Climate Change and Cultural Heritage:

developing a landscape-scale vulnerability framework to measure and manage the impact of climate change on coastal historic landscapes

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Abstract

The impacts of climate change, including sea-level rise, coastal erosion, and flooding, have the potential to damage or destroy archaeology and cultural heritage assets. Most studies that have modelled or measured the impact of coastal and climatic processes on archaeology have focussed on archaeological features as discrete entities rather than as part of the historic landscape. The results, therefore, can only inform a comparison between single sites and do not reveal threats to the wider cultural heritage and historic landscape.

This thesis develops a Landscape Vulnerability Framework, which uses several methodologies to establish the vulnerability of the historic landscape to climate change and identify sustainable management approaches. Each step of the framework is tested on the Dysynni valley and estuary (west Wales), which acts as a pilot study for the methods being developed.

Historic Landscape Characterisation characterises the historic landscape into definable areas with similar form, function and history. This is based on an analysis of aerial photographs, modern and historic maps, archaeological database records, archive research, and geophysical surveys.

A two-step vulnerability index is then developed to determine the vulnerability of the historic landscape to climate change. The first step assesses the vulnerability of archaeological sites and landscape features to climate change. The second step uses the results of the first vulnerability index, as well as spatial data on the landscape character areas and the threat in question, to calculate the vulnerability of each landscape character area to climate change.

The results of the vulnerability index are used to inform a sustainability assessment of different potential coastal and flood-risk management options. A multi-attribute value theory is used to calculate the level of impact that different management approaches would have on the most vulnerable historic landscape character areas, the local ecology, economy and community.

The Landscape Vulnerability Framework developed in this thesis can be applied to landscapes in the UK and beyond. It will provide a simple, well defined method for policy-makers and heritage organisations to effectively consider the vulnerability of the historic landscape to climate change, and inform a holistic, proactive approach to the sustainable management of cultural heritage.

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List of Abbreviations

AOGCM	Atmosphere-Ocean Global Circulation Model
BGS	British Geological Survey
CCW	Countryside Council for Wales
CHERISH	Climate Heritage & Environments of Reefs, Islands and Headlands: an EU funded project
DBA	Desk-based Assessment
EIA	Environmental Impact Assessment
ESM	Earth Systems Models
GAT	Gwynedd Archaeological Trust
GCM	General Climate Models
GHG	Greenhouse Gas
GIS	Geographic Information System
HEG	Historic Environment Group
HER	Historic Environment Record
HLC	Historic Landscape Characterisation
IPCC	Intergovernmental Panel on Climate Change
JNCC	Joint Nature Conservation Committee
LCA	Landscape Character Area
LCF	Landscape Character Feature
MAVT	Multi-attribute Value Theory
MCDA	Multi-criteria Decision Analysis

NMRW	National Monuments Record of Wales
RCAHMW	Royal Commission on the Ancient and Historical Monuments of Wales
RCM	Regional Climate Models
RCP	Representative Concentration Pathway
SMP	Shoreline Management Plan
SNPA	Snowdonia National Park Authority
SRES	Special Report on Emissions Scenarios
SSSI	Site of Special Scientific Interest
UKCP	United Kingdom Climate Projections
UKRI	United Kingdom Research Institute
UNESCO	The United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
VI	Vulnerability Index

Acknowledgements

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Chapter 1

Introduction

1.1 Background to Research

Climate change is one of the most widely-debated and contentious phenomena of the 21st century, although 98% of climate scientists agree that anthropogenic greenhouse gas (GHG) emissions have been the dominant cause of the recorded global temperature increase over the last half-century (Anderegg *et al.* 2010). This warming trend is predicted to increase in the foreseeable future, and will result in rising sea levels, changing weather patterns and exacerbated natural disasters (Kirtman *et al.* 2013). The impacts of these changes on ecological systems, and farming and subsistence economies will be severe, and include shifting habitat biomes and species ranges, altered growing seasons and life-cycles, disrupted food-webs, disease and parasite spread, and intensified droughts and floods (see Knox *et al.* 2010; King *et al.* 2018). These impacts, and potential adaptive approaches, are well researched within ecology, environmental sciences and agricultural sciences (e.g. Parmesan 2006; Rosenzweig *et al.* 2008; Nelson *et al.* 2009).

Climate change also poses a threat to cultural materials and heritage, through desiccation, erosion, weathering, inundation, and bioturbation, but this has been less thoroughly researched than the environmental or economic impacts (Hermann 2017). The threat of climate change is particularly significant in coastal areas, which are prone to accelerating rates of erosion due to sea-level rise and increasing storminess, causing archaeological remains located on the foreshore and in cliffs to be at risk (Murphy and Ings 2013). Coastal erosion is known to have destroyed over 150 documented settlements around the North Sea in the last millennium, such as Eccles, Clare, Foulness, Keswick, and Shipden (Custard 2017; Sear *et al.* 2011). Furthermore, coastal lowlands are at risk of more frequent flooding or even permanent inundation due to sea-level rise (*ibid*.)

Archaeological materials are a finite resource, and the information held within archaeological deposits can facilitate our understanding of past societies, environmental change, and the historic interaction between humans and their environment. Coastal regions in particular often have a higher density of archaeological remains than inland areas (Dawson 2013). Coastal cities and societies were important throughout the development of civilisation, so coastal archaeological sites are often rich in artefacts that can indicate the extent of trade networks (Bailey 2004). However, many historic coastal towns are now threatened by erosion and sea-level rise, so both cultural heritage and coastal communities are at risk (Murphy and Ings 2013). The waterlogged environmental conditions along many coastlines and in the subtidal or nearshore zone mean that there is a high potential for the preservation of organic remains (Fischer 2004, DONG Energy 2013). For instance, 30 Mesolithic canoes have been discovered off the coast of Denmark, while in the intertidal zone of Cardigan Bay, Wales, the preserved remains of a forest contains environmental and archaeological information from the Bronze Age and earlier (Godwin and Newton 1938; Milner 2012). The importance of coastal regions for archaeological information is high, and therefore it is especially important for the threat of climate change to be addressed. In order to effectively address this threat to cultural heritage, it is essential that archaeologists and heritage managers fully understand the ways in which cultural heritage is vulnerable to the myriad of impacts that may occur.

1.2 Previous Research

There has been some research on the threat of climate change to archaeology on several jurisdictional levels. Internationally, the EU-funded Noah's Ark project studied which meteorological changes will have the most impact on built historic structures (CORDIS 2007; Brimblecombe *et al.* 2011). UNESCO has funded research into the impacts of climate change on World Heritage sites such as Orkney (Scotland), Chavin Palace Complex (Peru), the monumental site of Panamá Viejo (Panama), and the ancient city of Timbuktu (Mali) (Colette 2007a; Ciantelli *et al.* 2018; Mullaney 2019). The purpose of both the UNESCO and Noah's Ark research is to identify which sites are most at risk, and the nature of the threat, in order to inform policy-makers and adaptation strategies.

