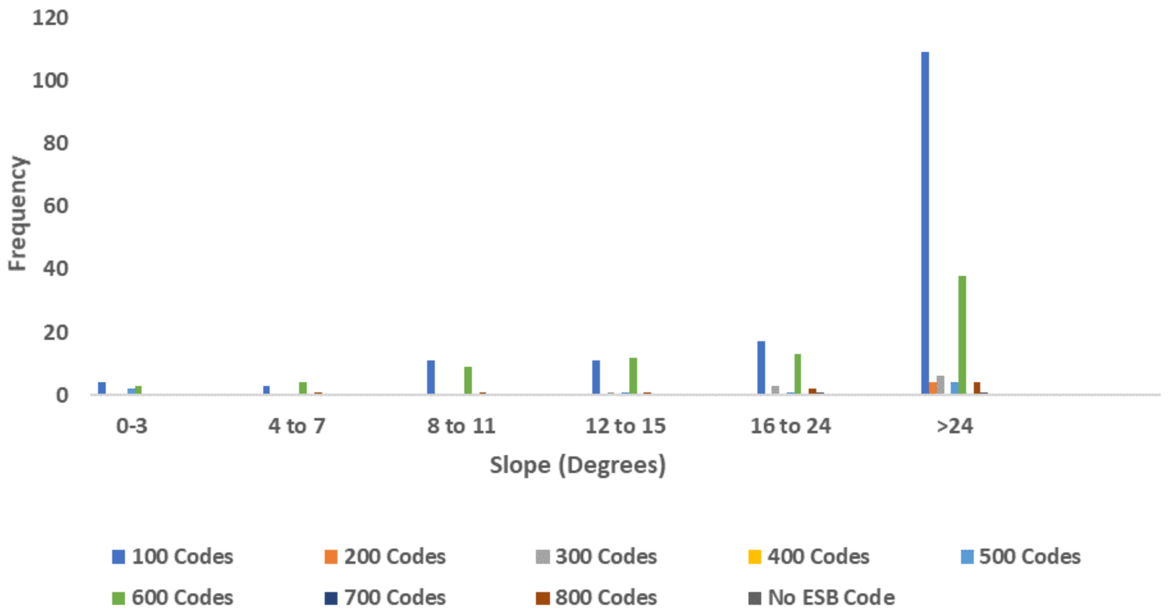


Figure 4.11: Frequency of 'Mass Movement' events occurring at different slope angles showing that the 100 code is predominantly the ESB soil parent material type where these events occur and particularly at angles > 24 degrees; Frequency scale: 0-120

Figure 4.12 shows a similar analysis for the 'Mineral Soil Erosion' category. Again, the frequency of soil erosion events is higher in ESB classes 100 and 600 because of their spatial dominance, with about 40 events occurring in both. The relatively low number of events recorded possibly reflects the high proportion of grassland in Wales (80%) and the low acreage of arable agriculture. Whilst a range of soil erosion processes were identified by the aerial survey, the difficulty in identifying specific erosion processes meant the highest numbers of events were found in the 'General Soil Erosion' sub-category. Sheet erosion was recognised within the aerial photos generally by locating deposition zones which were more recognisable. The ESB 500 class (alluvium) picks out riverbank erosion as the dominant feature.

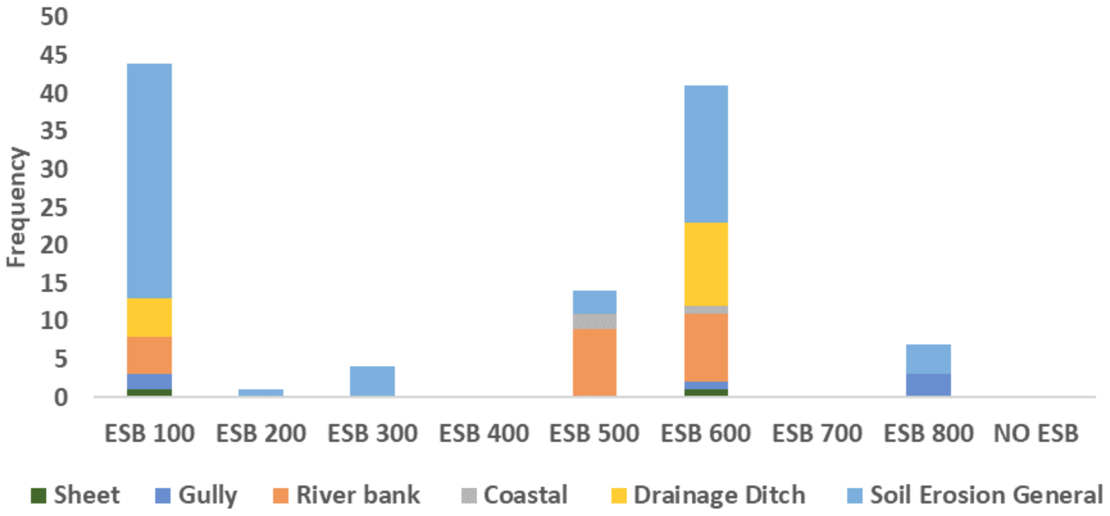


Figure 4.12: Number of events associated with ESB classification found for the Mineral soil erosion category; Frequency scale 0-50

4.6.1 Key analysis points

- The number of erosion events, for each of the 4 major soil erosion categories reflects the spatial distribution of the dominant ESB soil parent material classes (ESB 100 and 600) with peat dominant in ESB 500.
- For mass movement events, ESB class 100 dominates especially at steeper angles, possibly reflecting the geomorphology existing where soils are derived from bedrock in Wales.

4.7 The role of soil texture on erosion events

Soil texture is a function of soil parent material and also a key determinant on soil erosion, with silt and sandy textures being at greater risk of wind and water driven processes. The following plots show the number of soil erosion events which were associated with soil textures classes obtained from the BGS Soil Parent Material database for each sub-category of the 4 main types of soil erosion / disturbance. The number of events to a degree will reflect the texture of soils in the dominant ESB classes 100 and 600. As the majority of the bedrock in Wales is of sandstone or mudstone origin, the ESB classes 100 are likely to be dominated by 'loam' or 'loam > clay' soils. This bedrock geology will also be reflected in the ESB 500 and 600 soil parent material classes as they originate from bed rock via erosion and deposition processes. In Figures 4.13 - 4.16 this is demonstrated. However, this is possibly less a reflection on the nature of the soil's comparative erodibility but more a reflection on their spatial dominance of the Welsh Landscape. For the 'Peat Erosion' category there is a wide distribution of textural types possibly reflecting the inclusion of 'organo-mineral soils'. The 'Peat Erosion' category also includes the textural assignment to 'ALL'. As it is an organic soil, the 'All' category is typically assigned as any mineral contribution from the bedrock is often unknown.

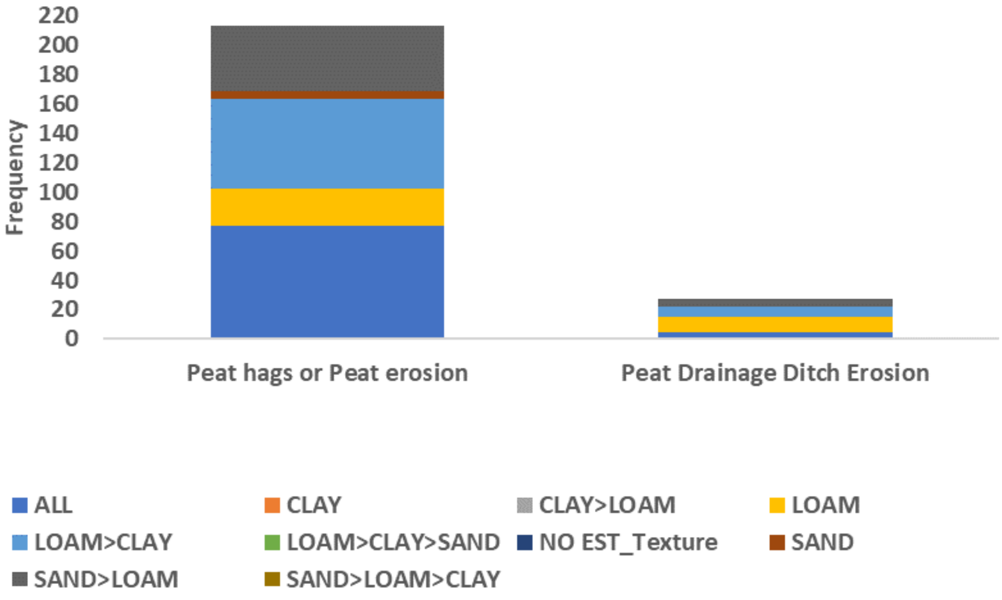


Figure 4.13: Number of erosion or disturbance events associated with soil texture recorded for each of the sub-categories of Peat Erosion; Frequency scale: 0-220

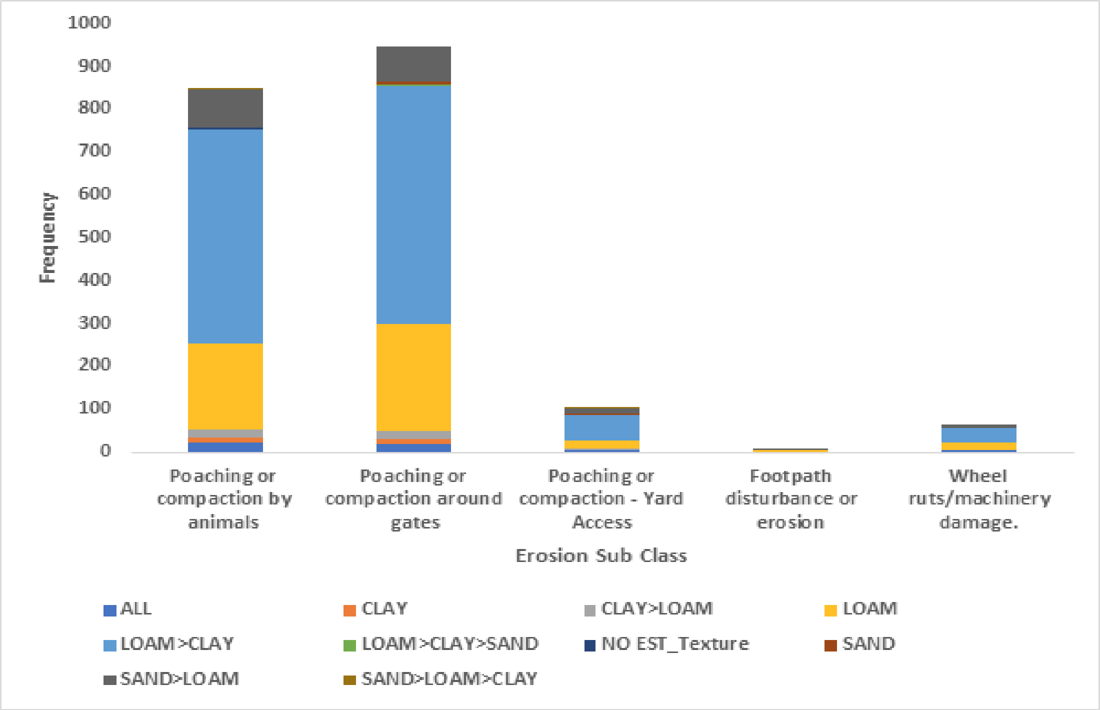


Figure 4.14: Number of erosion or disturbance events associated with soil texture recorded for each of the sub-categories of Soil Disturbance; Frequency scale 0-950

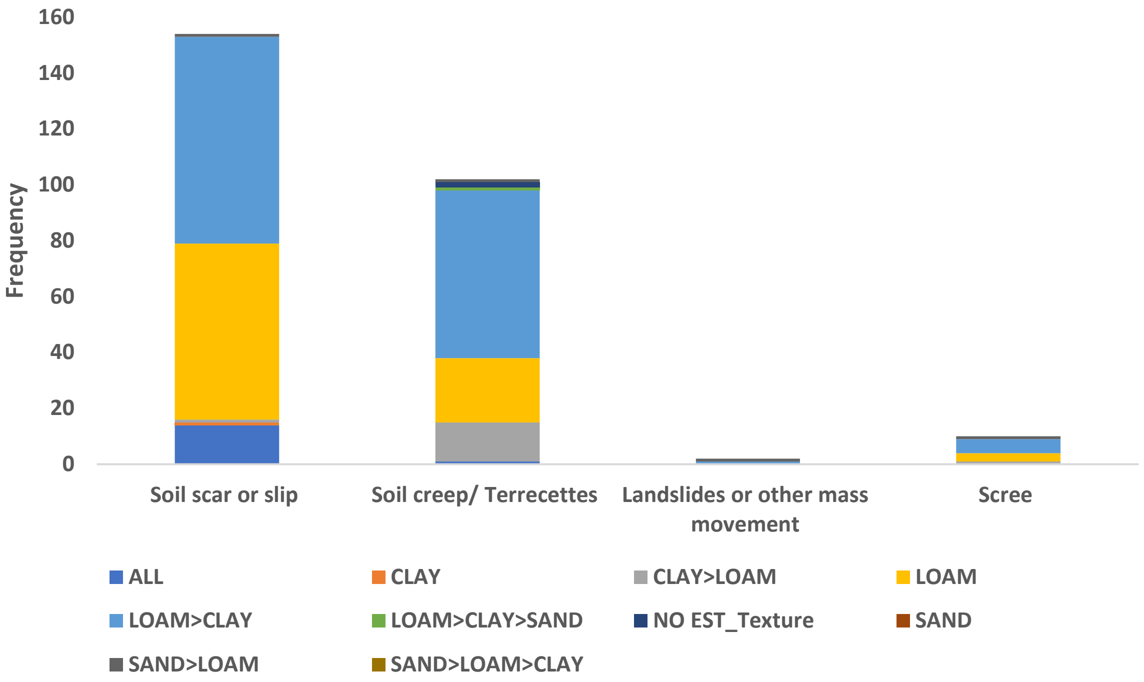


Figure 4.15: Number of erosion or disturbance events associated with soil texture recorded for each of the sub-categories of Mass Movement; Frequency scale: 0-160

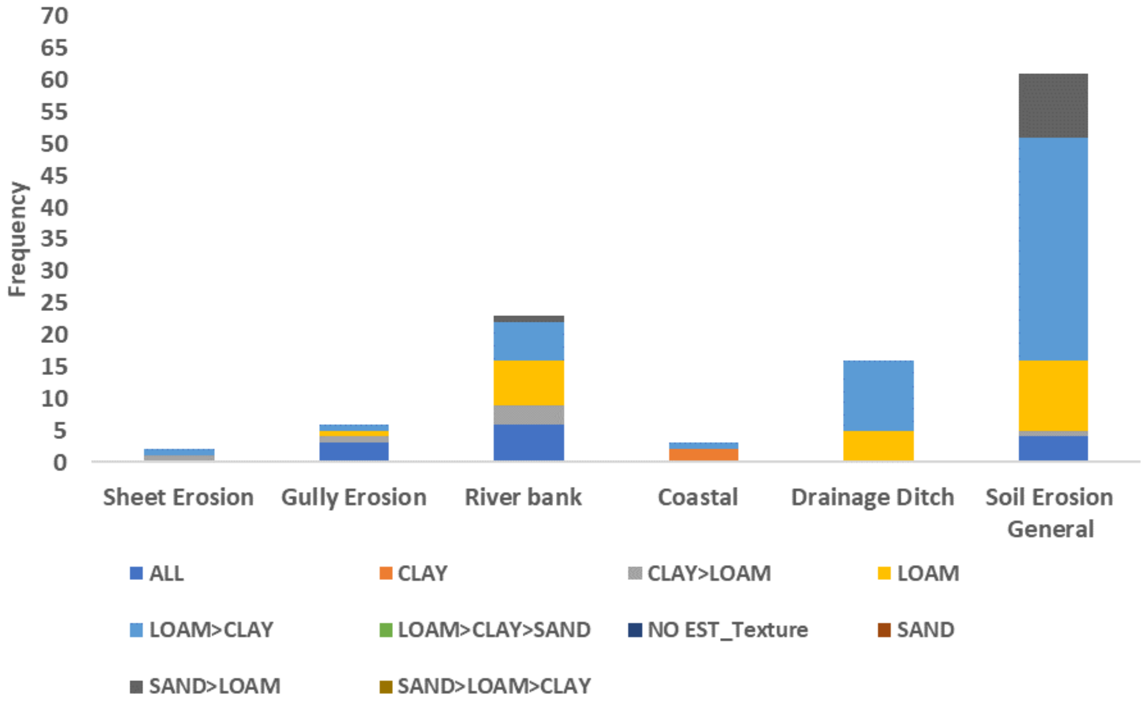


Figure 4.16: Number of erosion or disturbance events associated with soil texture recorded for each of the sub-categories of Mineral Soil Erosion; Frequency scale: 0-70

4.7.1 Key analysis point

- Soil texture is a key determinant on soil erosion and disturbance. Relatively few events were identified on light (e.g. sandy) soils as they are spatially small and few of the selected squares were on these soil types. As expected, most erosion events were recorded on 'Loam > clay' and 'Loam' categories as these are dominant spatially.

4.8 The Role of altitude on erosion events

The role of altitude on erosion is probably less well defined as a variable within general soil erosion analysis. However, it can act as a proxy, particularly in Wales, for the intensity of land use, vegetation coverage and recovery time after disturbance, in addition to a potential indicator that slope angle may increase with altitude. The average altitude of Wales is 494 m, with much (>50 %) of the land being >200 m (Rudeforth, 1984). Figure 4.17 shows a histogram describing the frequency of the 261 squares found at different altitudes. This was calculated as a mean of the altitudes of each polygon in each square and provides an indication of altitude for each square. It is worth considering the number of squares in each altitude class when examining the results because there were less squares examined at higher altitudes and recognising this may provide a better understanding of the data.

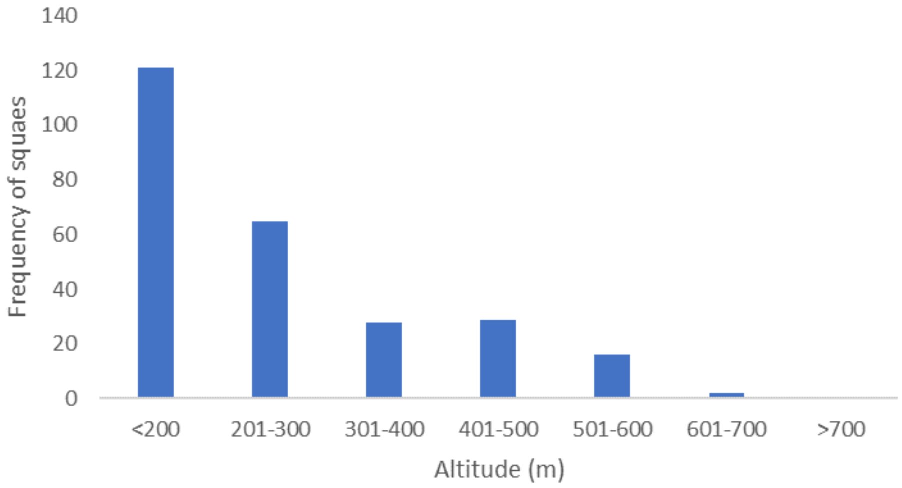


Figure 4.17: Frequency of squares assessed at each altitude step

For ‘Peat Erosion’ events (Figure 4.18), where more peat is likely to be found at higher altitude, the greatest number of events were found between 401-600 m, although only about 50 squares were examined at these altitudes. Few ‘Peat Erosion’ events were found at low altitudes reflecting the spatial distribution of peat formation (or organo-mineral soils), and the annual precipitation amounts required for peat or organo-mineral soils to form. At higher altitudes the landscape is possibly rockier and with greater slopes, which would limit peat formation, but few survey squares were located at these altitudes.

For ‘Soil Disturbance’ events, the frequency of soil erosion events recorded at lower altitudes (Figure 4.19) was much higher than at high altitudes. Poaching around gates and feeders are the main categories found. These results appear to reflect the more intensive agricultural practices at lower altitudes, including greater stocking numbers and the greater vehicular and traffic movements which disturb or compact soils. Potentially at higher altitudes the animal stocking rates are less but also it should be considered that the less managed vegetation may also hide soil disturbance from aerial survey. This may be picked up by the walk-on-survey. Overall, this relationship between soil disturbance events and altitude seems appropriate.

For ‘Mass Movement’ events, the greatest frequency of soil erosion events was at altitudes below 500 m, possibly a reflection of the average altitude, but also possibly that less squares at higher altitude were selected for survey (Figure 4.20). The interesting feature was that soil creep and terracettes dominated at low altitudes, whilst an increase in soil scarring and slipping occurred above 300 m; this possibly reflects the rainfall gradient with altitude in Wales. Wetter soils will have increased pore water pressure potentially leading to soil slippage. This may occur in conjunction with a greater number of steep slopes (see ESB 100 discussion earlier) and possibly less dense vegetation cover occurring as altitude became higher.