In the UK, the National Trust is conducting research into the risk posed by climate change to its historic properties and developing adaptation plans for each, with particular focus on those in coastal areas (see National Trust 2015a). They suggest working with coastal processes where possible, and taking a long-term perspective, in order to transition into more sustainable management approaches for heritage sites (*ibid*). English Heritage undertook a scoping study on climate change and the historic environment, to identify gaps in information and produce general recommendations such as promoting and supporting local decision-making, identifying a way to prioritise sites for conservation and protection, and using impact information to develop adaptation strategies and guidelines (Casser 2005). Finally, the Historic Environment Group (HEG) Climate Change Subgroup, an advisory group that advises Welsh Ministers, produced a report on the potential impact of climate change on the historic environment of Wales (see Powell *et al.* 2012; Murphy and Ings 2013). This report divided historic assets into nine groups based on asset type or location, for example assets below the one metre contour, assets on the foreshore, historic buildings, forestry and woodland, historic landscapes, and assets in upland environments. This is the only report that looked specifically at the impact of climate change on historic landscapes and determined that climate change threatens not only the historic assets within landscapes, but the character of historic landscapes themselves (*ibid.*). In a report about sustainable management of heritage assets, Cadw (2011) briefly discuss historic landscapes as heritage assets, and the potential impact of climate change on the ecological elements of historic landscapes. However, there is no specific mention of sustainable management of historic landscapes in the face of climate change.

The focus of this thesis is on historic landscapes as heritage assets. The HEG Climate Change Subgroup report estimated that historic landscapes will be the heritage asset most affected by climate change, due to the cumulative impact on the individual heritage assets within the landscape, as well as the woodland, parks, and gardens that characterise historic landscapes (Powell *et al.* 2012). Furthermore, the focus of impact and adaptation research in archaeology tends to be on single sites, buildings and monuments. This means that historic landscapes are an overlooked historic asset. This thesis follows two of the general recommendations produced by English Heritage: 'identify a way to prioritise sites for conservation and protection', and 'use impact information to develop adaptation strategies and guidelines' (Cassar 2005) (see 1.4).

1.3 Justification for Research

The importance of assessing and addressing the vulnerability of cultural heritage on a landscape scale, rather than on a site-by-site basis, is demonstrated by the limitations of a number of site protection projects. Matero (2008) states that the management and conservation of archaeological sites can result in a loss of place, and impact the visual integrity and legibility of the site within a landscape. Shelters are often constructed over archaeological sites to protect them from erosion, weathering, precipitation, and sunlight (Teutonico 2013), but this can have many unforeseen negative impacts. For instance, shelters can isolate archaeological features from their surrounding landscape, making them appear as independent artefacts, and therefore obscuring the relationships between features and their environs (Thompson and Abed 2013). This can be seen at Chur, Switzerland, where a closed wooden pavilion was built in 1986 to cover Roman remains (see Figure 1.1). The original Roman structures were single-storey, and the remains are now at ground level, but the shelters constructed are taller than a two-storey building (Martin 2013). These structures not only visually disrupt the landscape, but by covering the Roman remains, they remove the Roman character from the historic landscape and obscure the connection between the remains and their environment. Management approaches like this privilege the scientific and research value of the physical remains over the associative and aesthetic values of the site within the landscape (Matero 2008).

Shelters can also impact the character of the historic landscape as a whole. At Ephesus, Turkey, the remains of an ancient city including Persian, Hellenistic, Roman, Arabic, Byzantine and Christian remains, a shelter was built over a small section of the excavation (Bellibaş 2013). The shelter is stark white against the muted greens, browns and beige of the landscape, and is the most visible feature in the environment for many miles (see Figure 1.2). Shelters like this dramatically alter the character