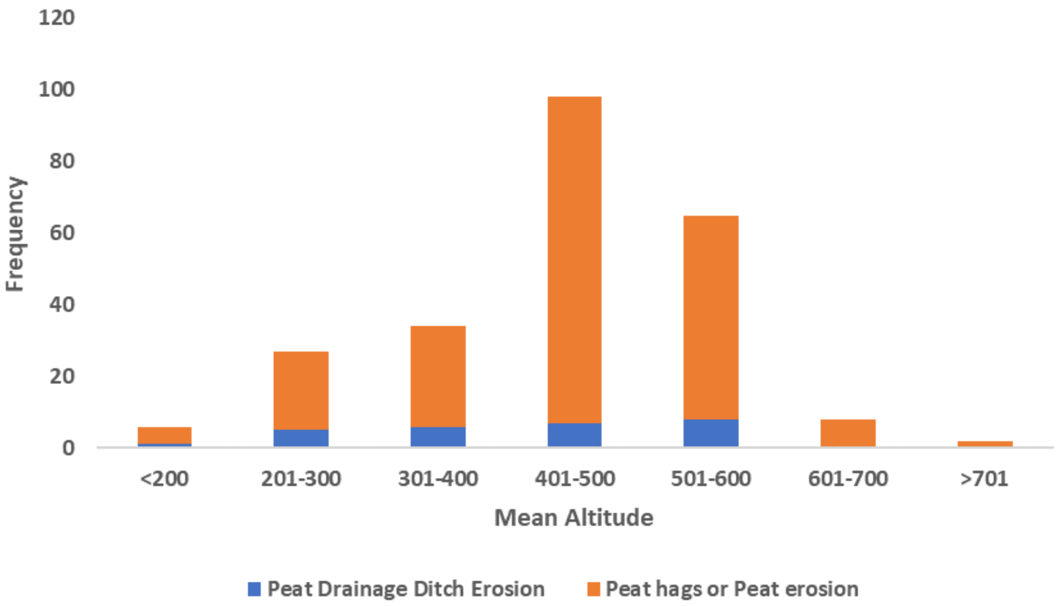


Figure 4.18: The role of altitude on the frequency of 'Peat Erosion' events recorded; Frequency scale: 0-120

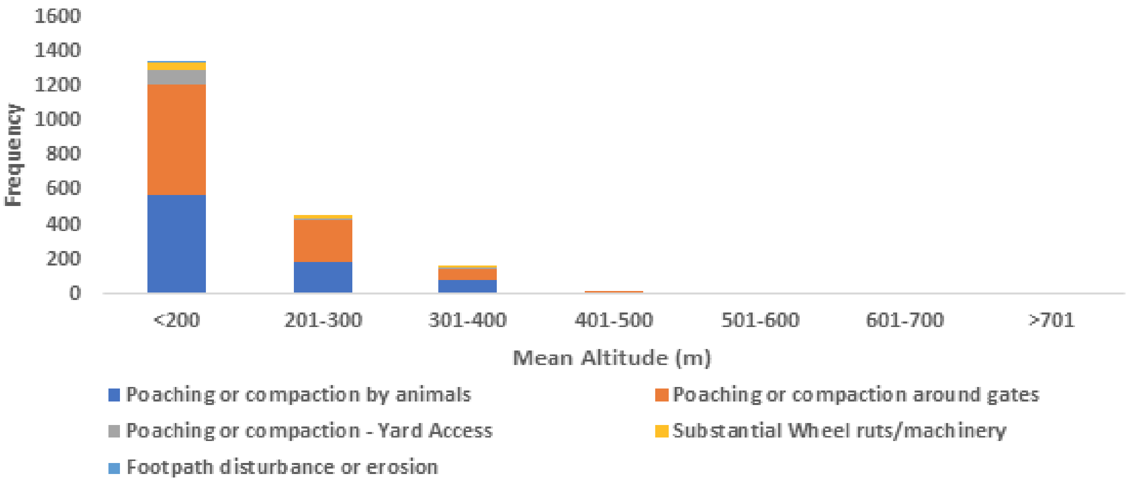


Figure 4.19: The role of altitude on the frequency of 'Soil Disturbance' events; Frequency scale: 0-1600

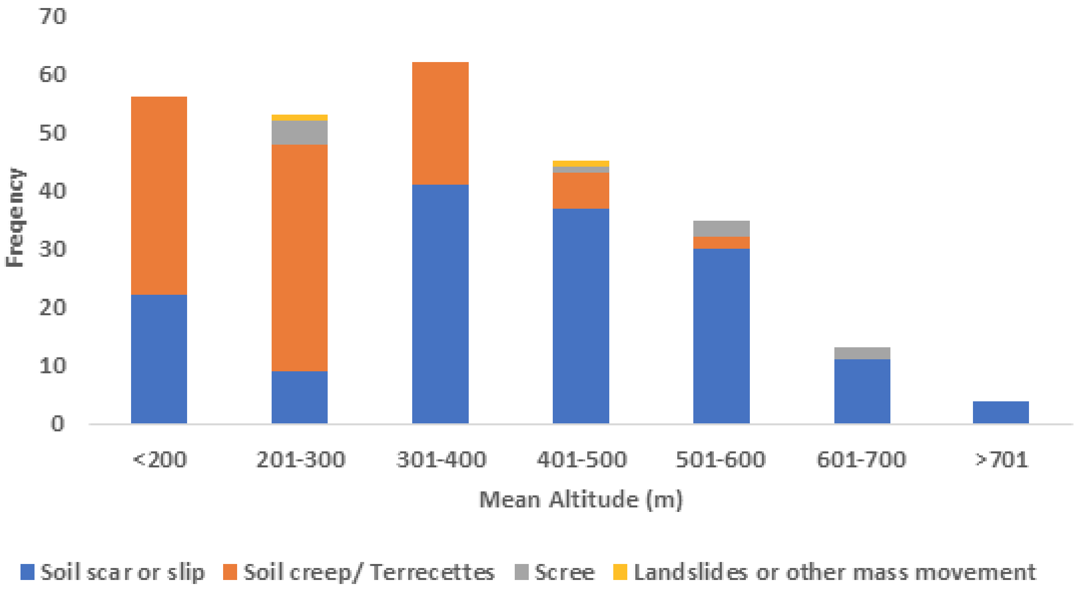


Figure 4.20: The role of altitude on the frequency of 'Mass Movement' events; Frequency scale 0-70

The number of 'Mineral Soil' erosion events appear to be fairly consistent with altitude up to about 500 m. Above this height the number of events drops off and the nature of events changes to 'general soil erosion'. None of the other erosion categories are found above this height, possibly reflecting the land use intensity, landcover and ecosystem type.

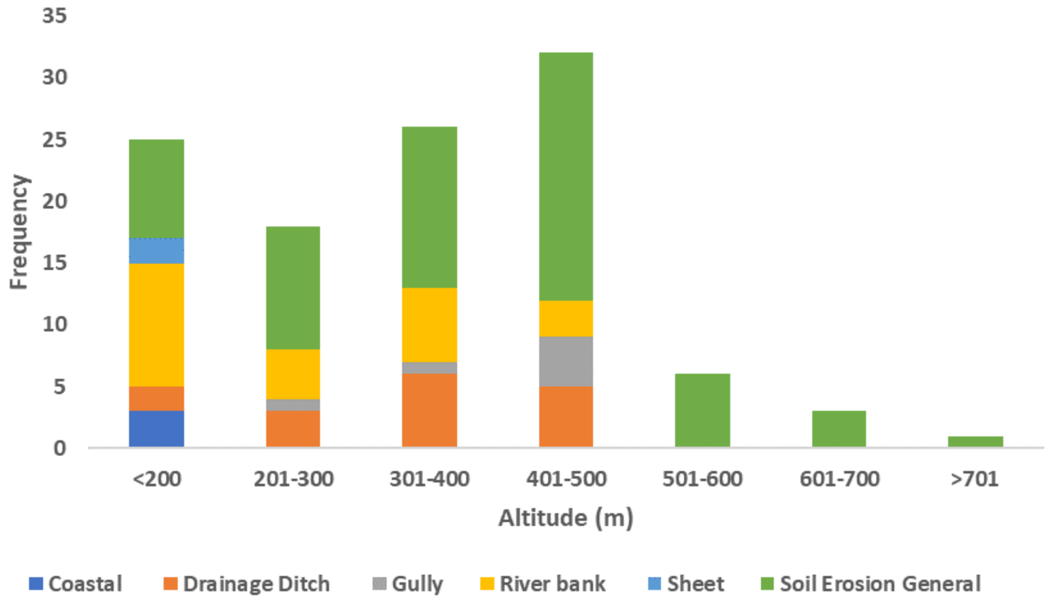


Figure 4.21: The role of altitude on the frequency of 'Mineral Soil Erosion' events; Frequency scale 0-35

4.8.1 Key analysis points

- Altitude showed different effects for each of the four major soil erosion/disturbance categories. For soil disturbance it was very focused towards lower altitudes where land use is more intensive.
- The number of soil erosion events dropped off with greater altitude and this may reflect the lower number of squares at the highest altitudes.

4.9 The Role of mean slope on soil erosion events

Slope is a key factor in soil erosion equations, both its angle and slope length. Erosion events have been split up into 5 slope categories. These are shown in Figure 4.22, to provide the reader with an indication of the slope that is being discussed. Graphs show average slope within a polygon expressed in %.

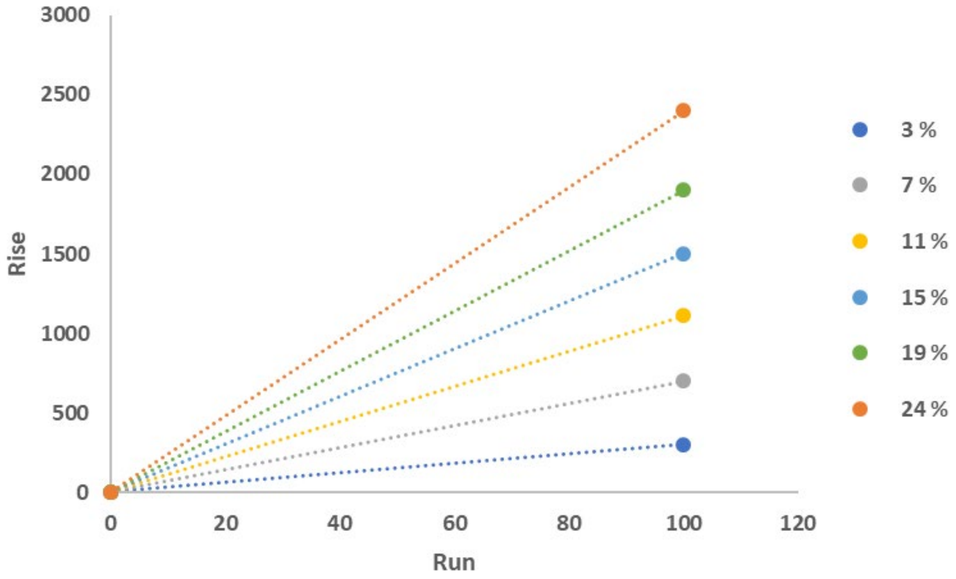


Figure 4.22: Demonstration of slope angles used in categories of erosion analysis

Key points to pull out from the analysis of this factor with respect to the aerial survey are as follows. For ‘Peat Erosion’ (Figure 4.23) fewer events occurred between 0-3% slopes which may be expected, as peat formation is likely to occur where there is low drainage and shallow slopes. However, a spike in events occurred at 3.01 - 7%, with almost double the number of events suggesting much peat may be vulnerable at these slope angles. However, if we also consider that some events may be on organo-mineral soils (see Section 4.6), this may reflect a greater land use intensity. At higher angles a question remains as whether these events are occurring on organo-mineral soils mapped as peat or that the events are occurring at the edges of peat deposits, where bog drainage is occurring.

The frequency of ‘Soil Disturbance’ events showed a peak between 3.01 – 7 % before declining as slope angle increased, with ‘poaching around feeders’ and ‘poaching or compaction around gates’ being dominant at each slope category. The pattern of the number of soil disturbance events steadily declining with increasing slope suggests that many feeders and gates are normally placed where slope angles are low. They may also indicate less intensification of land use as slopes increase (Figure 4.24).

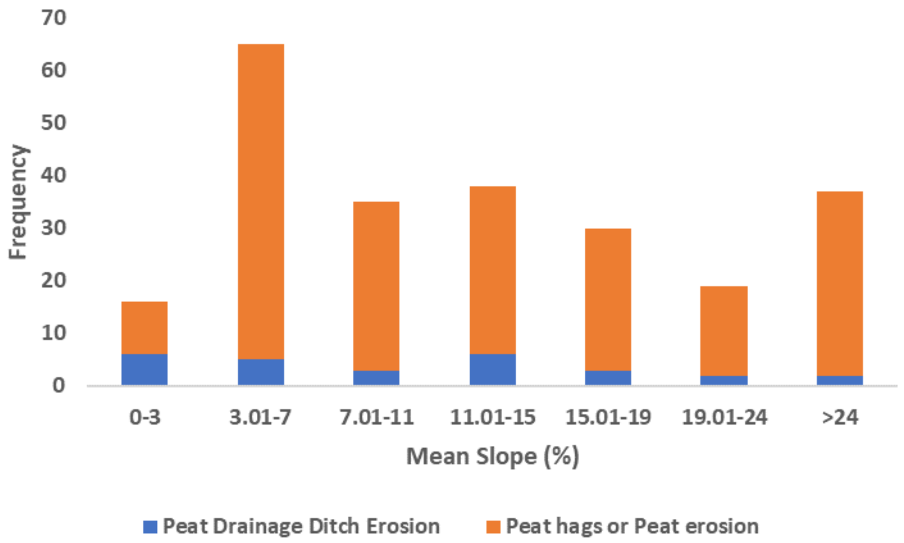


Figure 4.23: The occurance of mean slope (%) within a polygon with the frequency and type of recorded 'Peat Erosion' events; Frequency scale: 0-70

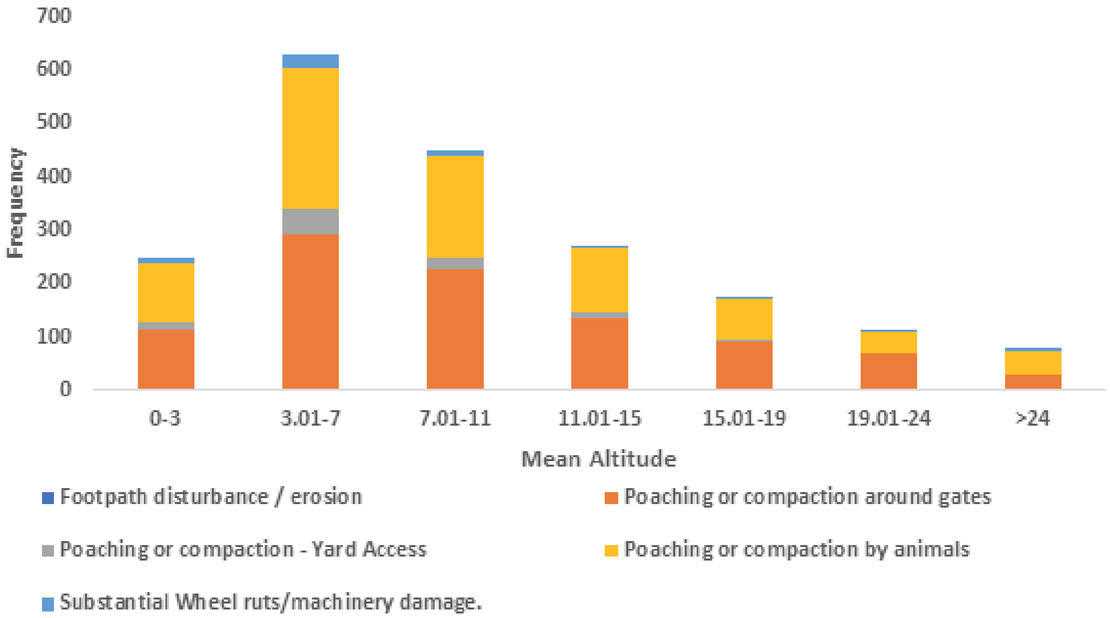


Figure 4.24: The occurrence of mean slope (%) within a polygon with the frequency and type of recorded 'Soil Disturbance' events; Frequency scale: 0-700

The number of 'Mass Movement' events (Figure 4.25) showed a steep increase at slope angles > 24 %. A similar number of 'soil scars or slips' as there were 'soil creep and terracettes' were found. In lesser slope categories 'soil scars' and 'soil slips' dominated, demonstrating that steep slope angles are required for soil creep and terracettes to start forming.

The slopes at which 'Mineral Soil Erosion' events (Figure 4.26) occurred reflected the role slope would be considered to play. Riverbank erosion dominated at the lower slope angles possibly reflecting animal access and 'general soil erosion' tripled in frequency when slopes became > 24%.

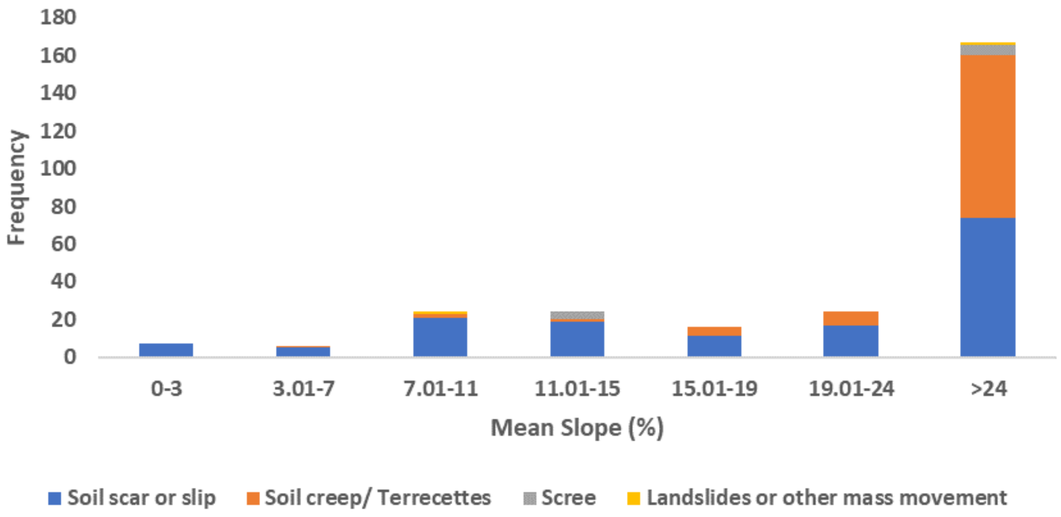


Figure 4.25: The occurrence of mean slope (%) within a polygon with the frequency and type of recorded 'Mass Movement' erosion events; Frequency scale: 0-180

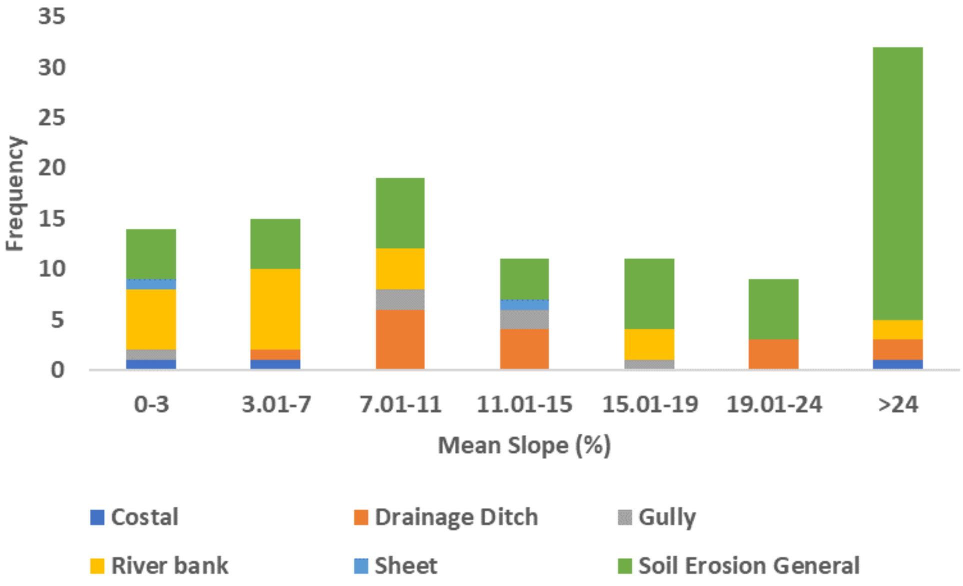


Figure 4.26: The occurrence of mean slope (%) within a polygon with the frequency and type of recorded 'Mineral Soil Erosion' events; Frequency scale: 0-35

4.9.1 Key analysis points

- Slope appeared to be a key determinant on the frequency of soil erosion and disturbance events. Higher slope angles (>24%) appeared to be important for 'peat', 'mineral soil erosion' and 'mass movement' events.

- The frequency of events at low slope angles for soil disturbance reflected the intensification of land use at lower slope angles.

4.10 Role of precipitation on number of soil erosion events

One of the principal drivers of erosion in soils is precipitation, which combines with slope characteristics, soil texture and vegetation in determining erosion extent. Within the survey few events were recorded where precipitation was below 1500 mm yr^{-1}. The dryer (<1000 mm yr^{-1}) parts of Wales tend to lie along the Wales – England border where few squares were analysed. For 'Soil Disturbance', the poaching and disturbance of soils may allow accumulation of water. This may lead to slower infiltration of precipitation, resulting in vegetation being slower to recover and animals increasing the size of disturbed area by avoiding wet areas. For the 'Peat Erosion' category most events occurred when precipitation was > 3000 mm yr^{-1}, reflecting the requirement for high precipitation for peat formation (Figure 4.27). For the 'Soil Disturbance' category, most events occurred when annual precipitation was between 1500 and 2500 mm yr^{-1}, suggesting that these precipitation amounts coincide with where land used is most intensified (Figure 4.28). Poaching was dominant in all precipitation categories. 'Mass Movement' events increased at annual precipitation values >2000 mm yr^{-1}. Between 2000 and 2500 mm yr^{-1} soil creep and terracettes dominated but above these precipitation levels, soil slips and scars dominated each precipitation class suggesting that differences in porewater pressure result in different types of events. For the 'Mineral Soil Erosion' category, no real patterns were found between erosion types but as annual precipitation increased, an increase in erosion events was generally found (Figure 4.30).