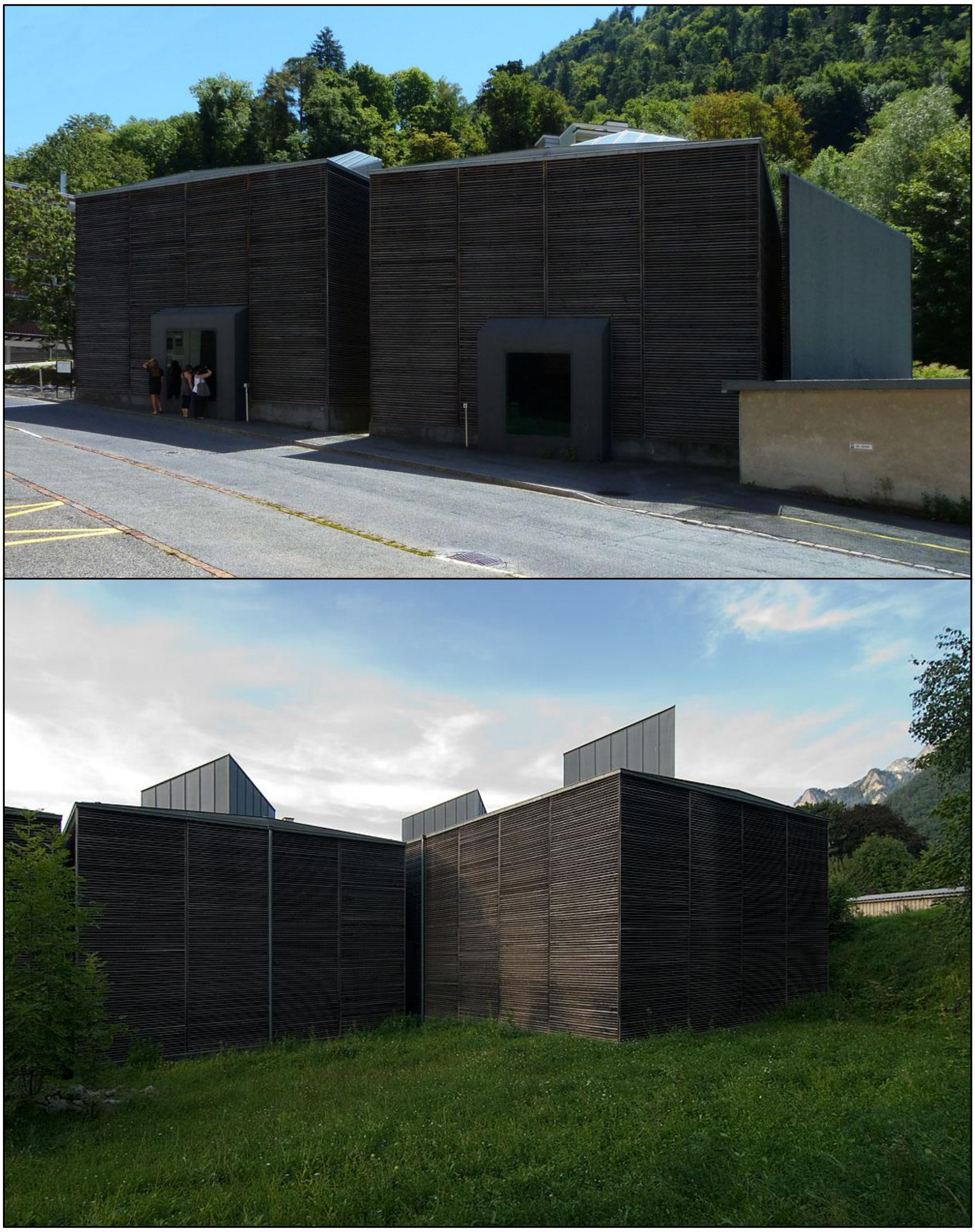


Figure 1.1: *Wooden pavilion constructed to protect Roman remains at Chur, Switzerland, obscuring them within the landscape. Copyright Pol Martin 2013 and Petr Šmídek 2008*

Figure 1.2. *A shelter constructed to protect some of the remains of the ancient city of Ephesus, Turkey. Copyright Ephesus Foundation 2016, Austrian Archaeology Institute 2019, and EarthTrekkers 2019*

of the overall landscape, as well as obstructing the view of the site, and are the result of a site-focussed cultural heritage management approach (Teutonico 2013).

Although these examples come from continental Europe, site-focussed cultural heritage management is also a risk in the UK. In a report for the HEG Climate Change Subgroup, Powell *et al.* (2012) warn that the construction of coastal and flood defences could impact the character of the historic assets and settlements that they are designed to protect. They estimate that the most serious impact of climate change on British settlements will be the impact on the historic character caused by coastal and flood defences (*ibid*.). Environmental Impact Assessments (EIAs) of such developments are required to consider cultural heritage. However, the predominance of list-based heritage management in the UK (Historic Environment Records, National Monuments Record) means that the EIAs often just consult existing national registers (King 2006). These registers can be incomplete for a number of reasons, including a lack of systematic survey in some landscapes, and a focus on architecturally or scientifically important sites rather than culturally significant areas (*ibid*). Cultural heritage as defined by lists and point-data also obscures the intangible elements of cultural heritage, such as local tradition, land-use, and sense of place, and geographically larger areas that cannot be easily defined as points, such as scattered remains or spiritually significant landscapes (*ibid*.)

Evidently, piecemeal protection of heritage assets, and site-focussed management structures, can fail to consider the impact of protection and management on the wider historic landscape. However, the historic landscape, defined in section 3.2.3 , is a cultural heritage artefact which is as at risk from climate change as any other asset.

1.3.1 Dunwich, Suffolk

The example of Dunwich, Suffolk, demonstrates the potential impact of climate change, and associated sea-level rise and coastal erosion, on historic landscapes. Dunwich currently has a population of less than 200 (ONS 2011), but was once a large port. During the 14th century it was similar in size to London at the time, and was an important centre for shipbuilding (Sear *et al.* 2015). The local geology is particularly susceptible to coastal erosion, with large areas recorded to have been lost in single events over the last 1000 years (Sear *et al.* 2011). The cultural heritage and historic character of the town has been destroyed due to erosion: Dunwich was unable to continue to act as a centre for trade following the loss of the market place and town hall in the 17th century; while the All Saints church, St Mary's Temple, Maison Dieu hospital and Franciscan Friary were all damaged or destroyed in the 18th - 19th centuries (see Figure 1.3) (Sear *et al.* 2011.). The loss experienced at Dunwich does not relate just to the disappearance of individual buildings and sites in isolation, but also to the loss of the heritage of the town and the historic character of the urban landscape. Climate change is projected to accelerate and exacerbate the coastal processes that here destroyed a whole urban landscape, and therefore has the potential to cause similar losses in both urban and rural historic landscapes.

Figure 1.3. *Map indicating coastline position and retreat at Dunwich, Suffolk, each century during the second millennium AD. The extent of loss of the urban landscape and cultural heritage at Dunwich to due coastal erosion is shown. Source: Discovering Britain, Copyright RGS-IBG*

1.4 Aims and Objectives

The range of impacts associated with anthropogenic climate change will undoubtedly have an effect on the archaeological resource, particularly in coastal areas. The archaeological resource can encompass any and every trace of past human activity, whether that is a single findspot or a landscape-wide relic field system. However, most studies researching and addressing climate change impacts on archaeology focus exclusively on archaeological 'sites' (see sections 2.7 and 7.2.5). This overlooks processes and impacts that occur at a higher or lower spatial level than that of 'sites'.

This thesis is guided by a single research question: *How can the vulnerability of cultural heritage to future climate change be assessed and managed at a landscape scale?*

A Landscape Vulnerability Framework is developed to address this research question. Within the framework, Hierarchy Theory and Historic Landscape Characterisation (HLC) are used to expand the spatial scope of archaeological analysis. These methods incorporate the wider historic landscape by creating a spatially continuous, landscape-level structure that can be used in vulnerability assessments. This addresses the problems caused by site-focussed vulnerability assessments and informs the sustainable management of the vulnerable historic landscape in the face of climate change.

A case study in northwest Wales, the Dysynni valley, is used to trial and exemplify the methods and Landscape Vulnerability Framework developed in this thesis. Although the results of applying the Landscape Vulnerability Framework to the Dysynni valley are discussed, the intention was to create a framework that can be adapted and applied to any historic landscape in the UK and beyond, in order to establish a universal methodology for analysing and addressing the threat of climate change to historic landscapes.

Three research aims were developed that feed into the overall research question, each of which is implemented using several research objectives.

Research Aim 1

The first research aim is to i*dentify a method of analysing and characterising the archaeological resource on a landscape level.* To develop a Landscape Vulnerability Framework, it is first important to identify, measure and characterise the archaeological resource of the landscape. The Dysynni valley study area is used to illustrate the methods chosen

Objectives

1a) Collect information on the known archaeological resource in the Dysynni valley

1b) Use aerial photography and geophysical surveys to enrich the archaeological record of the Dysynni valley

1c) Use Historic Landscape Characterisation to characterise the historic landscape of the Dysynni valley.