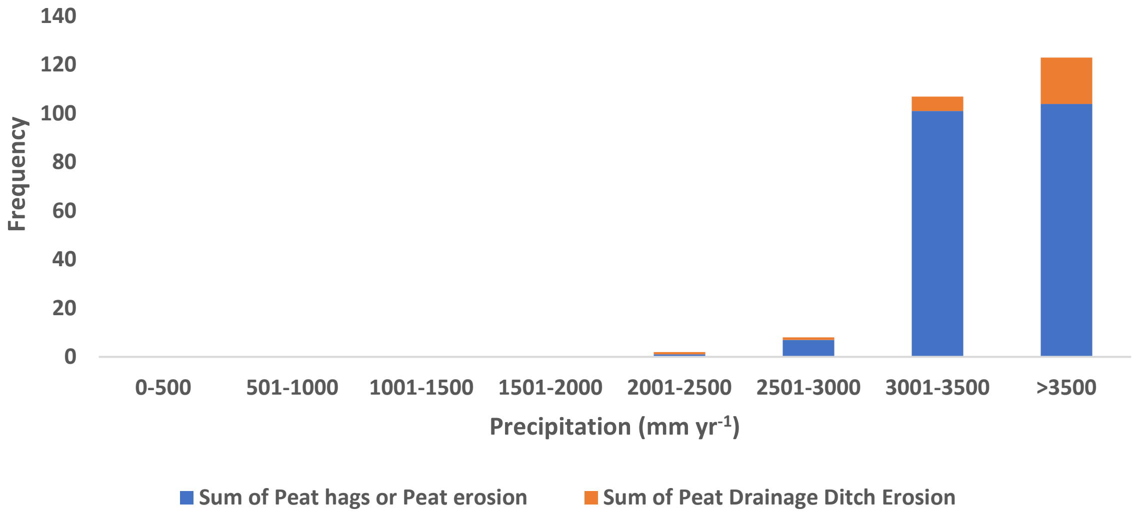


Figure 4.27: Precipitation classes and the frequency of erosion or disturbance events of the 'Peat Erosion' category; Frequency scale: 0-140

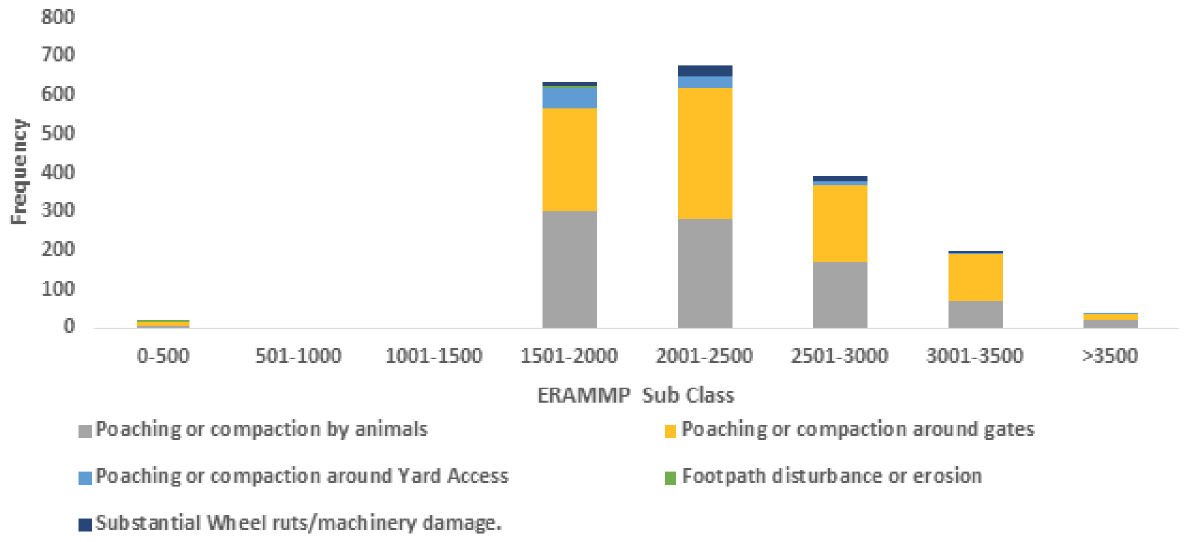


Figure 4.28: Precipitation classes and the frequency of erosion or disturbance events for the 'Soil Disturbance' category; Frequency scale: 0-800

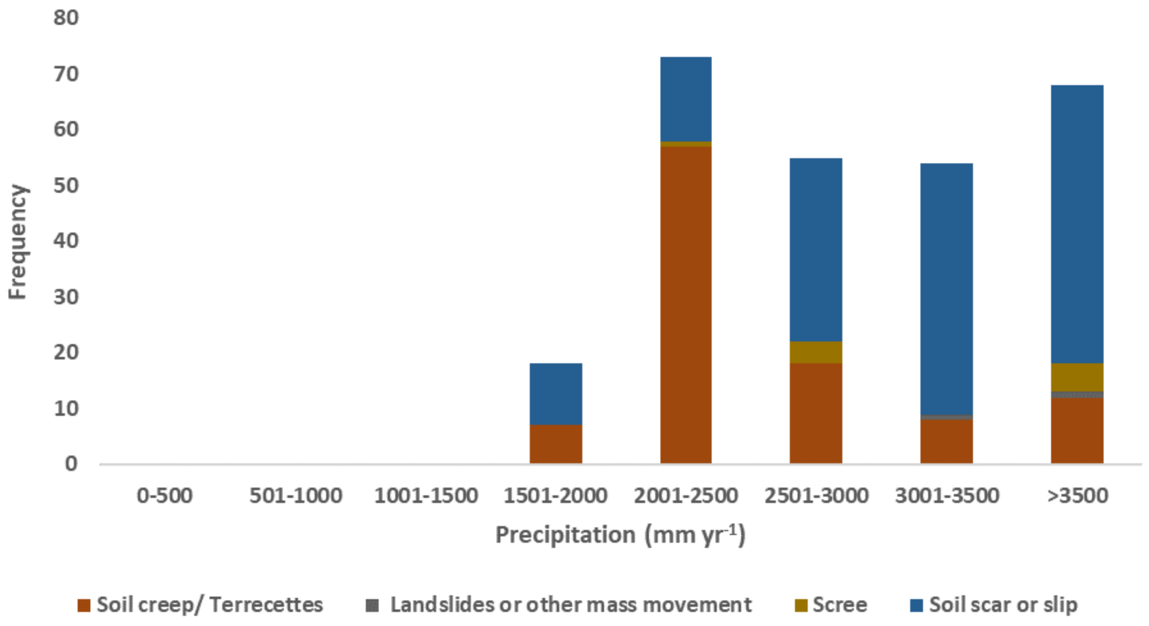


Figure 4.29: Precipitation classes and the frequency of erosion or disturbance events for the 'Mass Movement' category.

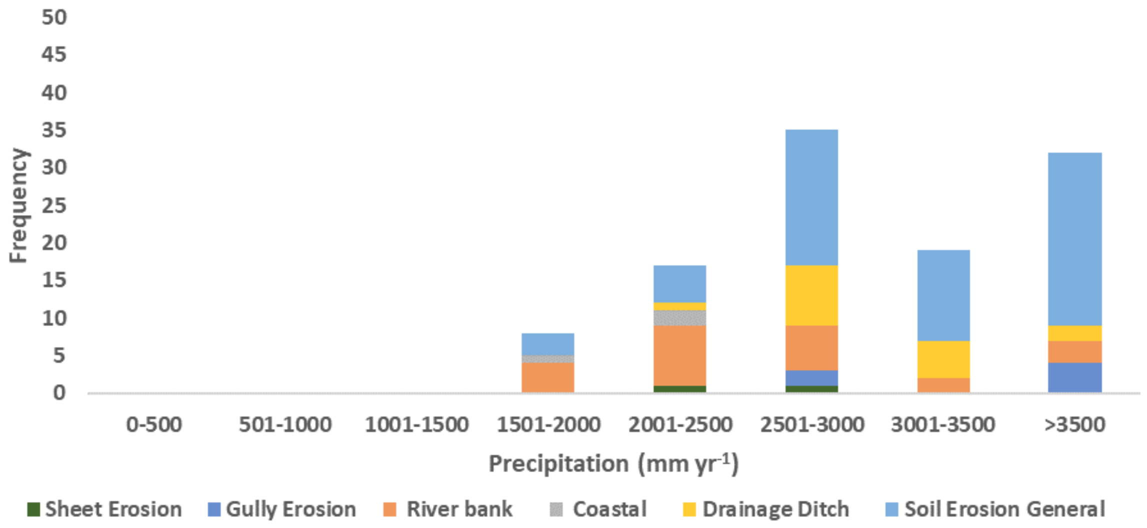


Figure 4.30: Precipitation classes and the frequency of erosion or disturbance events for the 'Soil Disturbance' category, Frequency scale: 0-50

4.10.1 Key analysis points

- Erosion to a degree reflects the annual precipitation. 'Peat' (or organo-mineral soils) only form in areas of high precipitation (and low ET) so the frequency of erosion events reflects this.
- Land intensification is greatest at low altitudes where there is lower annual precipitation. For 'mineral soil erosion' and 'mass movement' events there appears to be a dependency on precipitation quantities.

4.11 Role of landcover on number of soil erosion events

Within Wales Acid Grassland (AG) and Improved Grassland (IG) dominate the land cover. Enclosed farmland (as defined under SoNaRR reporting in Wales) includes IG and arable land and equates to ~45% of the land cover whilst semi-natural grassland which includes AG, neutral, and calcareous grassland types occupies ~13% (Tye et al. 2021). Thus, in the following graphs it would be expected the majority of events to occur in these categories.

Figure 4.31 shows that the majority of 'Peat Erosion' events are associated with either AG or Bog. Figure 4.32 demonstrates that the vast majority of 'Soil Disturbance' events were found on IG, possibly reflecting the greater intensification of land use, and animal husbandry. For 'Mass Movement' erosion events (Figure 4.33) the events were recorded mainly on the AG and IG categories. However, soil slips and scars occurred mainly on AG, whilst soil creep and terracettes were found predominantly on IG. This is probably again a reflection on grazing intensity and precipitation as acid grassland generally occurs where annual precipitation is higher. However, because the dominant landcover for the 1 km x 1 km survey square is being used, it doesn't mean that the slopes where terracettes and soil creep are occurring are likely improved (as they are likely to steep for re-seeding), but that they may occur in landscapes where grassland improvement has occurred.

For the ‘Mineral soil Erosion’ category the greatest numbers of erosion events occurred on AG and IG (Figure 4.34). This indicates that in Wales soil erosion is not confined to arable land, but that grasslands are vulnerable as well.

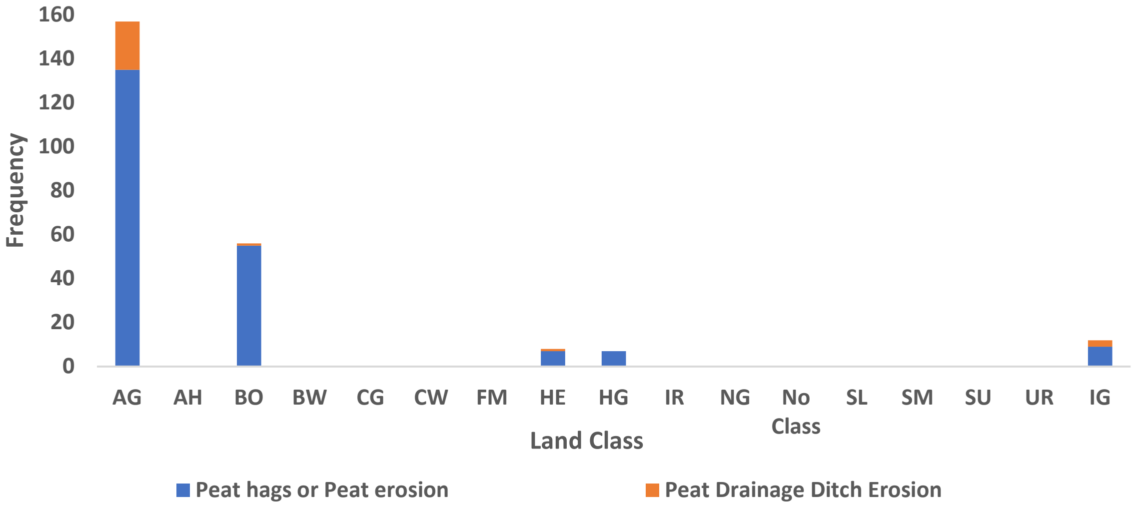


Figure 4.31: The frequency of ‘Peat erosion’ events in different CEH Landcover categories; Frequency scale: 0-160

Key: AG = acid grassland; AH = Arable and Horticulture; Bo = Bog; BW = Broadleaved Woodland; CG = Calcareous Grassland; CW = Coniferous Woodland; FM = Fen, Marsh and Swamp; HE = Heather; HG = Heather Grassland; IR = Inland Rock; NG = Neutral Grassland; SL = Supra Littoral; SM = Salt Marsh; SU = Suburban; UR = Urban; IG = Improved Grassland

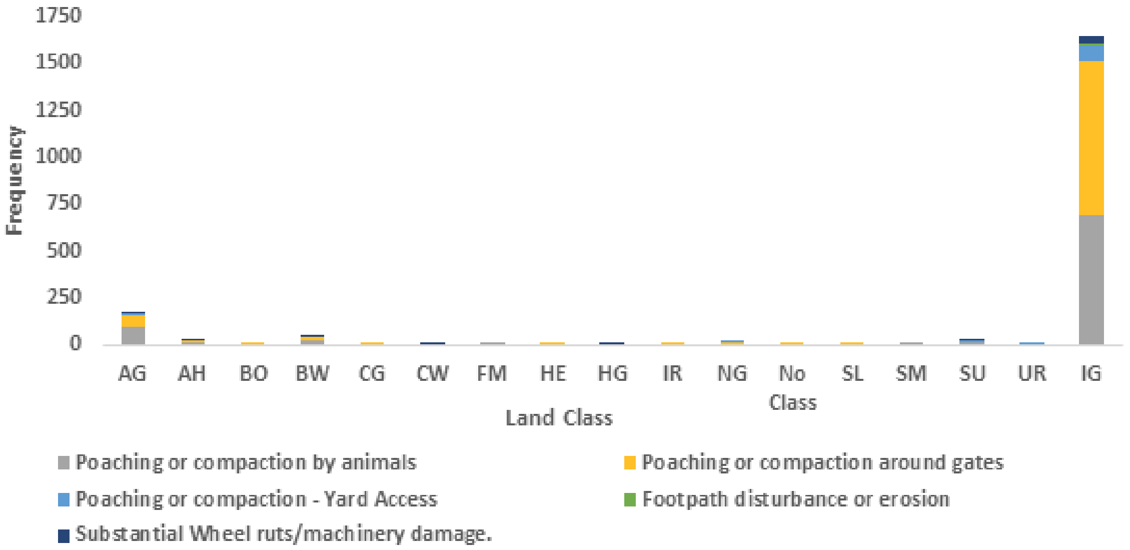


Figure 4.32: The frequency of ‘Soil Disturbance’ events in different CEH Landcover categories; Frequency scale: 0-1750

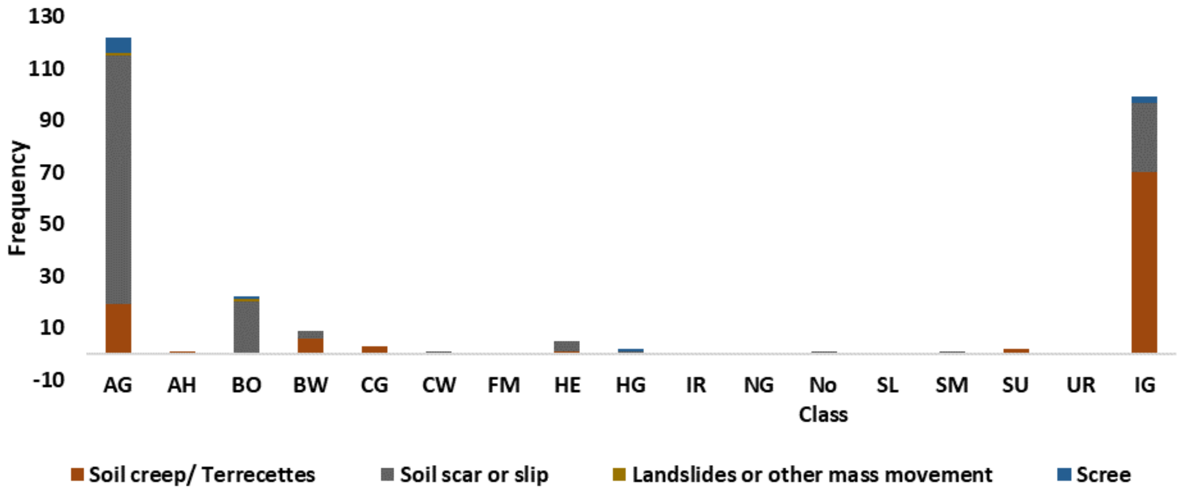


Figure 4.33: The frequency of 'Mass Movement' erosion events in different CEH Landcover categories; Frequency scale: 0-130

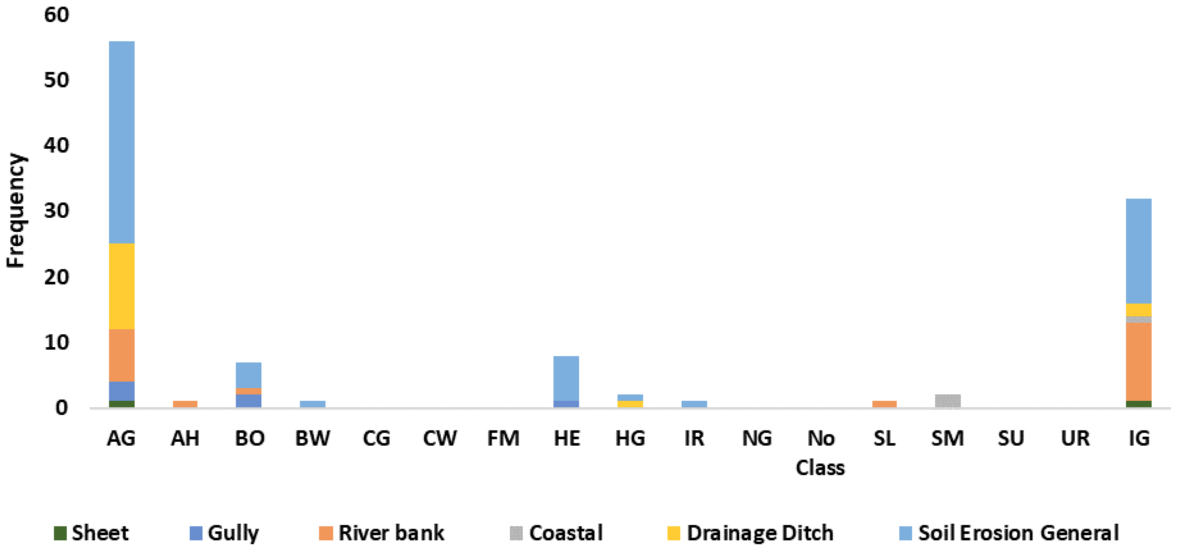


Figure 4.34: The frequency of 'Mineral Soil 'erosion events in different CEH Landcover categories; Frequency scale: 0-60

4.11.1 Key analysis points

- Erosion events largely occurred on the dominant landcover classes in Wales of Acid Grassland and Improved Grassland. This indicates that erosion is not constrained to bare soil on arable land.

4.12 Role of Agricultural Land Classes on number of events

In a similar manner, the increase on soil erosion / disturbance events with the intensification of land use can be examined by examining frequency of events in association to the Predicted Agricultural Land Classification. Land is categorised into one of the following grades:

- grade 1: excellent quality agricultural land
- grade 2: good quality agricultural land
- grade 3a: good to moderate quality agricultural land
- grade 3b: moderate quality agricultural land
- grade 4: poor quality agricultural land
- grade 5: very poor quality agricultural land

Figure 4.35 shows that the majority of the ‘Peat Erosion’ occurs on ACL4 and 5. This is similar to ‘Mass Movement’ erosion (Figure 4.37) and ‘Mineral Soil Erosion’ (Figure 4.38). However, the Soil Disturbance graph (Figure 4.36) shows that the frequency of events is mainly in Class 3a, Class 3b and Class 4, indicating that soil disturbance is likely related to the intensity of agriculture, and those areas with better agricultural soils and landscape in Wales.

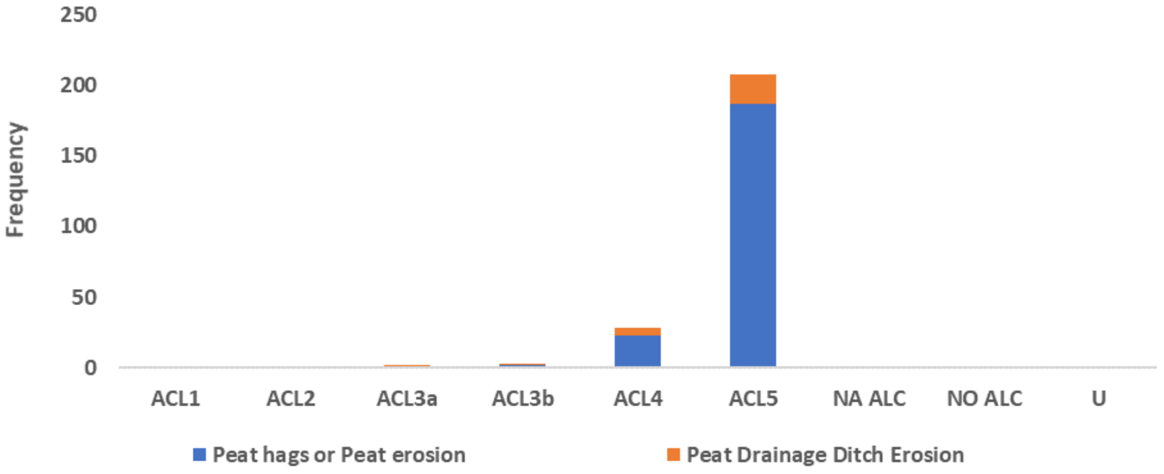


Figure 4.35: Frequency of ‘Peat erosion’ events found on different Predicted Agricultural Land Classification categories; Frequency scale: 0-250

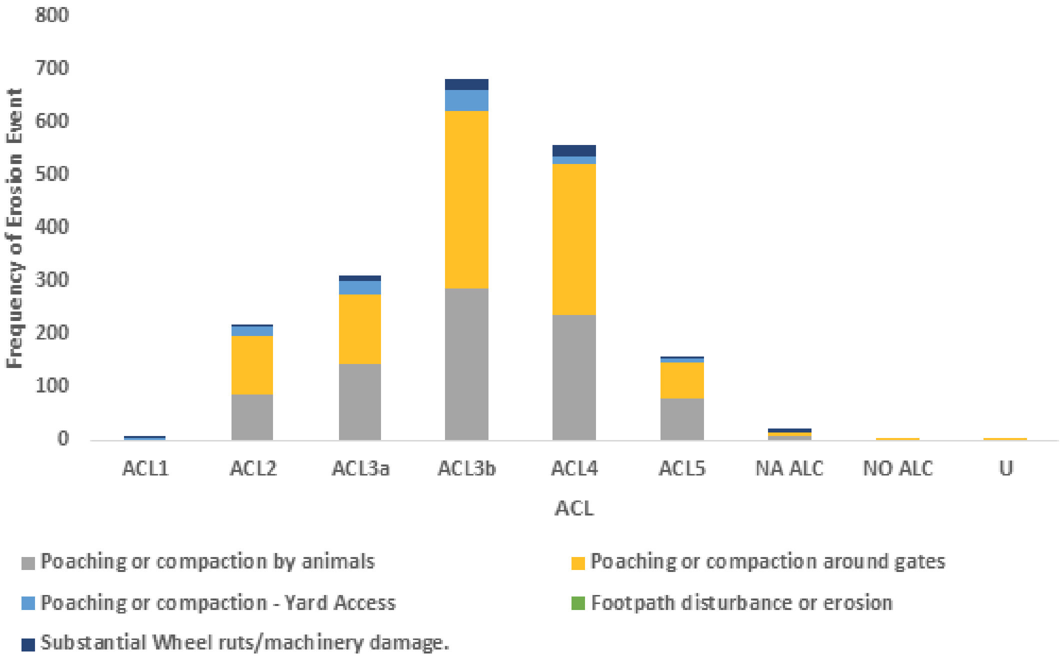


Figure 4.36: Frequency of 'Soil Disturbance' events found on different Predicted Agricultural Land Classification categories; Frequency scale: 0-800

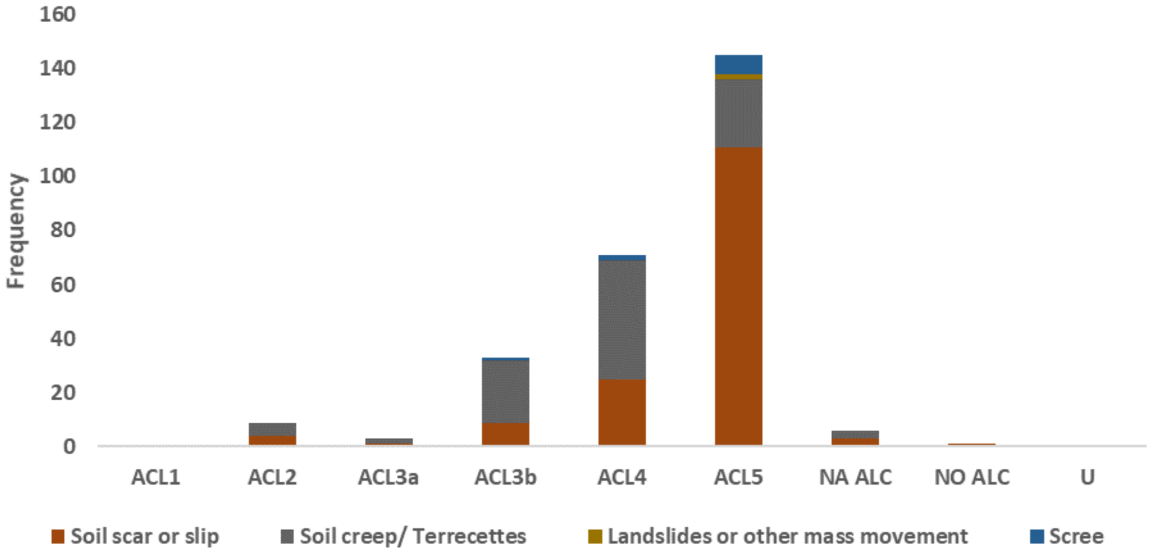


Figure 4.37: Frequency of 'Mass Movement' events found on different Predicted Agricultural Land Classification categories; Frequency scale: 0-160

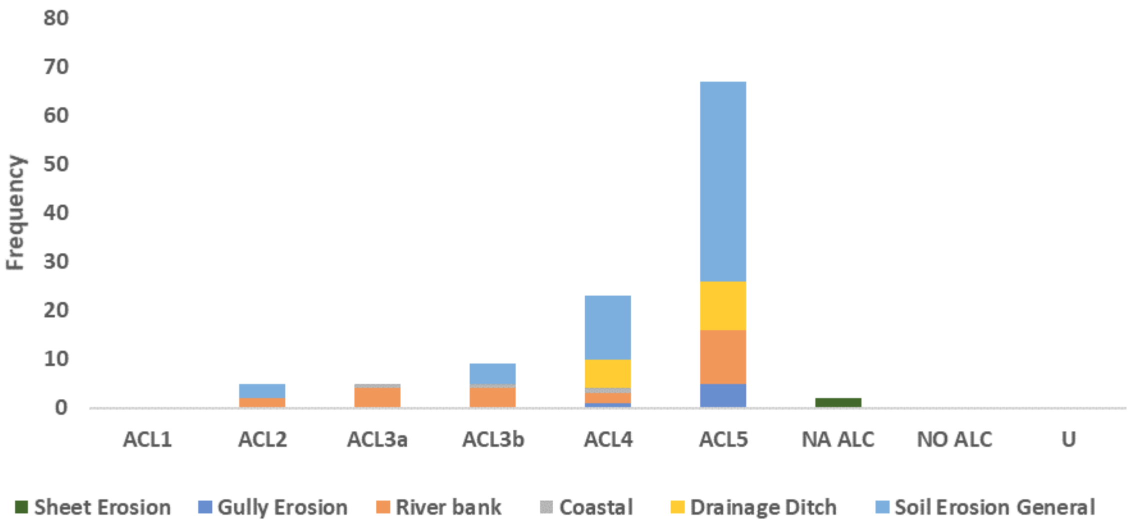


Figure 4.38: Frequency of 'Mineral Soil Erosion' events found on different Predicted Agricultural Land Classification categories; Frequency scale: 0-80

4.12.1 Key analysis points

- In a manner similar to the analysis for the Welsh landcover (as per UKCEH landcover map), a greater frequency of erosion events occurred on lower quality agricultural land, principally as these classifications are spatially dominant.
- Soil disturbance events were higher on better quality land as this is where more intensive agriculture is focused.

4.13 Analysis of areas vs. major erosion categories

Apart from the frequency of events occurring as a result of erosion variables, the other important metric that policy makers would be interested in is the area of soil erosion or disturbance per area. As part of the aerial photo survey, the area of erosion/ disturbance polygons were estimated through the GIS. The level of accuracy of mapping the polygon area depends on the GIS resolution at which the polygon was identified, so the area estimates are best described as 'first-order' estimates. These results are shown as Cumulative Distribution Functions (CDF) which show the percentile distribution of the areas of eroded or disturbed soils. Thus 50 % is equivalent to the median value and 95% is the 95th percentile and so on. Figure 4.39 summarises the distribution of soil erosion or disturbance areas for the 4 top level categories of soil erosion/ disturbance using cumulative distribution functions. It shows that the distribution of areas of erosion are reasonably similar for the 'Peat Erosion', 'Mineral Soil Erosion' and 'Mass Movement' categories, with a median value being between ~1000 m^2 – 3000 m^2. The distribution of areas for the 'Soil Disturbance' category are smaller and it can be seen that a median value of just over 100 m^2 is found, reflecting that most disturbance is around gateways and feeders.

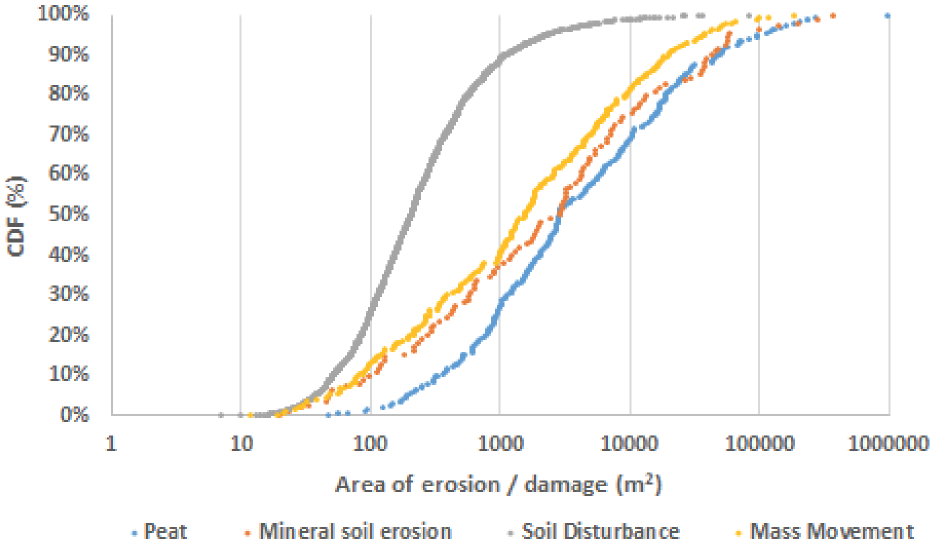


Figure 4.39: Cumulative Distribution Function (CDF) showing the distribution of the areas of eroded or disturbed soils for the 4 major categories of soil erosion or disturbance

The Cumulative Distribution Functions are shown for the subcategories in each of the 4 main categories shown above. For 'Peat' Erosion (organo-mineral soils) there were similar area distributions for both subcategories with a median value of ~2000 m^2 (Figure 4.40). For 'Soil Disturbance' it was evident that the greatest areas of disturbance were associated with poaching around yards or around the farm. These often could be a whole field. Generally, the median values for 'Soil Disturbance' were between 100 m^2 and 1000 m^2 (Figure 4.41). There were quite large differences in the size of areas recorded for the 'Mass Movement' category (Figure 4.42), with the median area for scree slopes being about 1 ha in size, whilst the median for soil slip and scar was < 400 m^2. For 'Mineral Soil Erosion' the median value for many of the sub-categories was ~5000 m^2, with the distribution of the riverbank erosion being smaller and a median erosion area of 127 m^2 (Figure 4.43).

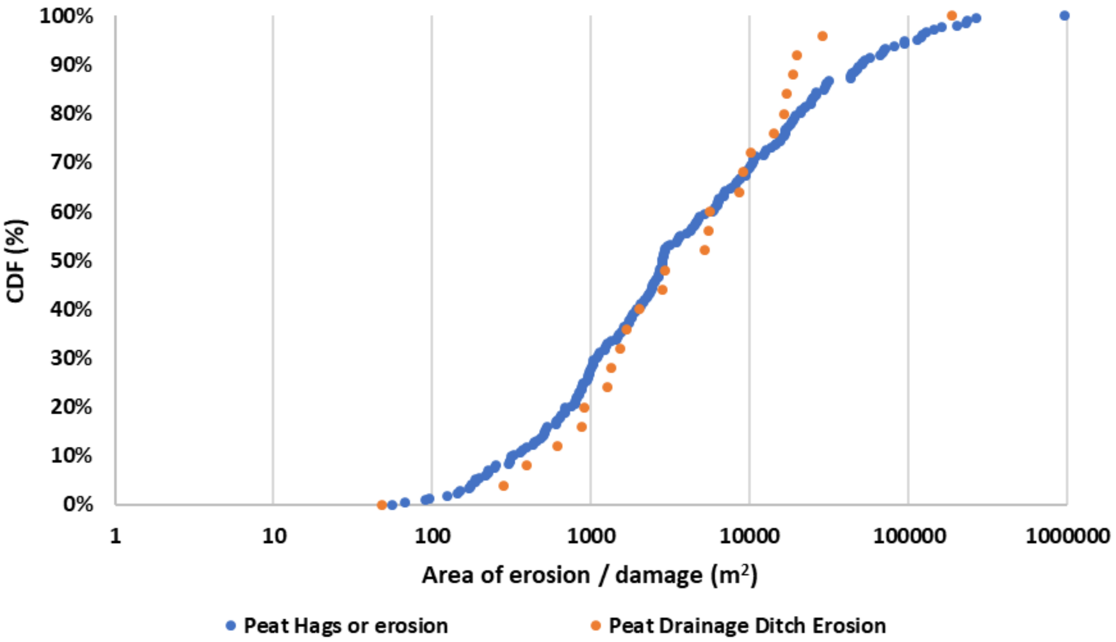


Figure 4.40: Cumulative Distribution function showing the distribution of the areas of eroded or disturbed soils for the 'Peat' category

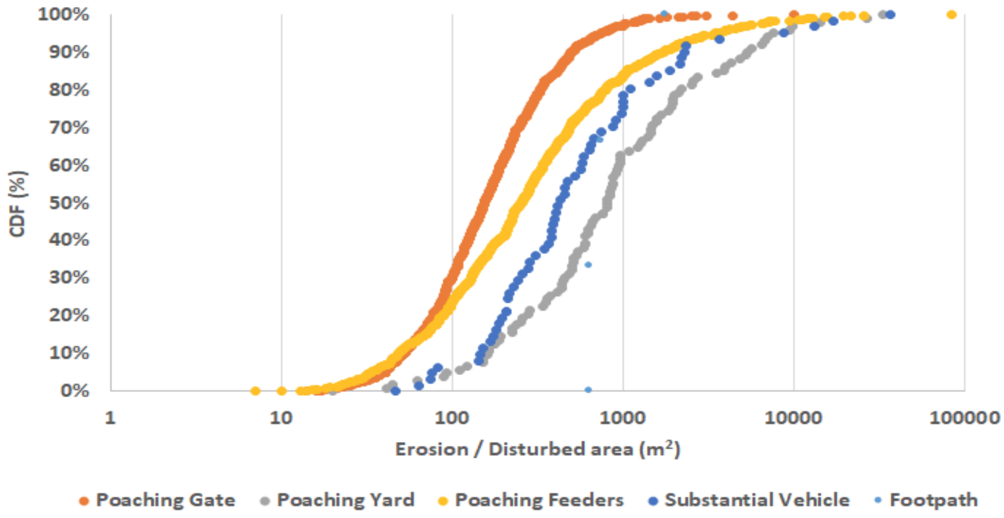


Figure 4.41: Cumulative Distribution function showing the distribution of the areas of eroded or disturbed soils for the 'Soil Disturbance' category

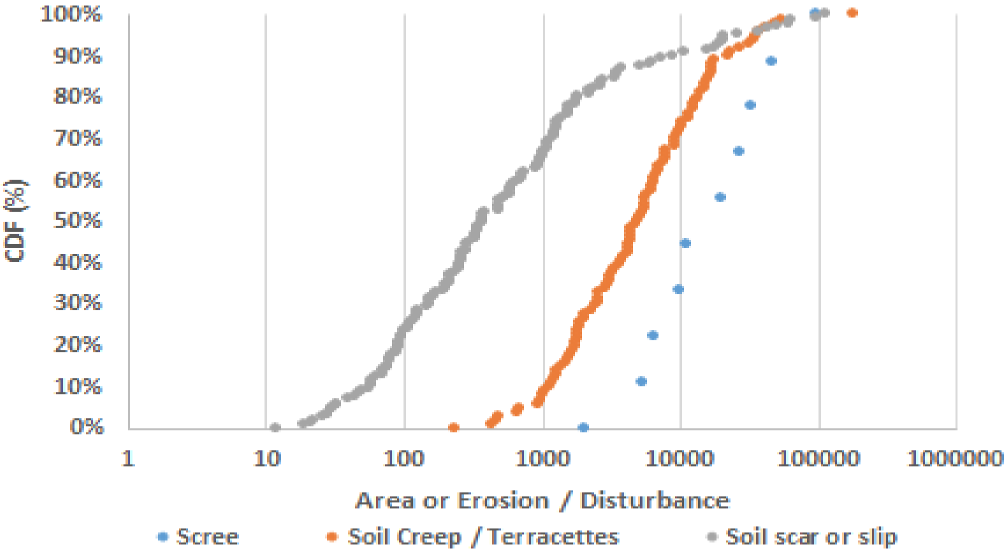


Figure 4.42: Cumulative Distribution function showing the distribution of the areas of eroded or disturbed soils for the 'Mass Movement' category

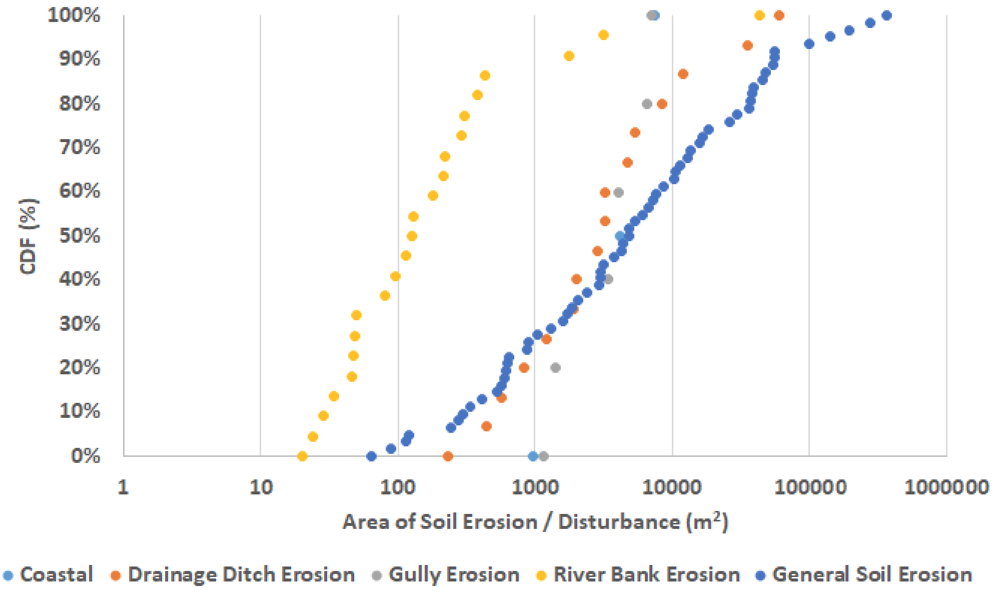


Figure 4.43: Cumulative Distribution function showing the distribution of the areas of eroded or disturbed soils for the 'Mineral Soil Erosion' category

4.14 Assessments of erosion area with altitude (Z) and change in altitude (Z_{Diff})

Erosion area was examined in relation to the (i) mean altitude and (ii) the change in altitude within the erosion or disturbance polygon. The basis for using altitude as a variable is that higher altitudes in Wales may be subject to greater annual precipitation, steeper slopes and less dense vegetation on slopes. Thus, altitude may act as proxy for a combination of all these factors. The size of eroded areas is also plotted against the difference in altitude within the erosion/ disturbance polygon (Z_{Diff}), a proxy potentially for slope. The following graphs split the data into the subcategories for each of the four main groupings that the survey is operating under. As the figures show altitude (z) is a poor variable in which to assess the size of eroded area and no relationships were found for the sub-categories (Figure 4.44 - 4.47). However, using Z_{Diff} within the polygon appears to show trends whereby the size of the eroded area recorded through the aerial survey increased as Z_{Diff} increased. There may be a slightly circular argument within this because it is more likely that small areas will only have smaller changes in altitude. However, the polygons were marked after erosion /disturbance had taken place which therefore provides an indication that greater erosion area may be found where there is a greater difference in altitudes within the polygon, and by proxy, slope. Greater slope angles may also influence the rate at which revegetation may occur, thus increasing erosion.