Research Aim 2

The second research aim is to *develop a landscape-level archaeology vulnerability assessment methodology*. This methodology is a key element of the Landscape Vulnerability Framework, and was developed to be applicable to other contexts, so the framework can be replicated for other historic landscapes.

Objectives

2a) Determine the potential climatic changes in the Dysynni valley in the 21st century based on the results of a variety of climate models

2b) Develop a vulnerability index for measuring and quantifying the vulnerability of historic landscapes, informed by the strengths and limitations of other archaeology vulnerability assessments

2c) Apply the vulnerability assessment established in 2b to the Historic Landscape Characterisation output for the Dysynni valley (objective 1c), to identify any weaknesses in the methodology developed

Research Aim 3

The third research aim is to *establish a way to identify the most appropriate approach(es) for sustainably managing the coastal historic landscape in the face of climate change.* The final part of the Landscape Vulnerability Framework uses the outputs from the vulnerability assessment (Research Aim 2) to inform the most suitable and sustainable approaches to managing the risk identified. In line with the concept of sustainability (see section 3.2.4), this includes consideration of the economic, social and ecological impacts of different management approaches, as well as the archaeological impacts.

Objectives

3a) Identify, through literature research, a sustainability assessment approach that could be used in the Landscape Vulnerability Framework

3b) Review the current coastal and flood-risk management approaches in the Dysynni valley, and research innovative sustainable alternatives

3c) Use the sustainability assessment approach (Objective 3a) to compare the current management policy in the Dysynni valley with potential alternatives identified in Objective 3b. This tests the suitability of applying this sustainability assessment methodology to the output generated in Research Aim 2.

1.5 Thesis Outline

The structure of this thesis is represented diagrammatically in Figure 1.4. After the Introduction (Chapter 1), there is a literature review of the current understandings of the potential impacts of climate change on archaeology, particularly in coastal areas (Chapter 2). Chapter three outlines the methodological approach followed in this thesis, including the conceptual framework and an explanation of how the methods chosen address the research aims. Chapter four provides an overview of the study area used to trial and exemplify the methods developed and used in this thesis. To address Research Aim 1, several primary and secondary research methods are used to enrich the archaeological understanding of the study area (Chapter 5) and inform a Historic Landscape Characterisation (Chapter 6). Chapter 7 addresses Research Aim 2, and involves the development of a landscape-scale vulnerability index, which is applied to the historic landscape as characterised in Chapter 6. This is based on a literature review of vulnerability assessment methodologies used in archaeological research, and addresses several of the limitations identified in common methods. In Chapter 8, Research Aim 3 is addressed, and a sustainability assessment methodology is developed to address the vulnerability of the historic landscape, as identified in Chapter 6. This involves a review of the current coastal and flood-risk management practices in the study area, an exploration of sustainable management approaches that could be employed, and a review of common sustainability assessment methods. Finally, Chapter 9 provides a summary of the thesis, the implications of the findings of this research, and recommendations for future research.

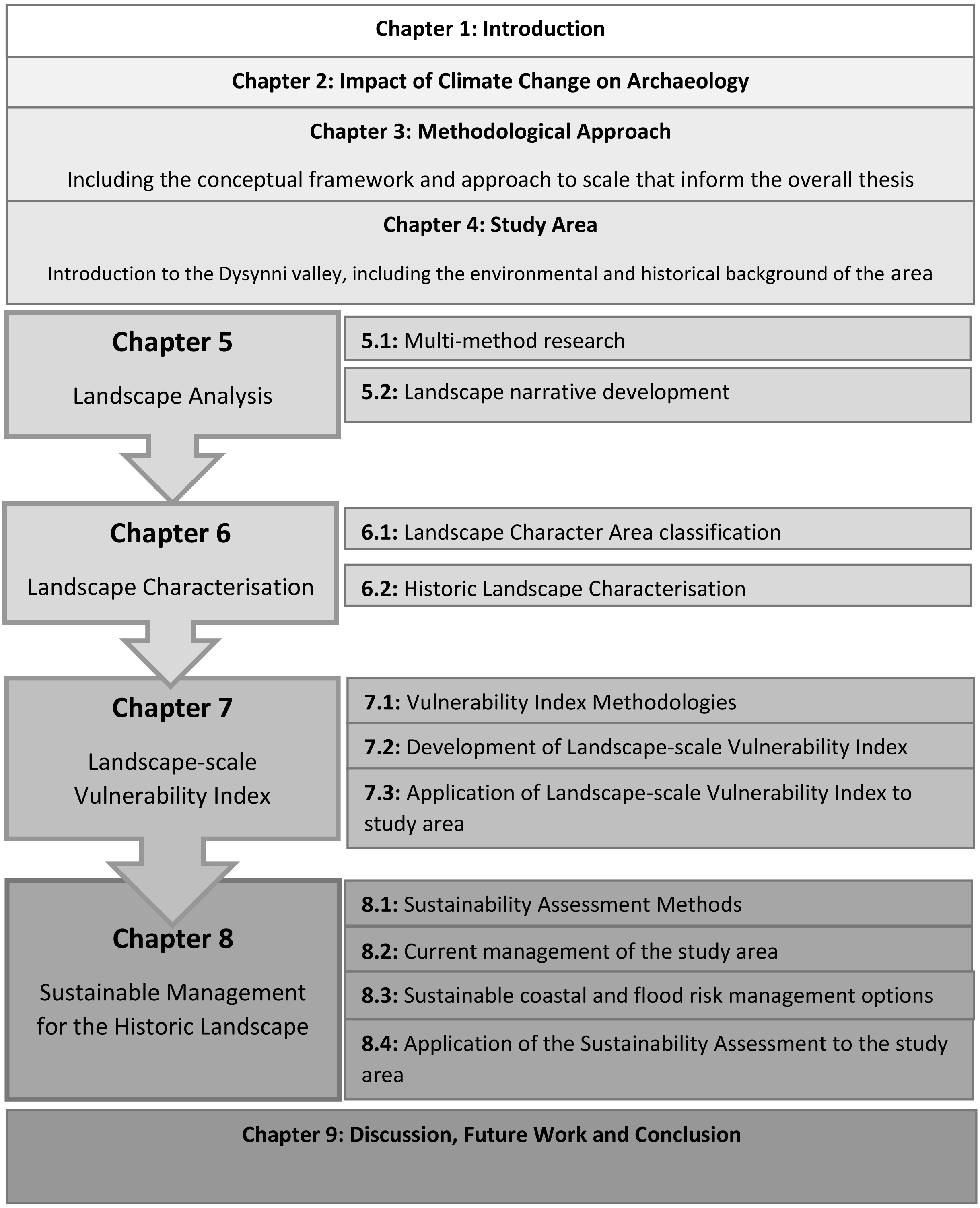


***Figure 1.4**: Visual diagram of the thesis structure*

1.6 Delimitation of Scope

It is necessary to define the scope of this research, as phenomena discussed throughout such as climate change, cultural heritage, and historic landscapes, have broad and often different meanings depending on the research study or discipline.