For the 'Peat Erosion' categories this may be due to the increase in slope, being at the edge of slopes (Figure 4.44) which reflects the range of Z_{Diff} being up to 150 m for Peat erosion and ~60 m for the drainage ditches. For 'Soil Disturbance' and the poaching around gates and feeders, the extent of Z_{Diff} was ~50 m and this was sufficient to start showing a relationship between slope and erosion area (Figure 4.45). There were no relationships found for the other sub-categories of the 'Soil Disturbance' category. The strongest relationships, as expected, were found for the ‘Mass Movement’ categories with all sub-categories showing strong relationships (Figure 4.44). These generally had the highest Z_{Diff} values of up to 300 m. For the ‘Mineral Soil Category’ there were also relationships between Z_{Diff} and the area of erosion (Figure 4.47) for ‘soil erosion general’, ‘drainage ditches’ and ‘riverbank’ erosion.

4.14.1 Key analysis points

- Z_{Diff} within a polygon was a reasonable indicator for slope angle that influences erosion area size.
- Relationships of different strengths were found for each of the sub-categories of erosion shown, where erosion area appeared to increase with Z_{Diff} within a polygon. This is consistent with slope being a large influence on erosion processes.

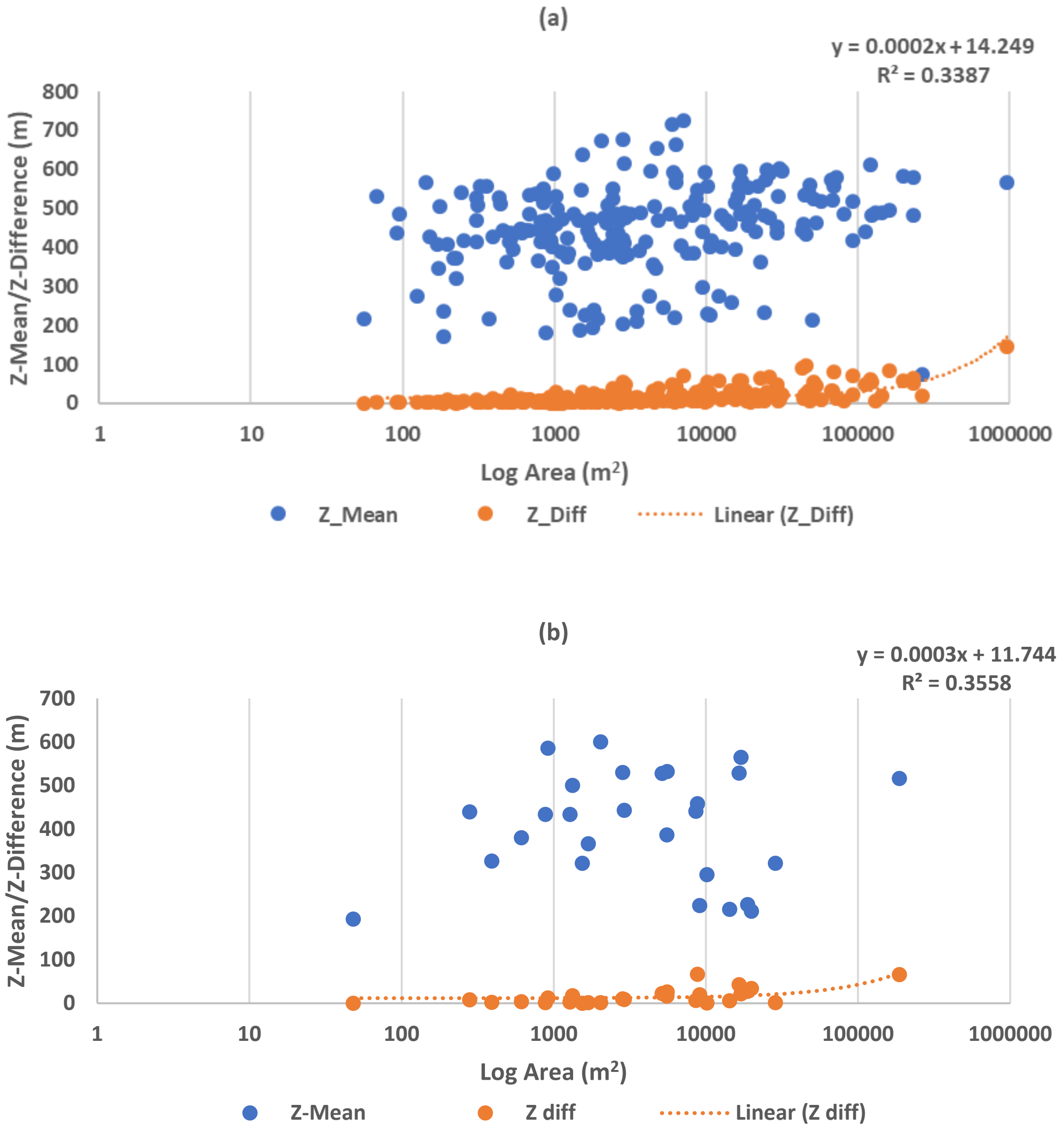


Figure 4.44: Relationship between erosion area and Z or Z_{Diff} for ‘Peat Erosion’ sub-categories (a) peat hags; and (b) erosion around drainage

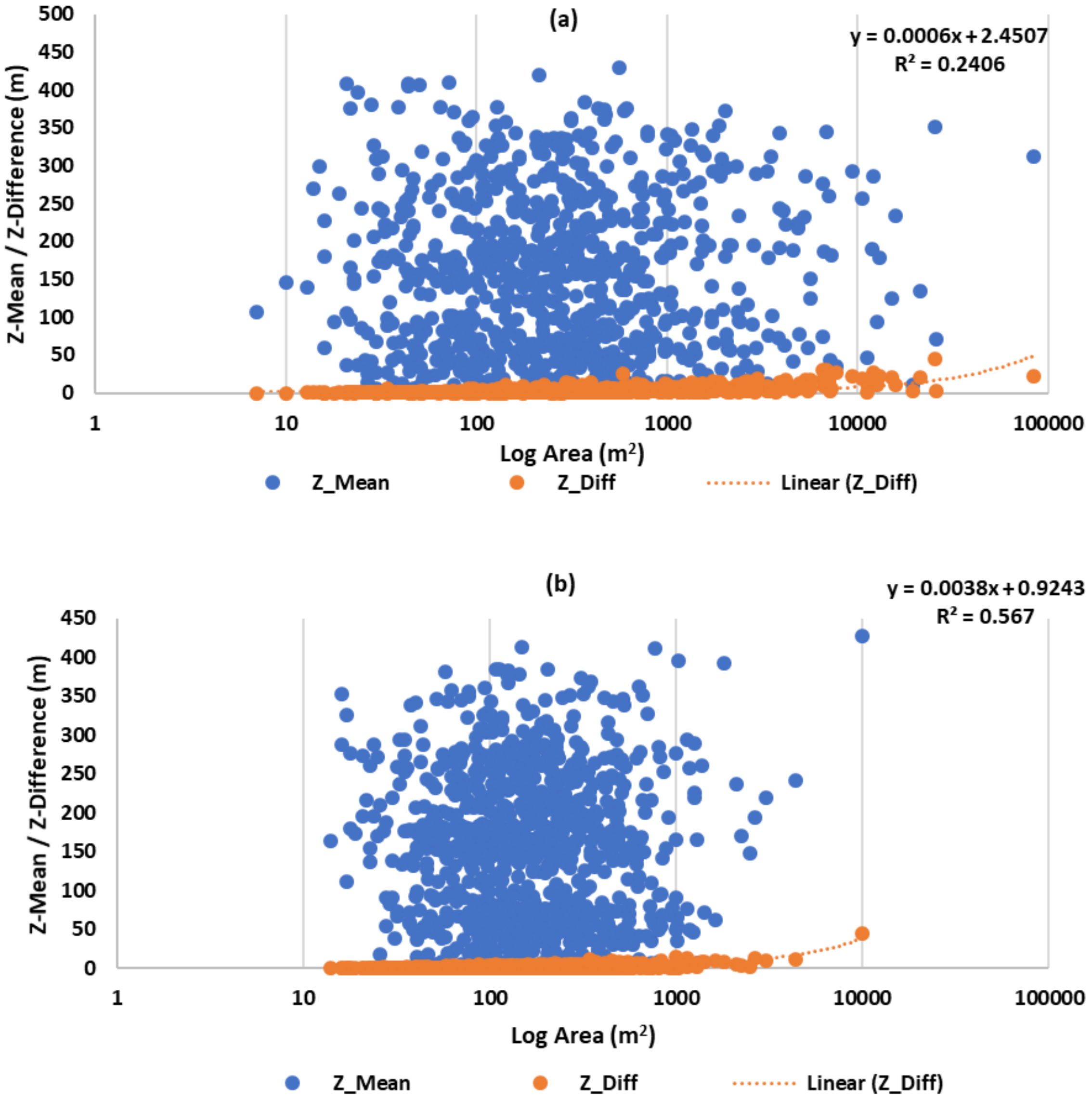


Figure 4.45: Relationship between erosion area and Z or Z_{Diff} for 'Soil Disturbance' sub-categories (a) poaching around feeders and (b) poaching around gates

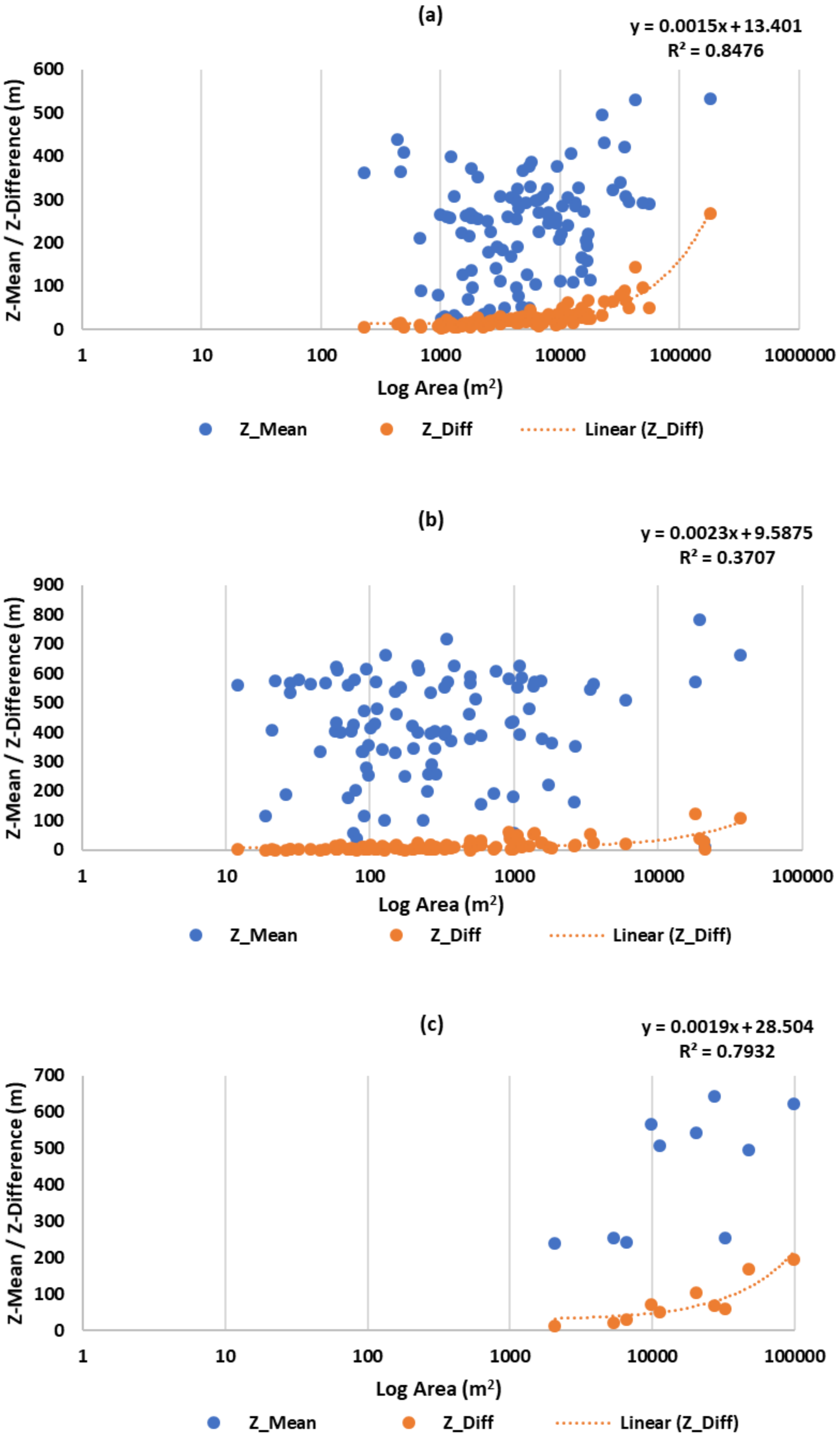


Figure 4.46: Relationship between erosion area and Z or Z_{Diff} for 'Mass Movement' subcategories (a) soil creep/ terracettes; (b) soil scars and (c) scree

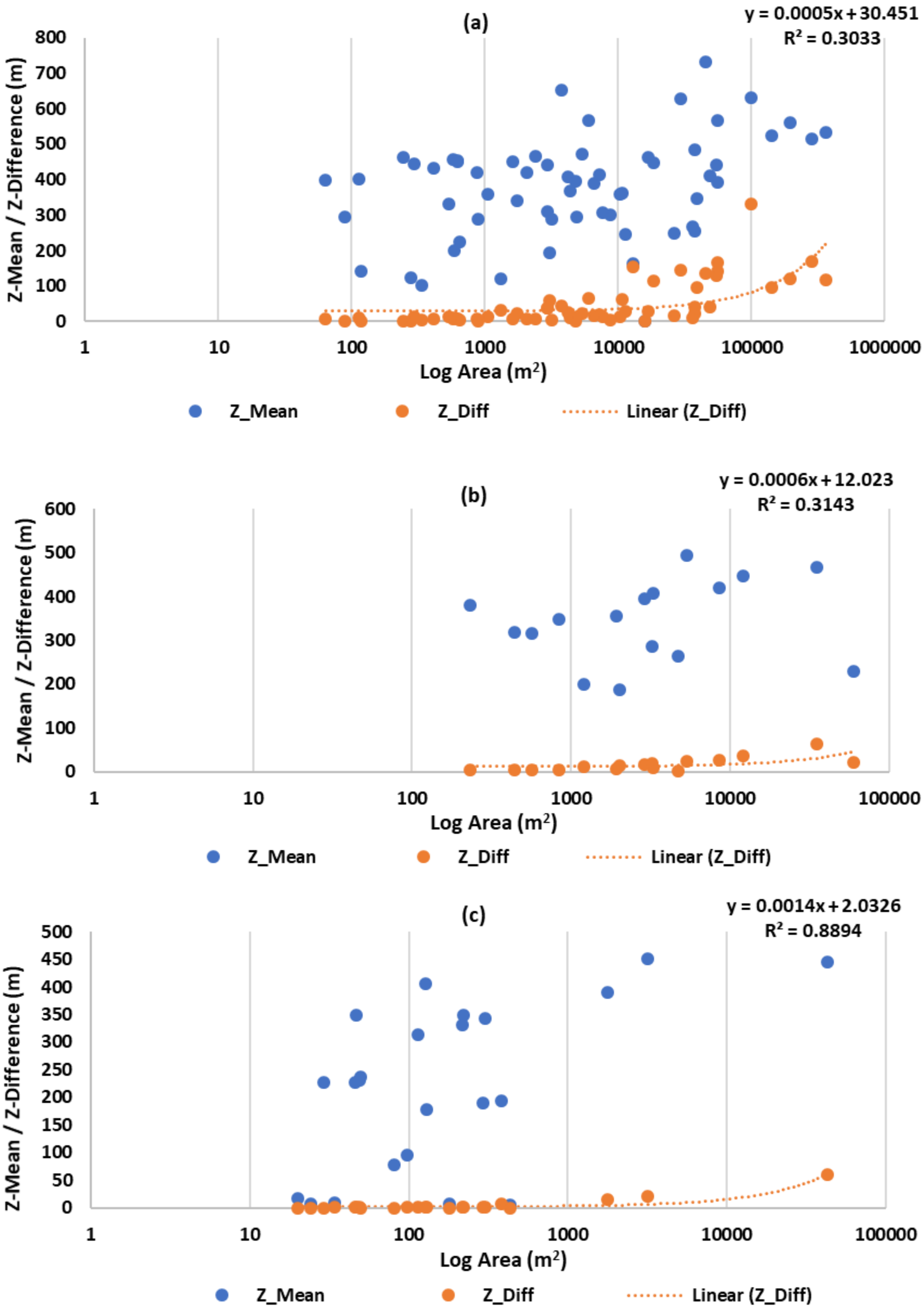


Figure 4.47: Relationship between erosion area and Z or Z_{Diff} for 'Soil Erosion' sub-categories (a) soil erosion general; (b) erosion around drainage and (c) riverbank erosion

4.15 Erosion area and the relationship to Z mean and Z_{Diff} based on land cover classification

A similar analysis regarding the size of erosion area, and Z_{mean} and Z_{Diff} was undertaken with dominant landcover class. This may identify how vulnerable ecosystems / land cover are to erosion processes as slopes increase. Not all landcover types had sufficient numbers of samples for meaningful assessments, so analysis concentrates on the dominant land cover types of (i) Acid Grassland, (ii) Improved Grassland and (iii) arable and horticulture. As in previous graphs the Z-mean within a polygon is not a good indicator of erosion area, whilst Z_{Diff} can be seen as showing relationships in the following graphs. Figure 4.48 shows that it is likely that erosion area will increase as the difference in altitude within a survey square increased. Analysis of the graphs suggests that no real difference exists in the area of erosion that occurs with the same difference in Z_{Diff} between the two grassland landcover classes. Insufficient numbers exist for an effective comparison between the Arable and grassland land cover classes.

4.15.1 Key analysis points

- Analysis of the areas of erosion or soil disturbance were assessed in relation to landcover types to assess whether there was a vulnerability for some landcover types to create larger eroded areas as a function of a proxy for slope.
- No differences were evident for the two grassland types which suggest that both were capable of dissipating rainfall energy and holding soil together with root systems equally.
- There may be an indication that this analysis may pick up an effect on arable soils but the dataset was too small for analysis.

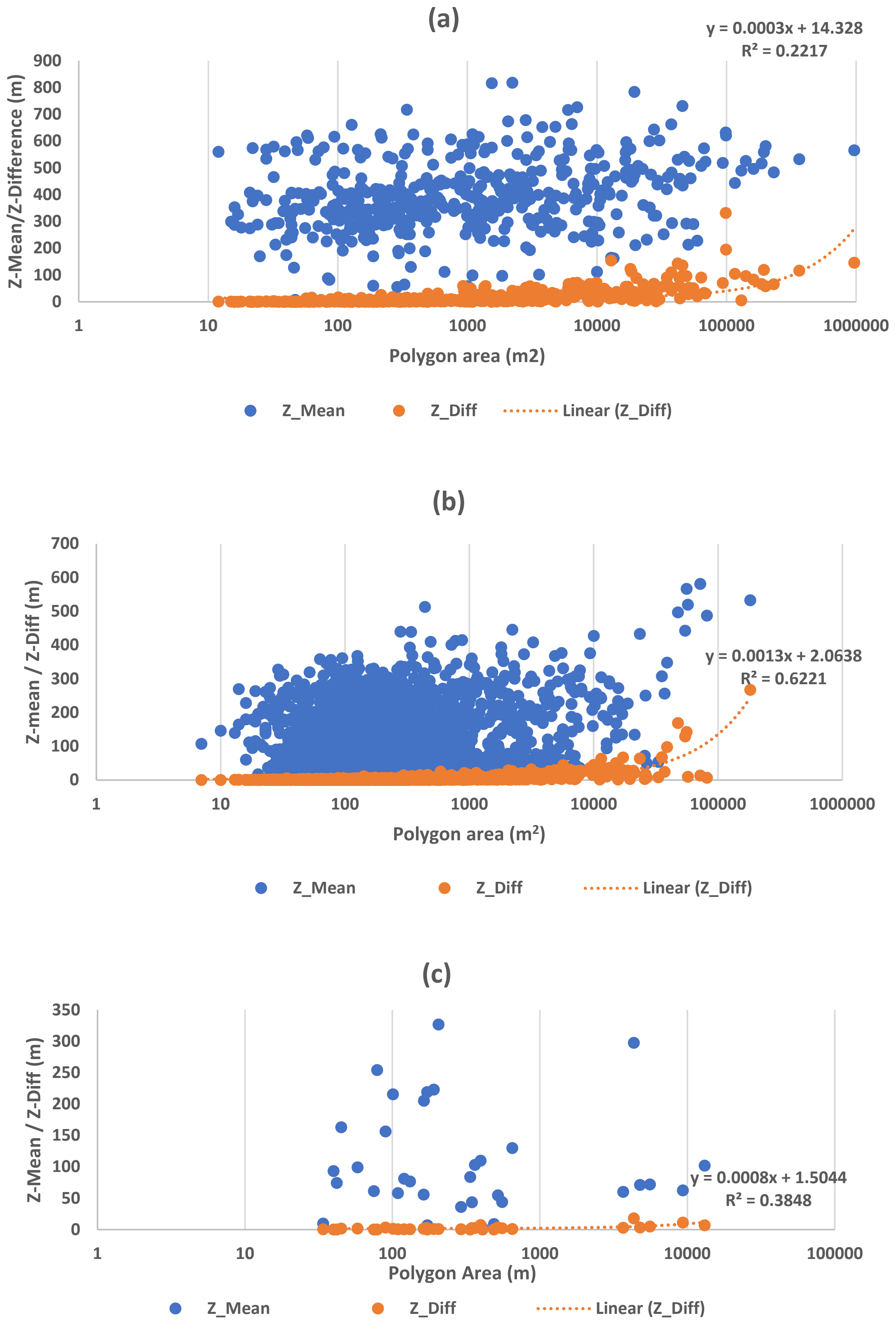


Figure 4.48: Relationship between erosion area and the Z-mean or Z_{Diff} within survey squares for (a) Acid grassland, (b) Improved Grassland and (c) arable

4.16 Erosion area and slope analysis

A similar analysis as those described in sections 4.14 and 4.15 were undertaken using slope (%) as the key variable. Unexpectedly, considering that Z_{Diff} provided evidence that slope may be important there were no relationships obtained using mean slope, the difference in slope ($Slope_{Diff}$) within the polygon or maximum slope. This is likely because of the way that slope is calculated and an eroded area polygon identified may have a variety of slope angles associated with individual pixels but these may end up cancelling each other out.