1.6.1 Climate Change

Despite the contentious nature of the climate change debate within the media, this thesis is based on the belief that increasing radiative forcing, and therefore increasing average global temperatures, is occurring due to anthropogenic GHG emissions. The focus of this thesis is on the projected climatic changes, and associated impacts, for the 21^{st} century. The uncertainty surrounding future emission pathways, and the lack of understanding of the impact of increased CO_2 concentrations on atmospheric and ocean processes, means that any projections or recommendations made for longer time-scales would be too unreliable (Schneider 2002; Maslin and Austin 2012; Collins *et al.* 2013; Hawkins *et al.* 2014).

1.6.2 Cultural Heritage

Cultural heritage is mentioned throughout this thesis, and is mainly referring to any *material* remains of human activity, including archaeological features, buried remains, historic buildings, and monuments (UNESCO 2010). Infrequently within this thesis it is also used in its intangible sense, to refer to the collective culture, traditions, and way of life of communities (e.g. UNESCO 2011). The meaning of cultural heritage that is being used is evident in the context, but it is most frequently used to refer to tangible assets.

1.6.3 Historic landscape

The concept of the historic landscape is discussed in greater detail in section 3.2.3. It is important to clarify that although the Introduction (1.2) mentions 'historic landscapes' as individual entities, as they are discussed in Welsh historic environment literature (e.g. Murphy and Ings 2013), this thesis uses the concept of the historic landscape as a continuous, dynamic artefact of past and current land use (see Fairclough *et al.* 2002). In Wales, Cadw has created a register of historic landscapes, which defines areas of special or outstanding historic interest (Cadw 2016). This means that these landscapes are more highly valued for their cultural heritage assets and are prioritised in terms of management. This approach implies that some areas of the landscape are 'more historic' than others, when in reality all of the British landscape has been occupied, used and managed by humans at some point in history. The concept of the historic landscape used in this thesis recognises the historicity of all landscapes, by acknowledging the existence of the historic landscape in all areas (Turner 2018; see section 3.2.3).

1.7 Summary

This chapter has introduced and justified the research topic of the thesis. The overall research question is *How can the vulnerability of cultural heritage to future climate change be assessed and managed at a landscape scale?* To address this research question, the Landscape Vulnerability Framework is developed as a conceptual and methodological approach for assessing and managing the vulnerability of the historic landscape to climate change.

Each of the research aims develops one of the three steps of the framework: a method for analysing and characterising the historic landscape (Research Aim 1 – Chapters 5 and 6); a vulnerability assessment methodology for the characterised historic landscape (Research Aim 2 – Chapter 7); and a sustainability assessment for management approaches to address the identified threat (Research Aim 3 – Chapter 8). The study area location was chosen for both practicality and its apparent vulnerability, which is explored in greater depth in Chapter 4. The following chapter (Chapter 2) reviews the impacts of climate change on archaeology, in order to further contextualise this thesis and provide a solid foundation for developing the Landscape Vulnerability Framework.

Chapter 2

Impact of Climate Change on Archaeology

2.1 Introduction

In order to measure and address the vulnerability of the historic landscape to climate change, it is important to understand the various mechanisms by which it threatens cultural heritage. This chapter provides a review of the potential ways that the impacts of climate change could damage archaeological and historic resources. First, there is a brief overview of the process of climate change and the general modelled climate change projections (2.2). Secondly, the potential impacts of different climatic changes on cultural heritage are discussed. This is divided into impacts associated with temperature change (2.3), impacts associated with changing weather patterns (2.4), and indirect impacts (2.5). Finally, the implications for the historic landscape are discussed (2.6).

2.2 Climate Change and Climate Projections

Increasing GHG concentrations in the atmosphere due to anthropogenic activities will cause, and indeed are already causing, changes to global weather and climate (see Figure 2.1). The 'greenhouse effect' of CO_2 and other GHGs causes an increase in radiative forcing, which means that more of the sun's radiation is being absorbed as less can radiate back into space (Forster *et al.* 2007). The resulting rising global temperatures are predicted to increase the rate of polar ice cap and glacial melting and cause thermal expansion of the ocean, leading to sea-level rise (IPCC 2013). Global average sea-level rise has shown an accelerating trend over the past few decades, from +1.8mm per year (yr^{-1}) between 1961-2003, to +3.1mm yr^{-1} between 1993-2003 (Murphy *et al.* 2009). Modelled future rates of sea-level rise are up to 16mm yr^{-1} by 2100 (Church *et al.* 2013).

Increased radiative forcing also causes changes to air and ocean circulation patterns, which can have dramatic impacts on weather patterns. For instance, a rise in sea-surface temperature will increase the strength of thermally-forced surface winds and result in an increase in the magnitude and frequency of storms (Anthes *et al.* 2006). This can also alter the timing, frequency, and magnitude of precipitation and drought events (IPCC 2013).