4.17 Erosion area and the relationship to texture

Soil texture is a fundamental variable known to influence soil erosion and disturbance. Sandy and silty soils are prone to both water and wind erosion. Data collected from the aerial survey regarding the area of erosion recorded were analysed using Cumulative Distribution Functions to examine differences with respect to different soil textures. Classes of soil texture were obtained from the BGS Soil Parent Material dataset. As shown (Figure 4.49) the distribution of erosion areas were similar for most of the soil types in the middle of the textural range (e.g. loam based soils). At the extremes of the texture range, there were indications that sandy soils were more prone to disturbance and clay soils may be slighlty more resistant to erosion. However both, the clay and sand texture datasets, were relatively small in comaprison to the major classes.

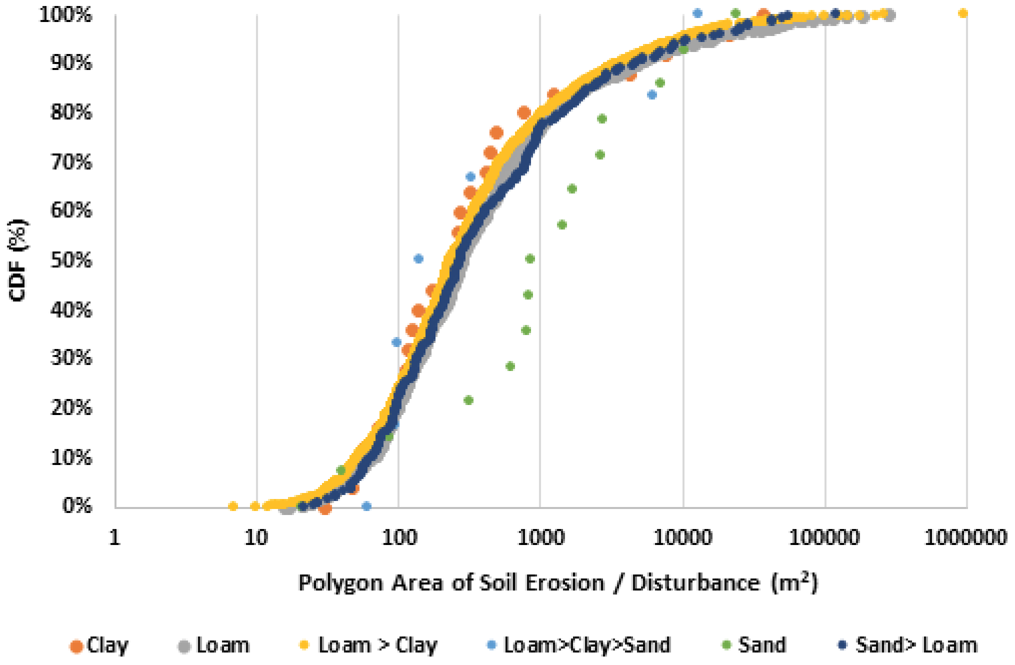


Figure 4.49: Cumulative Distribution Function (CDF) for area of soil erosion / disturbance based on textural nature

4.18 ESB class, environmental variables and erosion area

The following analysis is similar to that undertaken by McHugh et al. (2002) for a soil survey they undertook of upland England and Wales. Their survey of upland soil erosion was undertaken between 1997 and 1999, where the area of individual eroded areas was measured at 399 field sites, including National Soil Inventory (NSI) and a few Countryside Survey 2000 sites. However, in this current survey ESB parent material is used instead of the basic soil classification McHugh et al. (2002) recorded at their identified erosion sites. The three main classes of ESB soil parent material classification found in Wales are analysed as these provide a good sample size as they are spatially the most common. The graphs show mean eroded area plotted against max altitude (Z), precipitation and slope.

The first variable examined is that of slope which was split up into 6 sub classes (Figure 4.50). For ESB class 100 (mudstones and sandstones) the mean area of erosion/disturbance increased with slope angles over 12%, and with a big increase in mean area of erosion events occurring when slope angle was > 24% (n=207). This possibly reflects the geomorphology associated with ESB class 100 being more inclined towards greater slopes angles. For Class 600 (Glacial Till) there was less of an increase in size as slope angle increased. However, there was a large increase in erosion size when slopes were > 24% (n=62). For ESB class 800 (Peats) there is an increase in mean area eroded up to the category 16-24%. This then declines at >24% but the sample size was small (n=11). It is possible that peat is present less at these angles as water would likely run off. As previously discussed some of these samples may be organo-mineral soils as well.

The second analysis used max altitude within a polygon as a variable, with altitude being split into 100 m classes (Figure 4.51). It was found that the mean eroded or disturbed area increased with altitude for ESB Class 100, peaking at 501-600 m before remaining reasonably similar for higher altitudes. However, the sample sizes at these higher altitudes though were small (n=9, and n=3). The trend did suggest that mean eroded or disturbed areas were greater as altitude increased. For ESB class 600, there was a peak in eroded / disturbed area between 400 m and 600 m, before declining above 600 m. For the low altitudes, the low areas of erosion/ disturbance may suggest an association with greater land use intensity such as poaching. At altitudes >600m the sample sizes were only n=3 and n=1 respectively so a full analysis was not possible. For ESB class 800, the erosion increases at 500-700 m which is where peat soils are likely to be found. One final item to pull out (graph not shown) is for the ESB 500 class (alluvium, slope deposits) at altitude of 500-600 where a number of large events were identified. These large erosion events probably represent slope deposits such as scree, but will involve very few events. The final variable assessed was annual precipitation (mm yr^{-1}). Figure 4.52 demonstrates an increase in precipitation led to greater mean areas of eroded or disturbed soil for all three classes. As for previous variables discussed, there were fewer samples at the high classes of precipitation.

4.18.1 Key analysis points

- Soil erosion area is driven by variables such as slope angle, altitude and precipitation. This analysis based on McHugh et al. (2002) suggests that expected patterns exist. Generally, the standard error of the mean increased as the variable classification increased, suggesting that the size of erosion area became more variable in size.

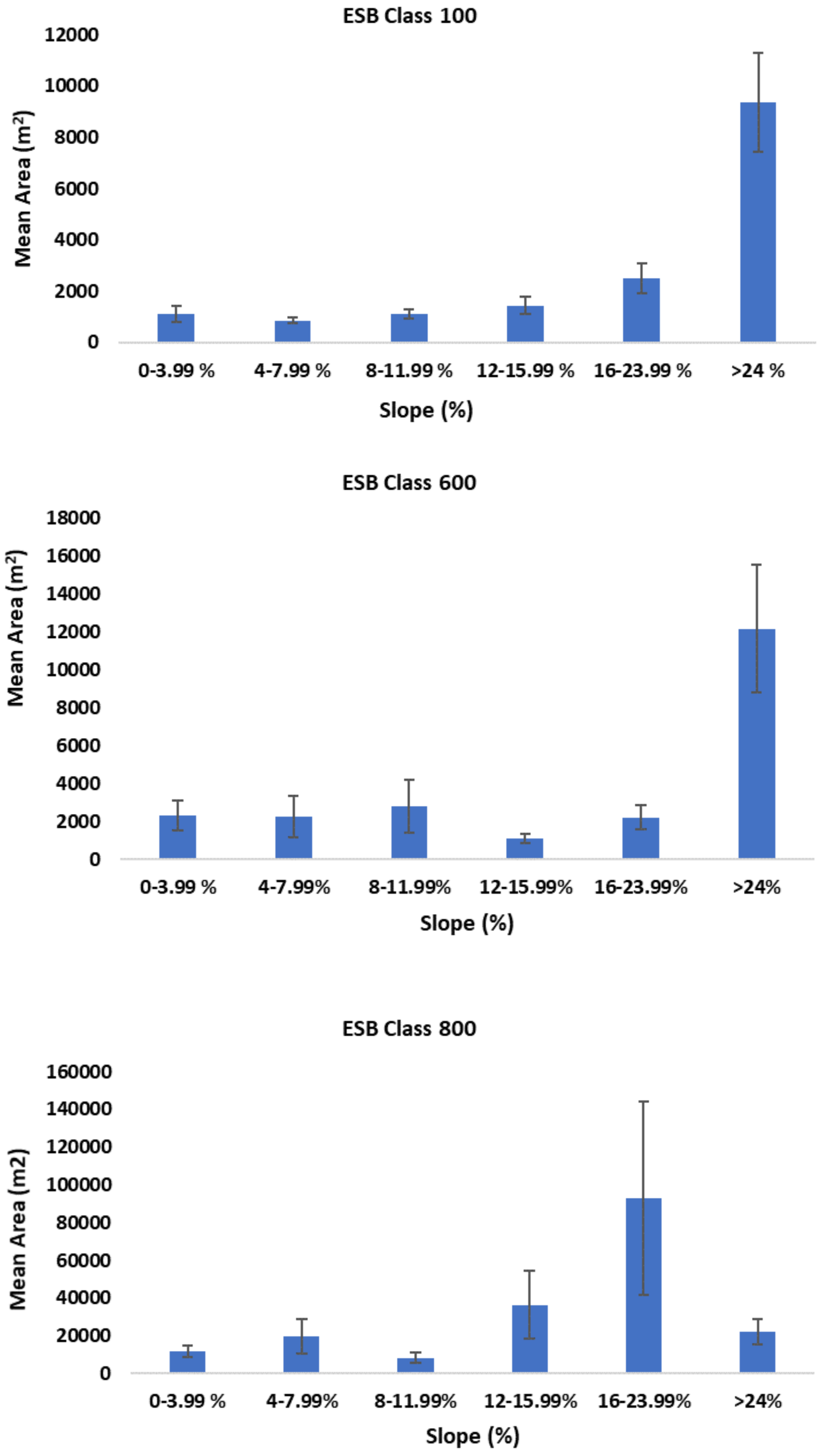


Figure 4.50: Effects of slope angle on mean eroded / disturbed areas recorded in the aerial photograph survey for ESB classes 100, 600 and 800

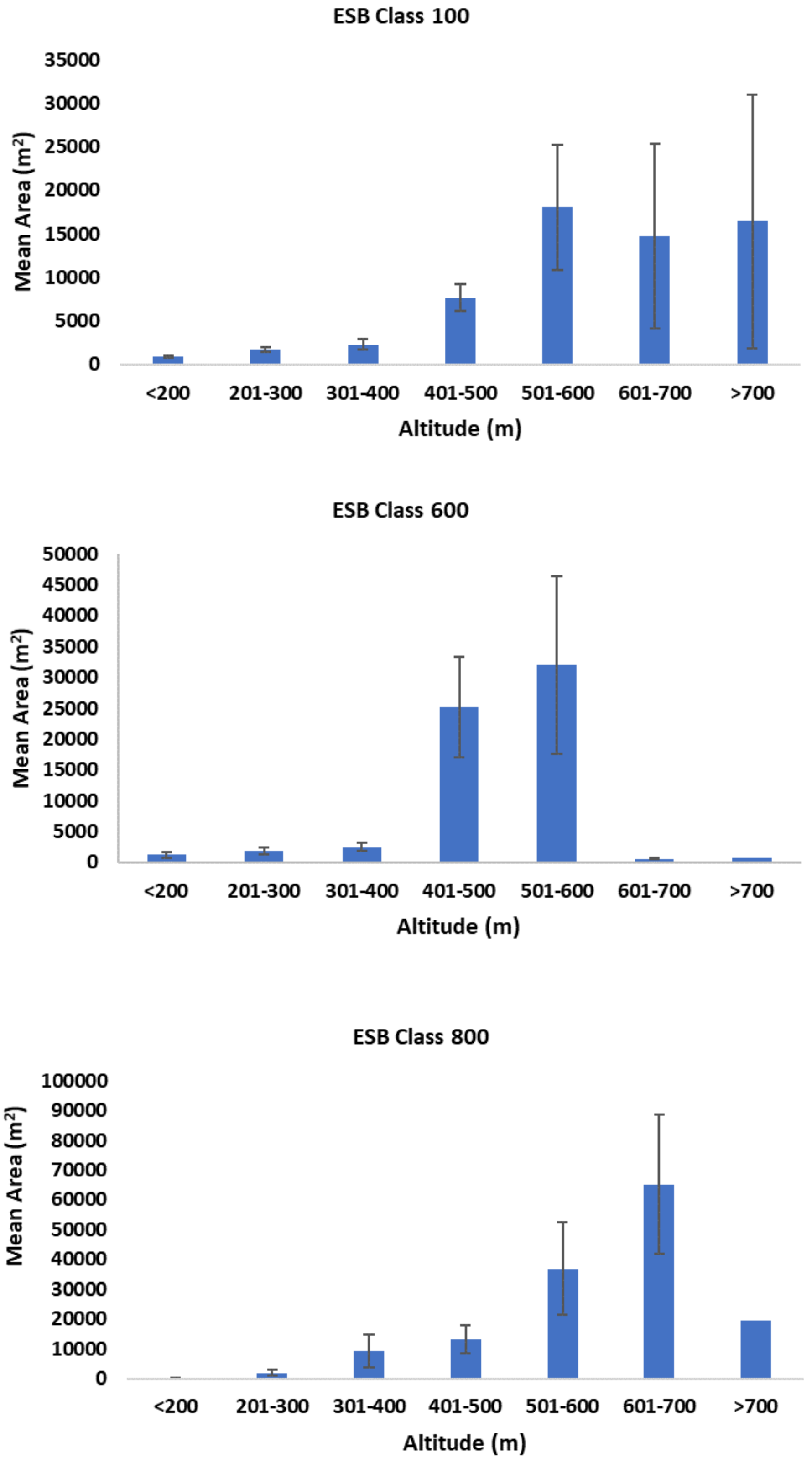
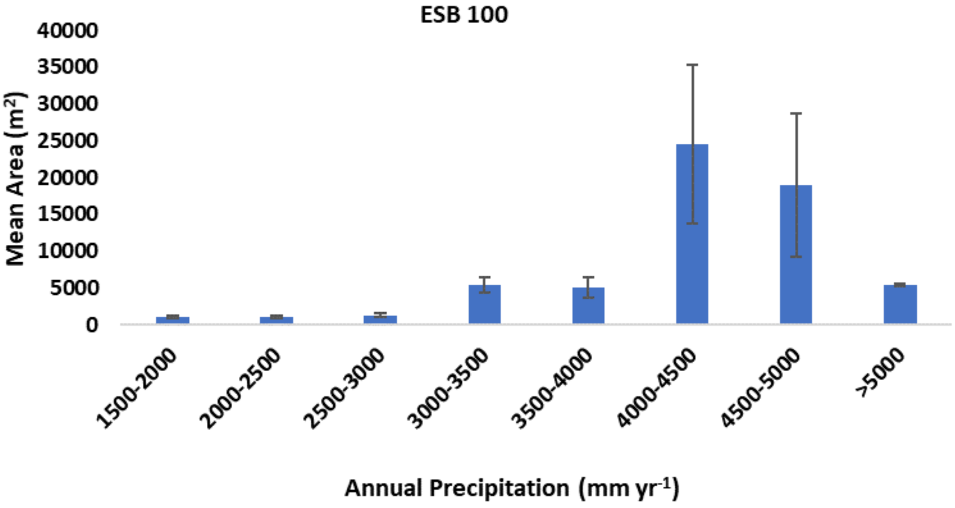
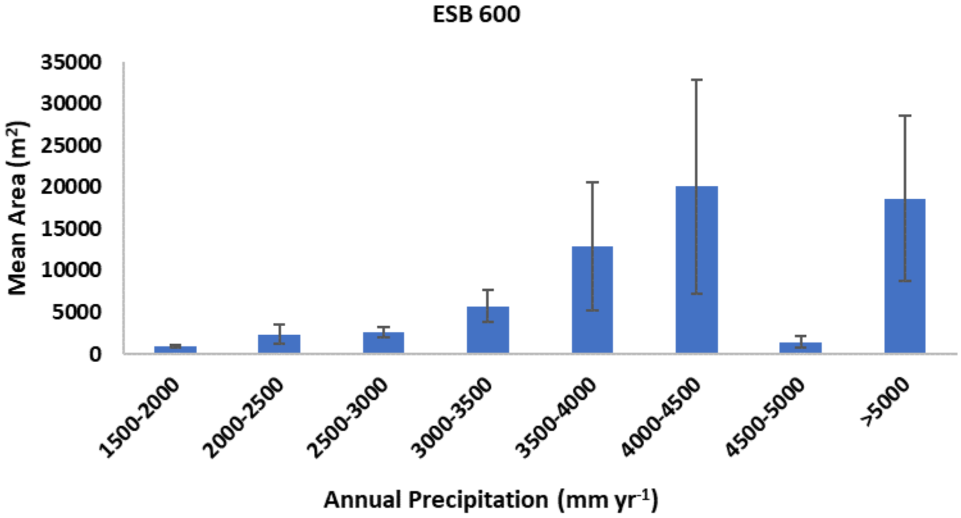


Figure 4.51: Effects of max altitude within a polygon on mean eroded / disturbed areas recorded in the aerial photograph survey for ESB classes 100, 600 and 800





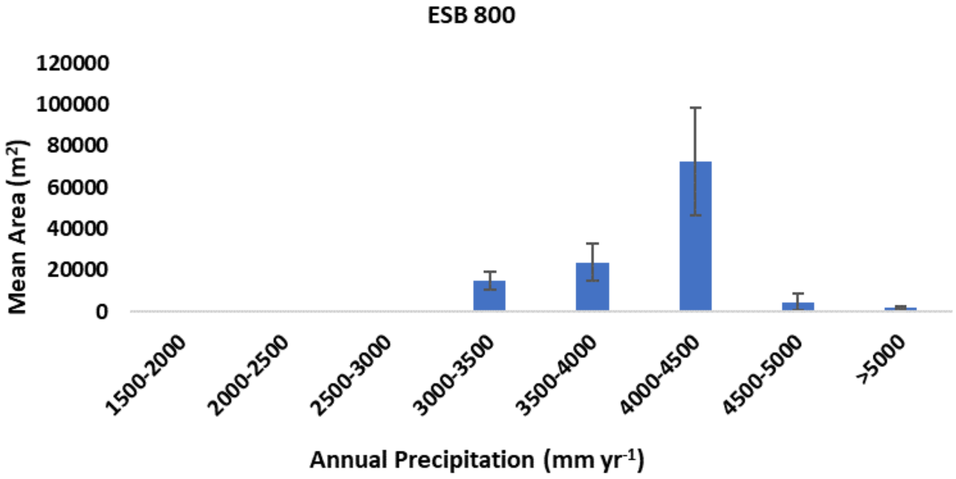


Figure 4.52: Effects of annual precipitation (mm yr⁻¹) within a polygon on mean eroded / disturbed areas recorded in the aerial photograph survey for ESB classes 100, 600 and 800

4.19 Total area of eroded or disturbed soil in squares

The total area of eroded and disturbed soil was calculated for each of the 261 squares examined in the aerial survey (Figure 4.53). A median value of 6728 m^2 of soil degradation was calculated.

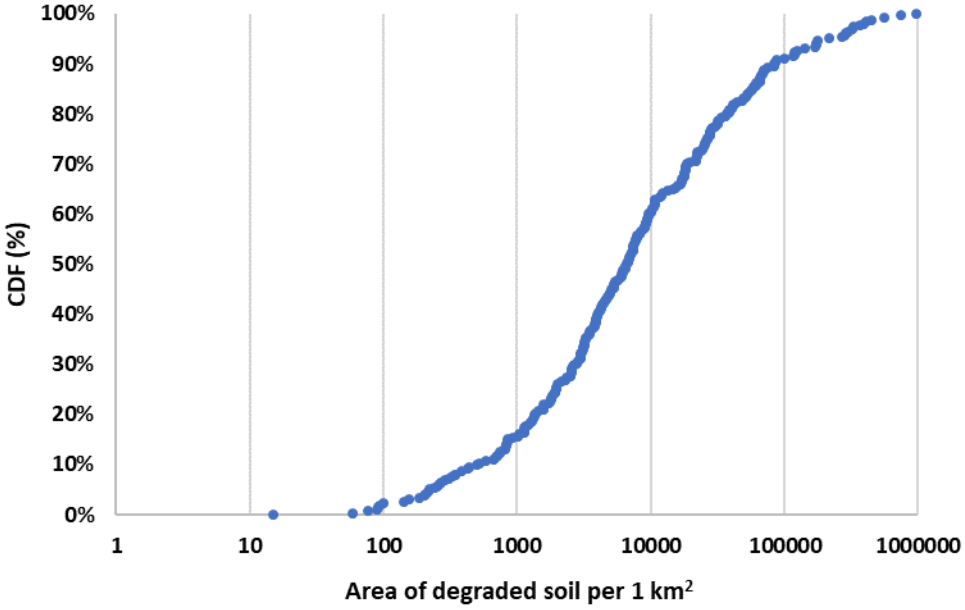


Figure 4.53: Cumulative distribution function (CDF) of the total area of soil erosion and disturbance found in the 261 squares of the aerial survey

5 Field Survey Results

This part of the report examines the extent that the BGS aerial photo survey and the ERAMMP field survey results corroborate each other, and where the differences in outputs from the two survey techniques exist.

There are issues with direct comparisons between the two surveys, as the ground truthing survey only had permission to access 72.7% of the land from land-owners. This means that some circles couldn't be fully accessed or not accessed at all. Thus, some under-estimation of recorded events may occur. However, the main focus is a general assessment of how representative the aerial survey can be and issues that may arise, using this approach.

5.1 Identifying BGS polygons from aerial survey in ERAMMP 200 m circles

Figure 5.1 shows the number of soil erosion or disturbance polygons recorded in the aerial survey that were identified in up to five 200 m circles in each selected square by the field surveyors. The slope of the line suggests that ~ 60 % of the BGS events were being recorded by the field surveyors.

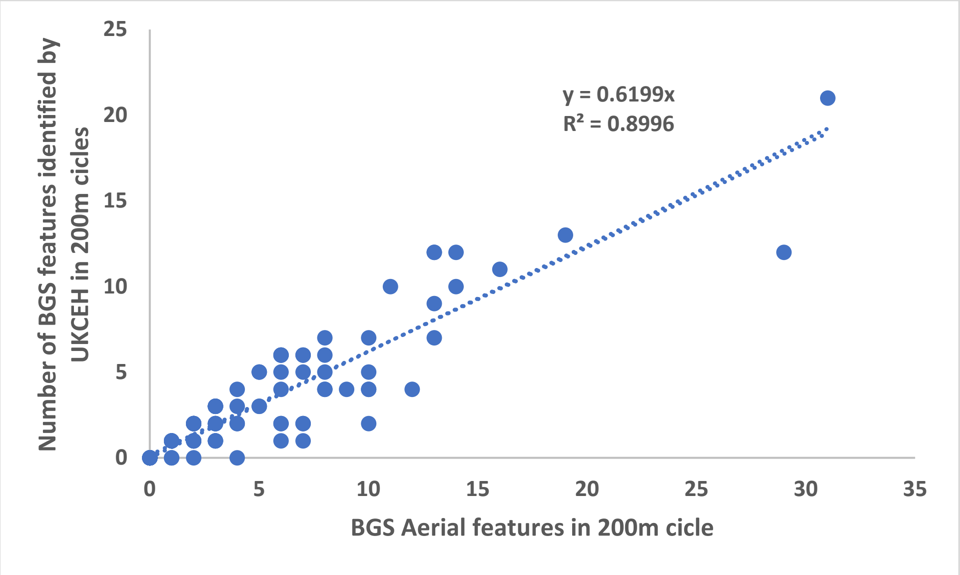


Figure 5.1: Total number of BGS features in the 200 m circles found in the aerial survey plotted against the number of BGS aerial features located by UKCEH surveyors. Features identified by BGS were found in 92 of the 105 squares surveyed.

In Figure 5.2, the number of polygons recorded by the BGS aerial survey and located in the 200 m circles, are compared to the total number of events recorded (either BGS survey or new features identified by UKCEH surveyors). The aerial survey accounted for ~50 % of the total number of events identified by the walk over survey.

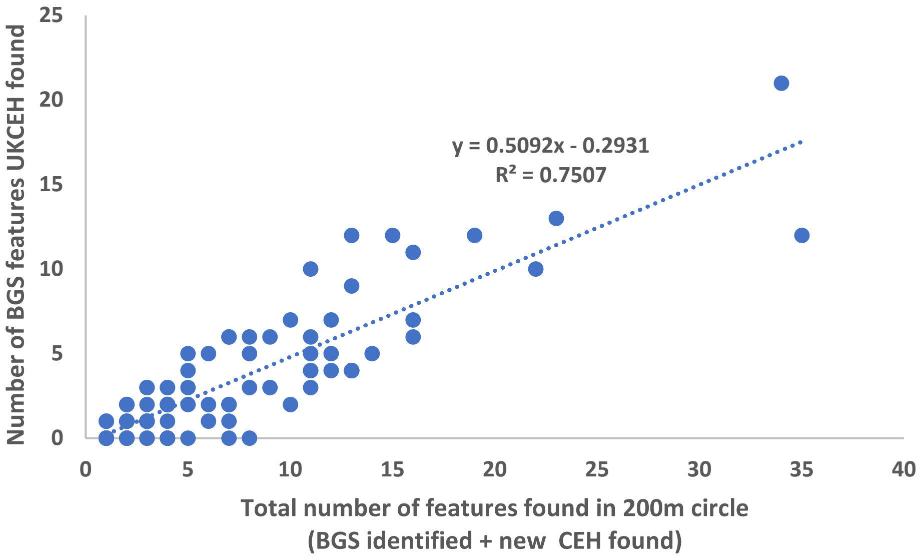


Figure 5.2: Number of BGS aerial survey polygons found in 200 m circles within each survey square compared to the number of events the UKCEH walk over survey identified in the ground truthing exercise

This data can be broken down further. For the four major soil erosion classifications, Table 5.1 shows the percentage of the BGS aerial survey events identified and recorded by the surveyors in the 200m circles. This table relates to (i) the relevance of the aerial photos that may be several years old and (ii) the ability to identify erosion or disturbance polygons. For the percentage of BGS events recorded through the aerial survey, an average of ~65% of the events across the 4 main categories were identified (similar to the slope of the line in Figure 5.1). The highest was for mineral soil but this only counted for 15 events.

Table 5.1: Results showing (a) the mean percentage of BGS aerial survey events identified in the ERAMMP 200 m circles and (b) the mean percentage of BGS aerial survey events identified compared to the total number of events identified in the ERAMMP 200 m circles when surveyed

	Percentage (%) recorded			
	Peat Erosion	**Mineral Soil**	**Soil Disturbance**	**Mass Movement**
BGS aerial features identified by UKCEH surveyors	58.9	75.0	68.2	65.6

A possible explanation why there were an increase in the events described by the ERAMMP field survey is that they could identify smaller erosion or disturbance features (Figure 5.3). To undertake this analysis the line length of the polygon recorded by the surveyors when they estimated the size of the event on their tablets were considered as a circumference of a circle. The area of the polygon was then calculated. There were 588 polygons in the ERAMMP field survey that had line lengths we could use to convert into areas. The BGS survey contributed 489 points and the ERAMMP data contributed 99 new polygons. All areas < 1 m were omitted from the rank and percentile analysis. Removing areas <1 m left 562 points. Whilst, this approach relies on estimates of polygon size and also includes some very small areas, it demonstrates that the field surveyors are able to account for smaller erosion or disturbance features, with some being < 10 m^2. These smaller areas were likely too small to achieve sufficient resolution with the aerial imagery, or hidden by vegetation (e.g. hedges or trees).

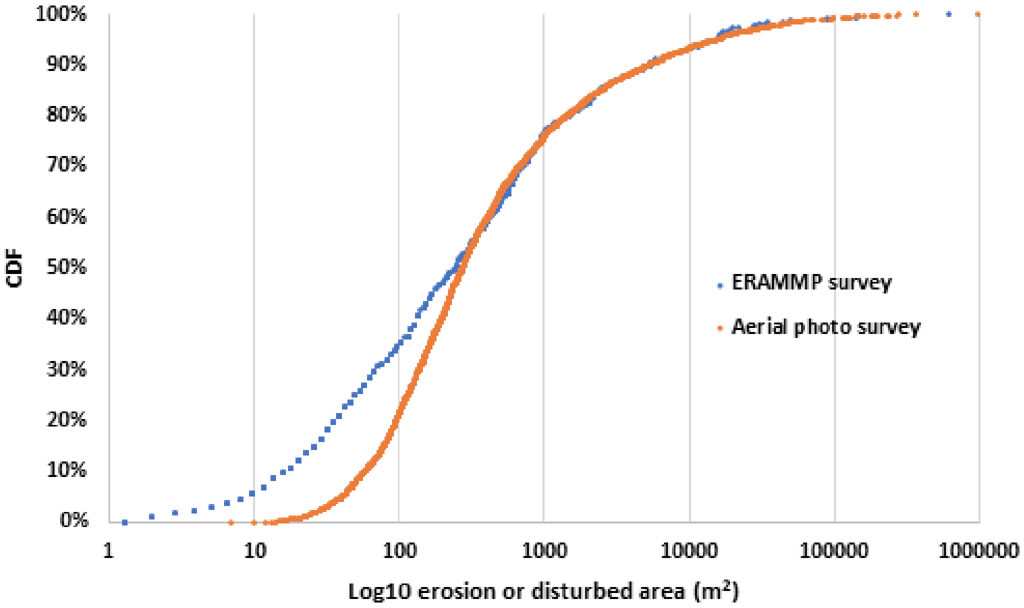


Figure 5.3: Cumulative Distribution Function (CDF) for the log$_{10}$ area of soil erosion and disturbance features recorded by the ERAMMP field survey and the BGS aerial survey

5.2 Soil erosion / disturbance results of the ERAMMP field survey

The next step was to examine the results of the ERAMMP field survey and compare results to the overall aerial survey. The dataset being used in this analysis includes both the BGS aerial survey polygons which were located in the 200 m circles along with any new erosion or disturbance polygons the ERAMMP surveyors identified, a total of 631 points. As the surveyors recorded the original aerial polygons with a first-order estimate of area, it is possible to compare the two surveys and assess their similarity. Figure 5.4 shows the break-down of results into the four major soil erosion/disturbance categories used from the ERAMMP field survey. The number of events in the subcategories of the four main erosion/disturbance categories is shown in Figure 5.5.

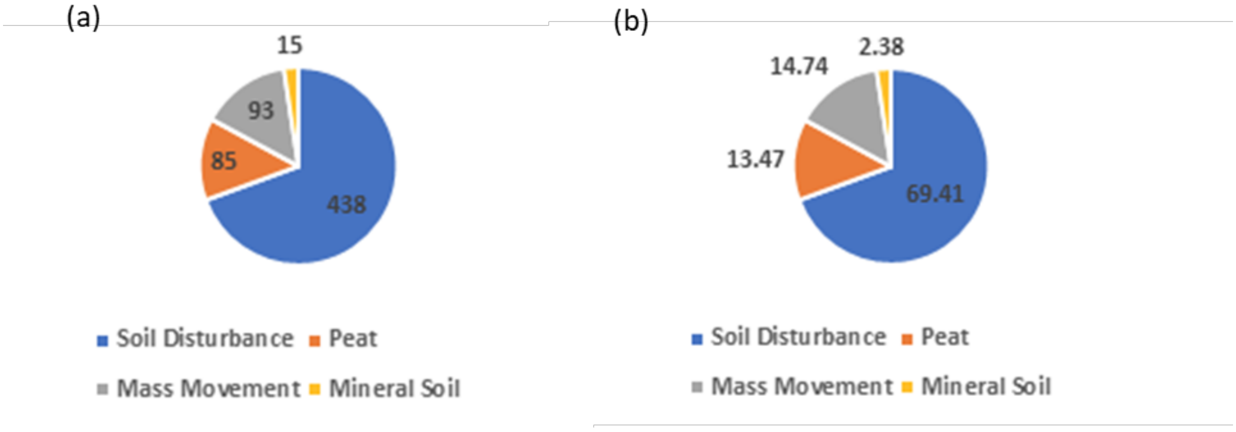


Figure 5.4: Summary of top-level erosion events recorded in the 200 m circles by ERAMMP surveyors as number of (a) events recorded and (b) % of total number of events

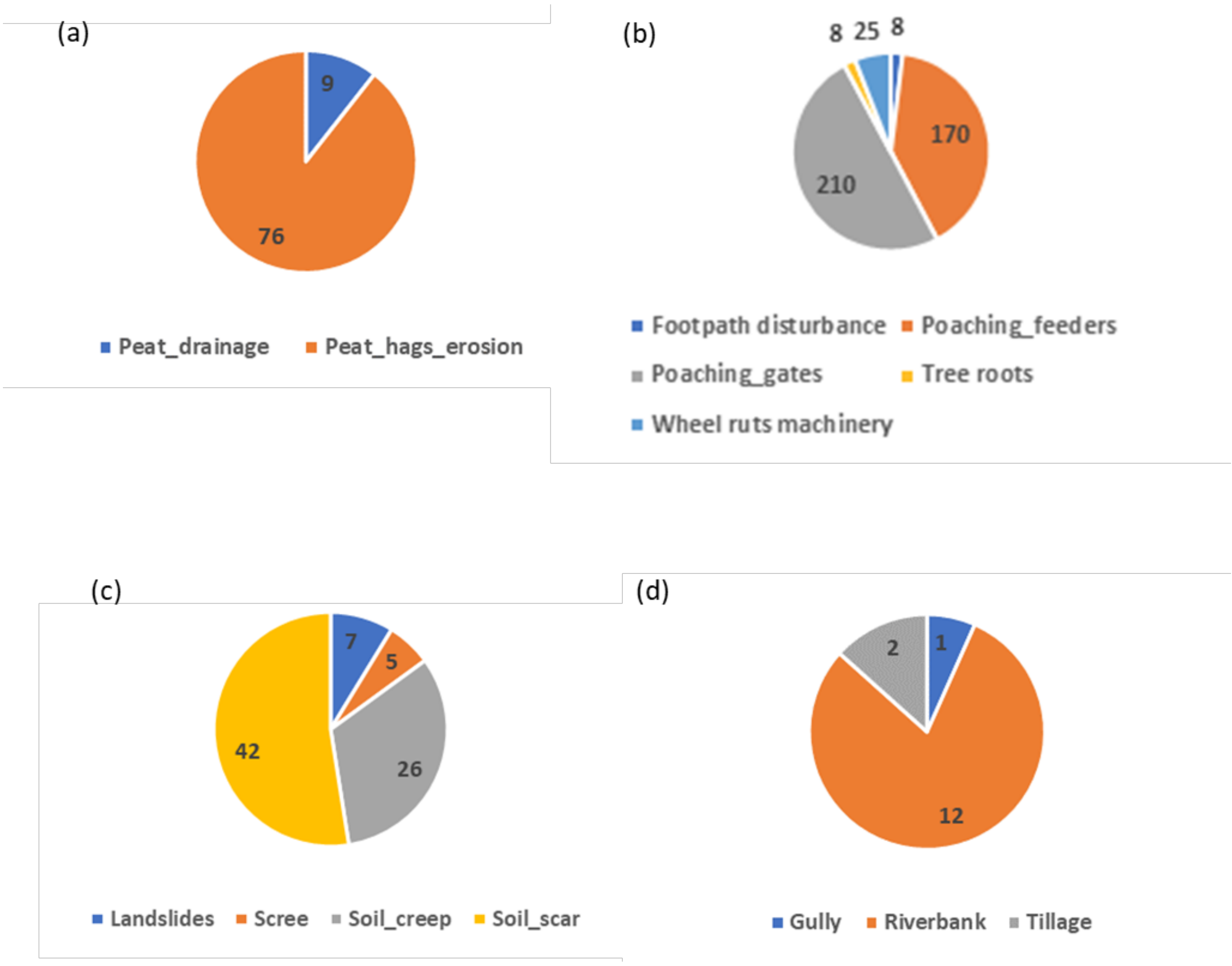


Figure 5.5: Number of subcategories events for (a) Peat, (b) Soil disturbance, (c) Mass movement, and (d) Soil Erosion general top-level categories. The number of events in each category are shown

5.3 Comparison of soil erosion / disturbance areas

Using the dataset outlined in Section 5.2 and for polygons where ‘first order’ areas could be calculated, a comparison of the distribution of the size of the eroded or disturbed areas were made. For the four major soil erosion/disturbance categories the broad distribution of eroded or disturbed areas are reasonably similar for the Peat, Mineral Soil and Mass movement categories. The distribution of areas in the ‘Soil Disturbance’ category was lower (Figure 5.6).

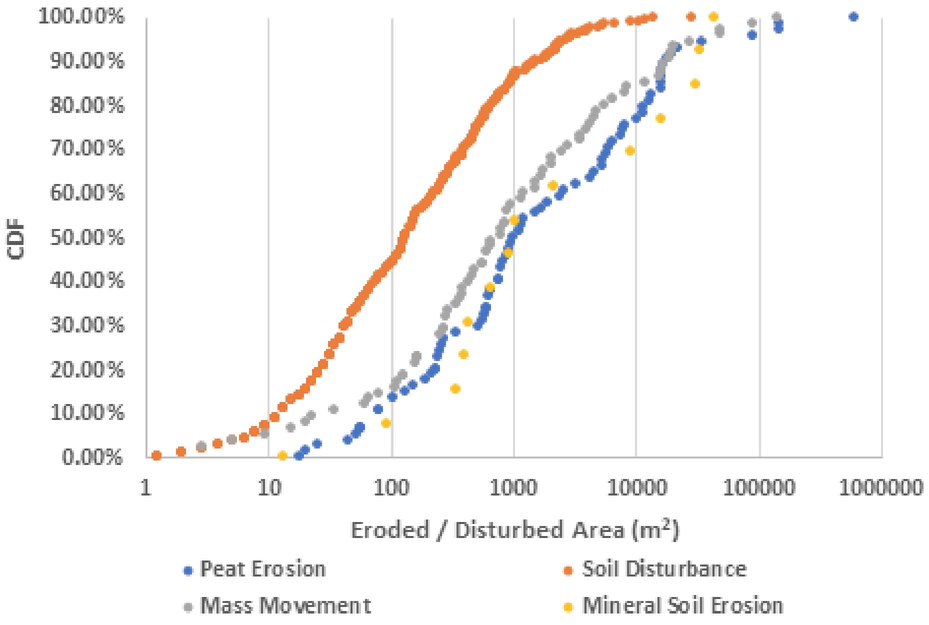


Figure 5.6: Comparison of the Cumulative Distribution Function (CDF) for soil erosion / disturbance areas associated with the four main categories of soil erosion / disturbance

In Figures 5.6-5.10, each of the 4 main categories are broken down into their subcategories. Figure 5.7 shows the cumulative distribution function for ‘Peat Erosion’. Peat hags have a median value of ~1000 m^2, and Peat drainage was between 300-700 m^2. For the ‘Soil Disturbance’ category the poaching around gates and feeders has a similar distribution of eroded / disturbed areas with a median area of ~100 m^2. However, both footpaths and wheel ruts appear to have greater disturbed areas with median values >500 m^2, but the sample sizes are a lot smaller (Figure 5.8). The ‘Mass Movement’ category shows that soil creep and terracettes tend to have the largest areas with a median value of ~3500 m^2 (Figure 5.9).

There were very few events recorded within the ‘Mineral Soil Erosion’ with only riverbank erosion having sufficient points to plot. This shows a median value for the area of erosion as being ~900 m^2 (Figure 5.10).