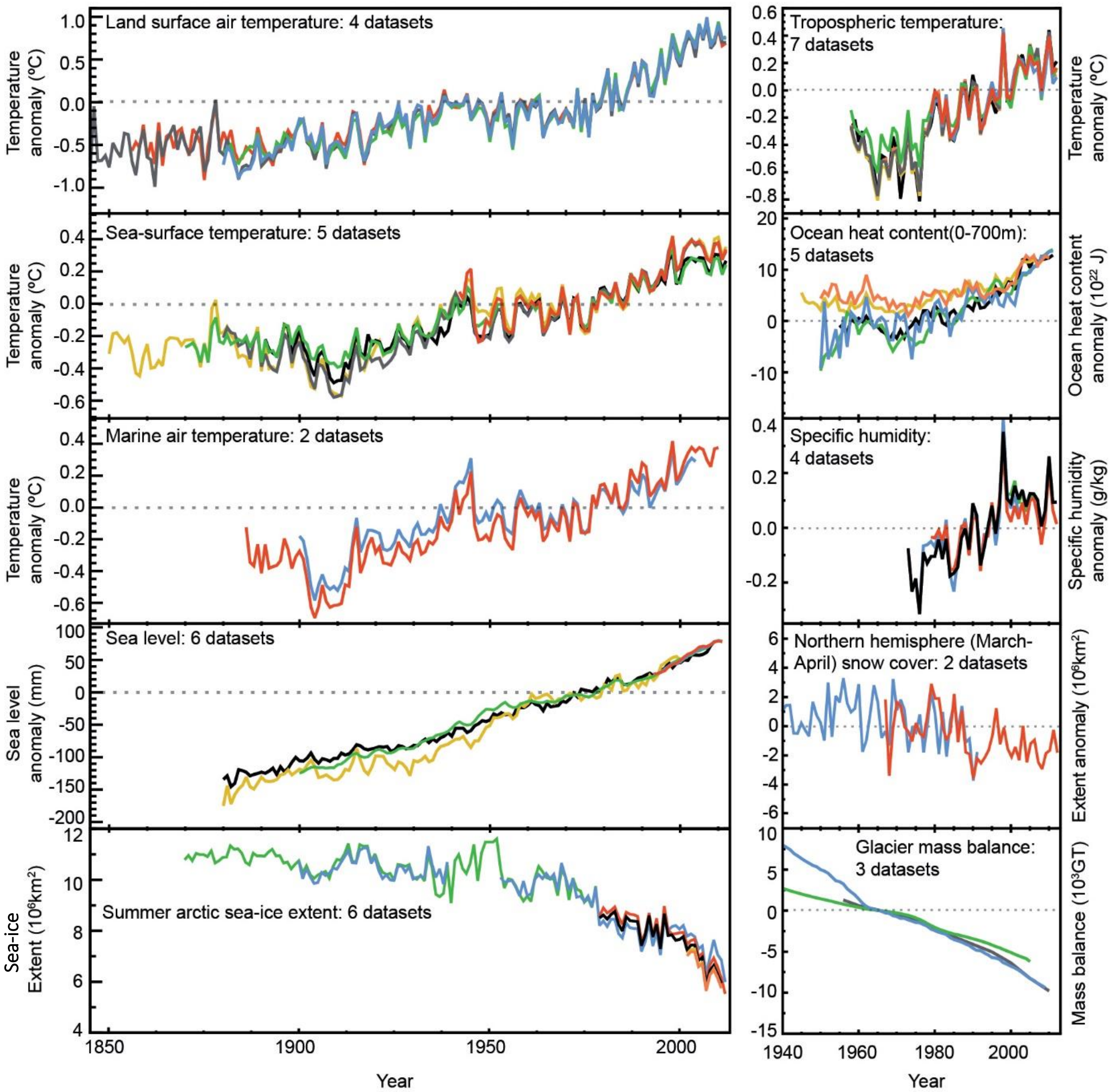


Figure 2.1. *Observed climatic changes during the 20th Century, according to the International Panel on Climate Change (IPCC). Source: Hartmann et al. 2013*

2.2.1 Climate models

Different climate change modelling projects often generate slightly different results. The climate system is complex, and the interaction between systems and the impact of changing CO_2 concentrations and radiative forcing on different systems is not yet fully understood. Therefore, future climate projections cover a wide range of potential future scenarios (see Figure 2.2). Numerous models are often used in conjunction during climate modelling projects, in order to make the results more reliable (Flato *et al.* 2013). Different climate change modelling projects use different collections, or 'ensembles', of models, which may have different input variables, baseline climate values, and spatial and temporal resolution, and use different algorithms to create projections (Murphy *et al.* 2009; Jenkins *et al.* 2009). For instance, the UK Climate Projections (UKCP) UKCP09 and UKCP18 ensembles included 15 variations of the Meteorological Office Hadley Centre global model, and 12 other international global models, including both General Climate Models (GCM) and Atmosphere-Ocean Global Circulation Models (AOGCM) (Murphy *et al.* 2009; Jenkins *et al.* 2009; UKCP2014a; Lowe *et al*. 2019). The Intergovernmental Panel on Climate Change (IPCC) Assessment Report 5 (AR5) produced 952 different simulations using 58 models, including AOGCMs, Earth Systems Models (ESM), and Regional Climate Models (RCM)(Flato *et al.* 2013; Emori *et al.* 2016). While the IPCC AR5 used more models than the UKCP projects, the spatial resolution of the UKCP09 and UKCP18 results is 25kmx25km, providing a relatively high level of detail, and useful for informing local-regional adaptation planning (Jenkins *et al.* 2009). The IPCC AR5 has a lower horizontal spatial resolution of around 100kmx100km, however the IPCC provides global coverage while the UKCP projections are for the UK only (Taylor *et al.* 2012). There is greater uncertainty and variation in the global projections compared to those focussed on a specific region. This is because there is spatial variation in projected temperature change, with polar and high latitude regions predicted to warm more rapidly than the low-mid latitudes (Kirtman *et al.* 2013).

Different models are often based on different GHG emission or concentration scenarios. The UKCP09 projections are given for ‘high’, ‘medium’, and ‘low’ emission scenarios (based on the Special Report on Emissions Scenarios (SRES) developed for earlier IPCC reports), while the IPCC AR5 and UKCP18 projections are based on Representative Concentration Pathway (RCP) scenarios (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) (Jenkins *et al.* 2009; Emori *et al.* 2016). The RCP value refers to the amount of radiative forcing (Wm^{-2}) due to GHG concentration projected for 2100, rather than a certain level of GHG emissions (Taylor *et al.* 2012). Where possible, the projections used in this thesis are informed by the medium (RCP6.0) and high (RCP8.5) concentration pathways or emission scenarios, rather than any low concentration or emission scenarios. This is because it is recommended that the precautionary principle is employed during climate change adaptation (European Parliament and Council 2002), meaning that pessimistic rather than optimistic scenarios should be used for planning purposes.