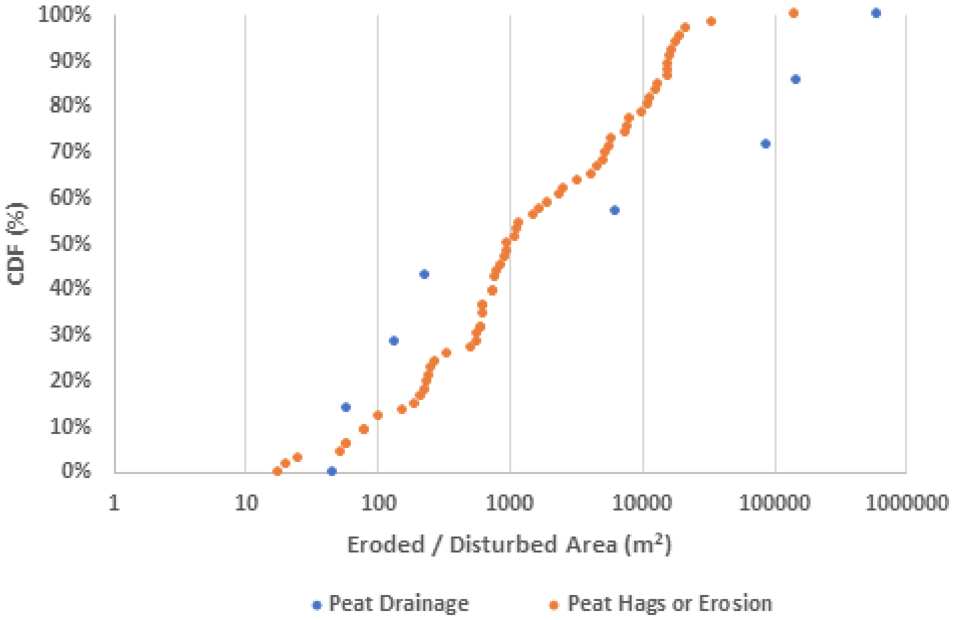


Figure 5.7: Cumulative Distribution Function (CDF) of %-ages of sub-categories in 'Peat' category

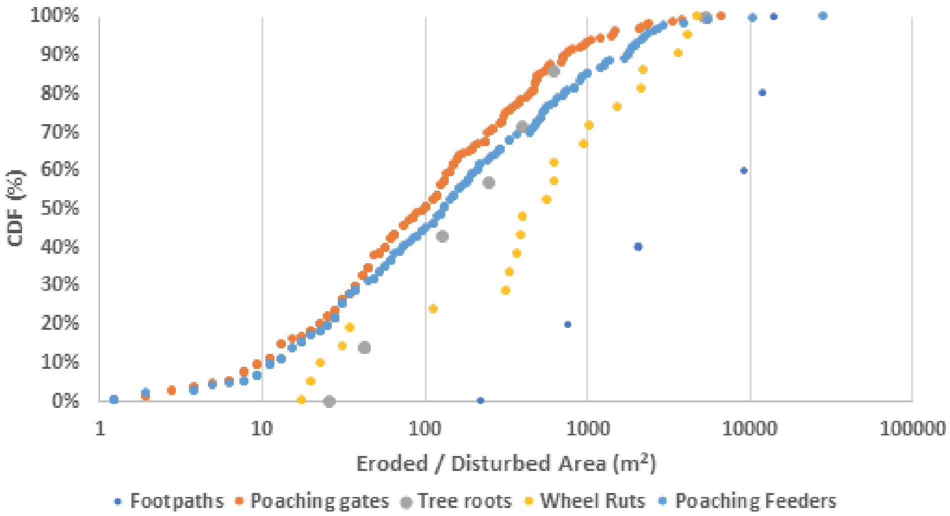


Figure 5.8: Cumulative Distribution Function (CDF) of %-ages of sub-categories in 'Soil Disturbance' category

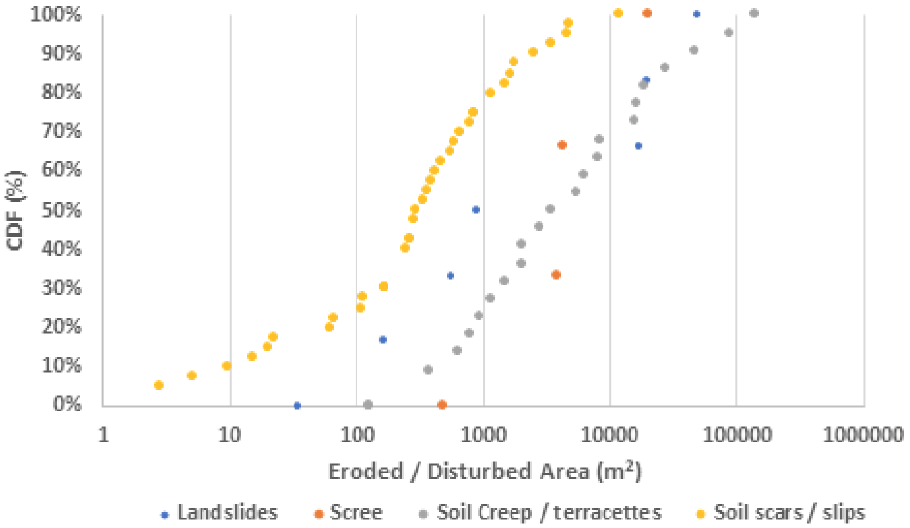


Figure 5.9: Cumulative Distribution Function (CDF) of %-ages of sub-categories in 'Mass Movement' category

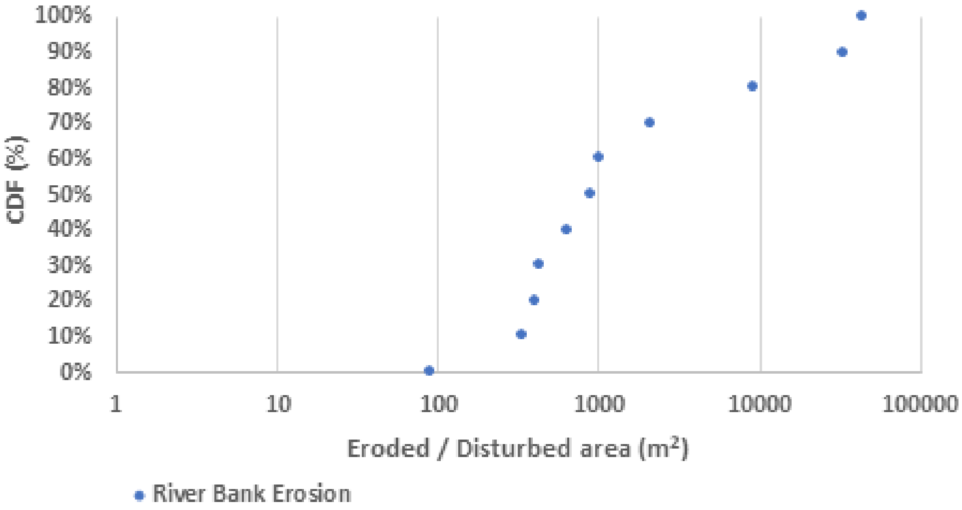


Figure 5.10: Cumulative Distribution Function (CDF) of %-ages of sub-categories in 'Mineral Soil Erosion' category

5.4 Comparison of the two surveys

An important test was to see whether the types and areas of erosion or soil disturbance events were similar between the two surveys. Again, we use the dataset from the ground-truthed survey (n=562) described in Section 5.2 and compare to the overall aerial survey data. Table 5.2 compares percentages of events from the aerial survey and the events recorded in the ERAMMP field survey (n=562). The percentages found in each survey for the top four categories are similar, and confirms that the Soil Disturbance category is the category with the largest number of soil erosion events.

Table 5.2: Percentages of Soil erosion or soil disturbance for the four top level categories and their sub- categories

	Aerial Survey				ERAMMP field survey			
	Mineral	Mass	Peat	Disturbance	Mineral	Mass	Peat	Disturbance
n	111	268	240	1961	14	76	75	397
% events	4	11	9	76	3	15	13	69

Drilling down into these results for each category we can see that the percentage of ‘Peat Erosion’ events were similar for the aerial and the ERAMMP field survey (Table 5.3). For the ‘Soil Disturbance’ events the percentage of events again were similar for the two surveys (Table 5.4). However, the ERAMMP field survey identified ‘Tree Roots’ disturbance and the Aerial survey identified yard erosion. For ‘Mass Movement’ events the percentages were very similar for the two main types of events recorded – soil creep and terracettes and soil slips and scars (Table 5.5). The ‘Mineral Soil Erosion’ events showed little tie up between the two surveys, but the size of the ERAMMP field dataset was very small.

Table 5.3: Percentages of soil erosion or disturbance for ‘Peat’

	Ariel Survey		ERAMMP field survey	
	Peat Drainage	Peat hags or erosion	Peat Drainage	Peat hags or erosion
n	27	213	9	76
% events	11	89	11	89

Table 5.4: Percentages of soil erosion or disturbance for ‘Soil Disturbance’ (where categories exist for comparison)

	Aerial Survey				ERAMMP field survey			
	Footpath	Poaching gates	Poaching Feeders	Substantial Vehicle	Footpath	Poaching gates	Poaching Feeders	Substantial Vehicle
N	4	945	847	62	8	210	170	25
% events	<1	48	43	3	2	50	40	6

Table 5.5: Percentages of soil erosion or disturbance for ‘Mass Movement’ events

	Ariel Survey				ERAMMP field survey			
	Landslides	Scree	Soil creep / Terracettes	Soil scar or slip	Landslides	Scree	Soil creep / Terracettes	Soil scar or slip
n	2	10	102	154	7	5	26	42
% events	1	4	38	57	9	6	32	53

Table 1: Percentages of soil erosion or disturbance for ‘Mineral Soil Erosion’ events

	Ariel Survey					ERAMMP Survey				
	Coastal	Drainage Ditch Erosion	Gully	Riverbank	General soil erosion	Coastal	Drainage Ditch Erosion	Gully	Riverbank	General soil erosion
n	3	16	6	23	63	-	-	1	12	2
% events	3	14	5	21	57	-	-	7	80	13

A further comparison between the two surveys can be made by comparing average and median erosion sizes. Below are tables comparing the mean, median and standard deviation of the initial aerial survey and the ERAMMP field survey.

Table 5.7 shows the comparison between the major 4 categories. The average values are likely to be skewed by large values at the top of the area range so the median value may be a better comparison. The median values for the ‘Soil Disturbance’ categories are fairly similar. However, the major types of poaching around feeders and gates are likely to be fairly constrained in size. Otherwise the median results (Tables 5.8-5.11) are roughly double in the aerial survey as compared to the ERAMMP survey. This may be because of the much smaller sample size of the ERAMMP survey, and the fact that it included more smaller areas of erosion or disturbance that the aerial survey could not identify. It was noticeable that when the sample size for any of the sub-categories were large, the median values appeared to be closer, as may be expected.

Table 5.7: Mean and Median areas (m^2) of soil erosion or disturbance for the 4 top level categories and their subcategories

	Aerial Survey				ERAMMP field survey			
	Mineral	Mass	Peat	Disturbance	Mineral	Mass	Peat	Disturbance
n	111	268	240	1961	14	76	75	397
Average	17840	7748	21598	700	9962	7341	17600	664
Median	2891	1543	2869	205	972	719	980	127
St dev	49904	18431	73165	2828	15095	20403	74123	2009

Table 5.8: Mean and Median areas (m^2) of soil erosion or disturbance for 'Peat Erosion' category

	Ariel Survey		ERAMMP field survey	
	Peat Drainage	Peat hags or erosion	Peat Drainage	Peat hags or erosion
n	27	213	9	76
Average	13941	22592	106857	6943
Median	4031	2836	3302	980
St dev	36053	76632	211319	18520

Table 5.9: Mean and Median areas (m^2) of soil erosion or disturbance for the 'Mass Movement' category

	Ariel Survey				ERAMMP field survey			
	Landslides	Scree	Soil creep / Terracettes	Soil scar or slip	Landslides	Scree	Soil creep / Terracettes	Soil scar or slip
n	2	10	102	154	7	5	26	42
Average	-	26286	10422	4824	12486	7205	17364	1084
Median	-	15885	4819	367	894	4102	3508	336
St dev	-	29355	20151	15425	18394	8786	33441	2144

Table 5.10: Mean and Median areas (m^2) of soil erosion or disturbance for 'Soil Disturbance' category (where categories exist for comparison)

	Ariel Survey				ERAMMP field survey			
	Footpath	Poaching gates	Poaching Feeders	Substantial Vehicle	Footpath	Poaching gates	Poaching Feeders	Substantial Vehicle
n	4	945	847	62	8	210	170	25
Average	941	253	933	1827	6377	351	722	1120
Median	692	154	253	420	5630	100	130	493
St dev	544	4470	3618	5274	6098	793	2525	1832

Table 5.11: Mean and Median areas (m^2) of soil erosion or disturbance for 'Mineral Erosion' category

	Ariel Survey					ERAMMP field survey				
	Coastal	Drainage Ditch Erosion	Gully	Riverbank	General soil erosion	Coastal	Drainage Ditch Erosion	Gully	Riverbank	General soil erosion
n	3	16	6	23	63			1	12	2
Average	-	8878	3956	2228	27787	-	-	-	8450	-
Median	-	3052	3756	127	4830	-	-	-	910	-
St dev	-	15996	2492	9002	63934	-	-	-	15438	-

6 Discussion

6.1 Practicalities of the Aerial and ERAMMP field surveys

Some comment on the logistics of the aerial survey were presented in ERAMMP Report-45 *Soil Degradation: Erosion & Compaction Phase-1*[1] (Tye & Robinson, 2020) and are worth repeating in this report, especially with the experience and data of the ground-truthed data from the ERAMMP field survey.

The methodology used 25 cm resolution aerial images, which are updated via a 3 year cyclic update programme, meaning that those used in this work undertaken in 2020 would have been collected since 2017. This means that the two surveys were not entirely contemporaneous. However, because the farming systems operated are unlikely to have changed dramatically, the same pressures on soil erosion and disturbance are likely to have persisted. For example, cattle and transport will still need to go through gateways, cattle will move to wooded and walled areas of fields to shelter, farmers will deposit feeders in similar positions, often close to gateways to avoid travelling on wet ground in the winter. These then could be considered as ‘inherent soil disturbance or erosion factors’ and are a possible reason for the reasonably high (~60%) number of sites identified in the aerial survey that were located in the subsequent ERAMMP field survey. The difference in time between when the aerial imagery was taken and the ERAMMP field survey is one that may be solved using the most recent satellite imagery and this was examined in ERAMMP Report-57: [2]￼ (Robinson et al., 2021).

The second factor concerns the resolution of the aerial imagery. The aerial survey requires aerial imagery that allows a good image within the GIS software to be obtained. A resolution at ~1:1250 (i.e. 1 cm on the screen represents 1250 cm in real life) appeared to be most effective with the imagery used. Higher resolutions tended to create pixilation, and in some cases removed the contextual setting of the landscape (often seeing the surrounding area helped in identifying erosion). Thus, there are limitations in identifying erosion and soil disturbance using even high-resolution imagery. This was also borne out by Figure 5.3 where it was noticeable that the field survey was able to identify smaller areas of erosion than using the aerial imagery. Discussion would need to be held regarding the minimum area of erosion/ disturbance that is required in any future monitoring schemes and linking to the best available resolution imagery. The resolution at which the polygons are marked is also a factor in how accurate the area measurement is of the polygons.

There were a range of issues due to resolution with the aerial survey that would not be found in the ground survey (ERAMMP Report-45; Tye & Robinson, 2020). Identifying peat erosion / bare peat / upland soil erosion was particularly difficult and required further analysis of sites using images from Google Earth, to build up a longer term understanding of what erosion processes may be operating. Issues included the following: (i) determining the differences between some vegetation types and soil / peat. These include distinguishing dried bracken and sedges from organo-mineral soil and peat as bare, dried surfaces are similar shades of brown; (ii) aerial imagery could not identify the smaller scale erosion processes such as sheet erosion. Evidence for soil erosion was often identified in the delivery zone at the bottom of

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[1] www.erammp.wales/45

[2] www.erammp.wales/57

slopes. This led to a ‘General Soil Erosion’ category being created for the aerial photos; (iii) erosion and disturbance were difficult to identify within woodlands.

One advantage of the aerial survey is that it may be less time intensive than field survey. The time required was about 2 to 2.5 hours for five 1 km squares. However, some heavily impacted squares (e.g. lowland dairy farming in Anglesey) may take 40 minutes or more. However, this time requirement did not include trying to delineate the many animal or vehicle tracks (incl. tramlines). These were found to be too numerous and diffuse for the time constraints of the project, but are potentially important in acting as erosion pathways through the channelling of water, which may end up in gully erosion features. It was noticeable that the identification of the ‘Wheel-Ruts-Machinery’ sub-category in the ERAMMP field survey was double in percentage terms (6.2%) when compared to the aerial survey (3.1%) within the number of events recorded in the ‘Soil Disturbance’ category. However, these features would be easily identifiable using a machine learning approach for which the aerial dataset provides a good training dataset for this automated approach.

6.2 Aerial Survey Results

Results of the aerial survey reflect the major drivers of erosion (precipitation, slope, vegetation, soil texture, altitude) and agricultural land uses in Wales. Thus, the following main points can be drawn from the results.

(i) Soil disturbance is more prevalent than soil erosion events reflecting the nature of the agricultural landscape in Wales and it being largely grassland farming. Vegetation coverage is a key variable in reducing the impact of wind and water erosion, dissipating energy and also reducing the soil pore water pressure through evapotranspiration. In grassland areas we would expect soil erosion generally to be low, although animal and vehicle tracks may instigate some rill of gully erosion on slopes.

(ii) As arable agriculture is only a small part of the agriculture system in Wales the extent to which the assessment of erosion in these systems by aerial photography was not extensively tested. This also applies to the cultivation of maize as animal feed, which is likely to increase in the future. Most cultivated land appeared to be recently sown with maize, and dry or in full vegetation in the photos reflecting the time of the growing season (as expected in May time when most of photos taken). A larger dataset of events from squares with arable agriculture would be useful as these were not represented well within the 1 km x 1 km squares chosen.

(iii) Soil disturbance largely reflected the movements of animals and vehicles that are associated with livestock and their husbandry. Thus, disturbance around feeder areas, shelter areas and around gateways are commonplace. In addition, several large poaching areas were identified where animals (cattle) were being held prior to or after milking, or as a part of winter shelter. These occurrences must be considered as being ‘inherent soil disturbance’ associated with the agricultural systems in place.

(iv) The responses to erosion are detailed within the text. Overall, there is substantial evidence that those drivers (precipitation, slope, vegetation, soil texture, altitude) were seen to influence both the frequency of events and the size of erosion area through the aerial survey.

(v) The areas of individual soil disturbance and erosion polygons cover several orders of magnitude, although most recorded events (>90%) are less than 1 ha in size, and 70%

of events are < 1000 m altitude, with 30% of events being between 100-1000 m^2 in size.

(vi) Footpath erosion did not feature highly in the survey. This is an area of concern, as erosion often results as a consequence of footpath overuse. The low recognition of them was partly as few were picked out in the squares examined and because they are also at the limits of photo resolution. Figure 6.1 shows a typical footpath, at about maximum resolution possible (1:800). The resolution issue may make it hard to use EO to look at footpath disturbance. Given we know where many footpaths are, e.g. based on Ordnance Survey (OS) data a methodology could likely be produced to use the OS data to constrain where to look for disturbance and determine the scale of the issue.

Figure 6.1 Image showing maximum resolution of a typical footpath in aerial imagery. The bottom part of the image is the OS map with footpath marked.

Contains OS data © Crown copyright and database rights 2022; Derived in part from DTM of Great Britain at 5m resolution © Bluesky International Limited

6.3 ERAMMP field survey

The analysis of the ERAMMP survey covered the re-identified aerial survey polygons in the 200 m circles and any new polygons the surveyors found. Generally good agreement was found between the surveys, in terms of estimated area, type and frequency of erosion event identified. Numbers of samples had an impact when assessing mean and median values between the two surveys. This may have been down to the surveyor led survey identifying smaller polygons, beyond the resolution of the aerial survey.

The ERAMMP field survey ground-truthing of BGS identified soil erosion/disturbance features was limited to up to five 200 m circles. Firstly, this is a considerably smaller area than covered by the BGS aerial survey, potentially missing areas of erosion. Secondly, the plot locations were not random in the landscape, but located in commonly found habitats across the 1 km x 1 km survey square, potentially introducing a bias on the distribution of erosion features within the circles.

6.4 Comparisons with previous surveys

The purpose of undertaking these combined surveys was to assess the relevance of the technique to monitoring soil erosion on a national scale, revealing trends with respect to erosion and disturbance. Results need therefore to be assessed in relation to other surveys. In particular results from the aerial survey should be compared to a previous study be McHugh et al. (2002) who undertook a field survey of erosion at sites in upland England and Wales, between 1997 and 1999. They visited 399 field sites and estimated that 25000 ha or 2.46% of the total upland area surveyed suffered from soil degradation, although almost half had been re-vegetated. Taking data from Figure 4.53, which describes the range of erosion in the 1 km^2 squares, we found that a median value of 0.67% of land was degraded in each square. A mean percentage of erosion / disturbance across the survey squares of 4.06% is however found in this report, which is higher than the McHugh et al. (2002) value. This comes from 261 1 km x 1 km squares surveyed and a total area of degraded soil as 10,613,884 m^2. With respect to the length of time taken to conduct the survey no indication was provided in McHugh et al. (2002) so a comparison of whether the aerial photography approach offered greater efficiency can't be made.

Evans (2002) assessed arable land in England by surveying fields and found that on average 14% of the arable landscape was eroded each year (range: 1.5-24%) on sandy soils, 3.9% of silty fields and 1.6% on clayey soils. These figures obviously reflect different farming systems than are generally present in Wales. Previous surveys also tended to report soil erosion as a volume eroded as a key measure (e.g., Chambers & Varwood, 2000). This may have been due to the lack of useful GIS systems in the past. However, with respect to monitoring via aerial photos, area is a consistent measure that can be applied.

6.5 Conclusions and further work

High resolution aerial photography was assessed as a basis for being a methodology that could be used to monitor soil erosion and disturbance on a national scale across Wales, and provide a basis for repeatable analysis. Results suggest that within its limitations (e.g., size of erosion area that can be found) it could be a valuable tool. ERAMMP Report-57 (Robinson et al. (2021) tested the applicability of using high resolution satellite imagery in a similar manner and this worked as well as the aerial imagery used. The advantage of the satellite imagery is that it could be provide more up to date images. What the methodology fails to achieve is to identify the small-scale erosion events such as those through rill erosion. On the plus side in the Welsh landscape, arable acreage is low and it identifies grassland erosion and disturbance well, thus being able to give a baseline. The other benefit of this approach is that there is potential for it to be undertaken using machine learning systems to automate the assessment. The current dataset could act as a training dataset for such an approach.

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