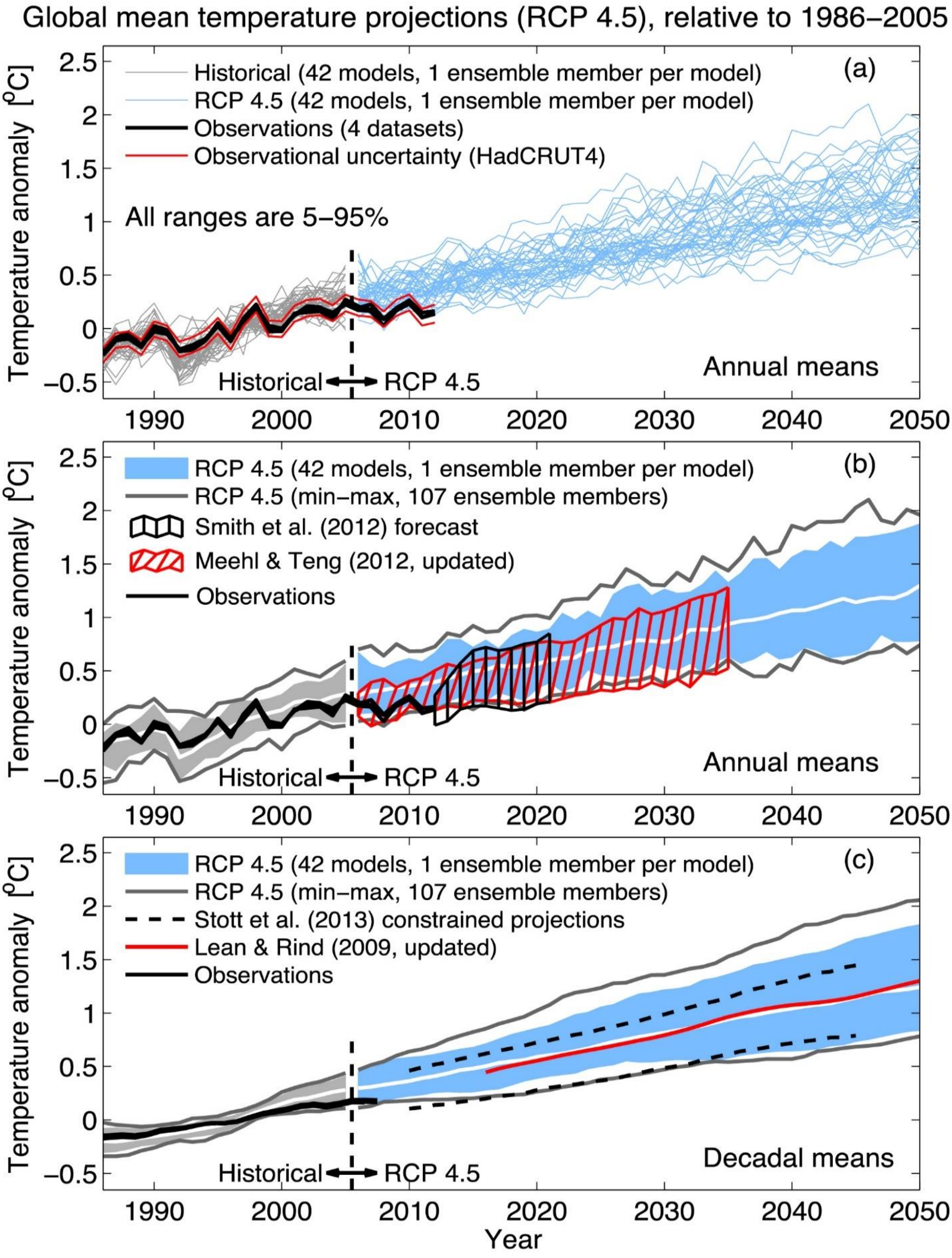


Figure 2.2. *Graph indicating the wide range of potential future temperature conditions, based on different models used by the IPCC. Source: Kirtmann et al. 2013*

2.3 Impacts of Temperature Change

2.3.1 Sea-level rise

Sea-level rise, due to both thermal expansion and melting ice caps and glaciers, is predicted to cause an increase in the frequency of flood events due to higher water levels, an increase in the frequency of storm surges, and a change in tidal ranges (Fitzpatrick *et al.* 2006; Kelly 2009). A study by Hunt (2011) calculated that 89% of coastal English Heritage properties are at risk from coastal flooding. Past research has indicated that newly flooded areas will develop new drainage patterns, which may create channels that could cause scour and erode archaeological deposits (Long and Roberts 1997; Chapman 2002; Edwards *et al.* 2007; Herle *et al.* 2009; Kelly 2009). During severe high-water events such as storm surges, dunes or sea walls may be breached, meaning that sites that were previously protected from coastal processes could be subjected to saturation and erosion (Murphy *et al.* 2009). Therefore, climate change will increase the number of archaeological sites that are threatened by such coastal processes (Sabbioni *et al.* 2008; Kelly 2009; Daly 2011).

Another impact of flood events is the saturation of dry soils, or the generation of wet/dry cycles, which can both result in a loss of soil structure, and increase the likelihood of instability and landslides (Colette 2007b; Herle *et al.* 2009; Brimblecombe 2014), thus endangering the integrity of any archaeological sites within the flooded area (Herle *et al.* 2009; Holický and Sýkora 2010). Some stones, such as clay-bearing sandstones, are at a higher risk of destabilisation and cracking due to wet/dry cycles, although areas with igneous and metamorphic geology are not significantly affected (Holický and Sýkora 2010). This threat is not unique to coastal sites, as inland areas can also be affected by fluvial and pluvial flood events. However, archaeological remains within coastal landslides and cliff-collapses may then be subject to coastal erosion, resulting in the permanent loss of archaeological information (as discussed in 2.4.1) (Croft 2013).

As well as flooding, sea-level rise can cause the permanent inundation of low-lying areas, resulting in the submersion of some previously land-based archaeological sites (Berenfeld 2008; Kelly 2009; Perez-Alvaro 2016). Macphail *et al.* (2010) argue that inundation causes ‘gravity-controlled down-profile drainage’, in which fine soils move downwards, causing a loss of stratigraphic evidence (see also Colette 2007a). The loss of stratigraphic integrity, due to both flooding and sea-level rise, is a threat to the archaeological resource as it may hinder its interpretation and reduce the resolution with which archaeologists can reconstruct the past (Erlandson 2007). Inundation and the introduction of foreign water to a site may also cause changes to the soil chemistry and environment in which the archaeological resource is preserved, which could potentially damage archaeological remains (Long and Roberts 1997; Chapman 2002; Cassar and Pender 2003; Colette 2007a, 2007b;

Sabbioni *et al.* 2008; Macphail 2009). For example, an increase in the salinity of groundwater can impact wooden artefacts, as salt crystallisation damages the wood's cellular structure (Long and Roberts 1997). Moreover, the magnetic signal from a hearth or burning activities can be lost due to the presence of Na^+ ions in seawater, making the initial discovery of some sites more difficult (Crowther 2003).

The increase in atmospheric CO_2 is also causing ocean acidification: the average pH of oceans has dropped from 8 to 7.9 during the twentieth century (Daly 2011; Perez-Alvaro 2016). The warmer waters around the equator and tropics have a lower CO_2 partial pressure, however cold waters in the northern latitudes can absorb more atmospheric CO_2 (Sabine and Feely 2007). Therefore, it is predicted that the pH of polar waters may reach 7.4 during the 21st Century (Daly 2011; Perez-Alvaro 2016). This increase in acidity could result in greater corrosion of metal remains in submerged archaeological sites, or in areas that will become inundated in the near future (Berghäll and Pesu 2008; Kelly 2009; Daly 2011; Dunkley 2013).

Conversely, the inundation of archaeological sites can be beneficial, as it may result in anoxic conditions, which are particularly good for preserving organic remains (Long and Roberts 1997; Lewis 2000; Davidson 2002; Macphail *et al.* 2010; Daly 2011; Milner 2012; Perez-Alvaro 2016). For instance, the submersion of sites beneath saltmarshes may increase their preservation due to waterlogging, and the reduced threat from land use and development (Lewis 2000). However, the submersion of archaeological sites may not necessarily preserve them as severe storm waves, and changes to sedimentation rates and currents, can erode and destroy submerged sites (Lewis 2000; Berghäll and Pesu 2008). The submersion and burial of sites may also reduce the possibility of discovering those archaeological remains, thus resulting in a loss of available archaeological information (Lewis 2000; Chapman 2002; Daly 2011; Croft 2013). For archaeological sites that are already underwater, even a small rise in sea level will make them much more difficult to explore and excavate (Dunkley 2013; Perez-Alvaro 2016).

2.3.2 Biological impacts

The temperature changes associated with climate change are altering the distribution and behaviour of certain fauna, for instance an extension of insect species ranges to higher latitudes, and an increase in over-winter survival (Bale *et al.* 2002). As a result, there may be an increased threat of insect attack on organic archaeological remains (Colette 2007b; Daly 2011). The shipworm *Lyrodus pedicellatus* is the most oft-cited biological threat within the British archaeological literature, as its northward expansion into British waters could cause damage to shipwrecks and other wooden submerged remains (Murphy *et al.* 2009; Croft 2013; Dunkley 2013). Mollusca and crustacea in the intertidal zone can bore into archaeological remains and disrupt the stratigraphic integrity of some sites (Long and Roberts 1997). A combination of an expansion in the range of damaging species, and an increase in the number of sites in the intertidal and subtidal zone due to sea-level rise, means that more sites may be exposed to molluscan borers (*ibid*.).

Some terrestrial remains are also threatened by changing biological activity. Warmer and more humid conditions are increasing the risk of insect infestation and fungal growth in historic buildings (Murphy and Ings 2013). This has the potential to affect both the structural elements of buildings, such as the timbers, but also the historic interiors such as carpets, tapestries, cloth, and wooden furniture and floorboards (Brimblecombe and Lankester 2012). It can be particularly difficult (and expensive) to control the interior atmospheric conditions in historic buildings, which are not well sealed and would be spoiled by the installation of air-conditioning and de-humidifying units (*ibid*).

Faunal activity is not the only biological threat posed to the archaeological resource due to climate change. In the Baltic Sea, Milner (2012) argues that the climate change driven decline in the eelgrass *Zostera marina* L. has resulted in an increased exposure of sediments, leading to a decrease in stability and an elevated risk of erosion. Furthermore, the CO_2 fertilisation effect and longer growing seasons, may increase terrestrial plant growth and therefore raise the risk of bioturbation of archaeological sites by plant roots (Daly 2011).

Finally, organic archaeological remains can be well preserved in frozen conditions, such as permafrost (Harmsen *et al.* 2018). Temperatures are already rising at a greater rate in polar regions than the global average due to air circulation patterns (Ecochard 2011). Figure 2.3 demonstrates the higher rate of warming in the Arctic, and the projected decrease in permafrost extent. The result of melting permafrost and changing microbial communities will be accelerated decomposition of remains such as bone and wood, as well as the destabilisation of structures and monuments on ground that is no-longer frozen solid (Hollesen *et al.* 2016; Harmsen *et al.* 2018).

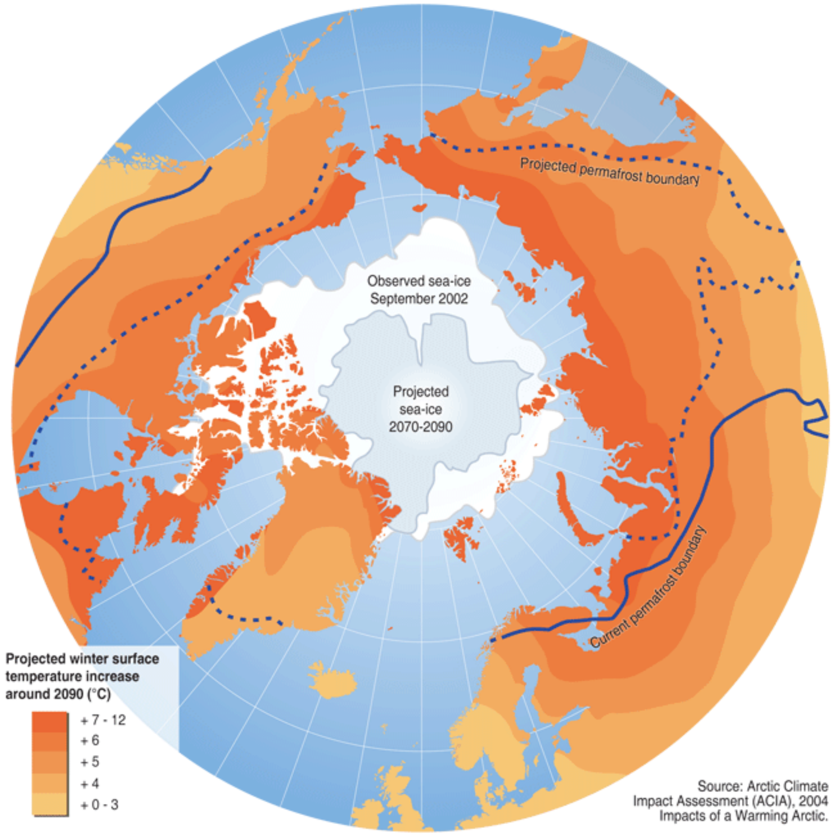


Figure 2.3. *A map to demonstrate the contracting extent of the Arctic permafrost and the accelerated warming trend in polar latitudes compared to temperate regions. Copyright Hugo Ahlenius*

2.4 Impacts of Changing Weather Patterns

2.4.1 Coastal erosion

Climate change will cause an increase in the frequency and magnitude of coastal storms, which will result in an increase in coastal erosion and the destruction of archaeological sites in some areas (Cassar and Pender 2003; English Heritage 2006; Erlandson 2008, 2012; Colette 2007b; Berghäll and Pesu 2008; Reeder *et al.* 2012; Croft 2013; Perez-Alvaro 2016). Cassar and Pender (2003) argue that the biggest causes of coastal erosion, and therefore the most significant threat to coastal archaeology, are storm surges and increased storminess. These can cause large losses of coastal material in a short period of time, and are therefore more difficult to plan for or adapt to compared with gradual sea-level rise (see also Lewis 2000; Egloff 2006; Kelly 2009; Marzeion and Levermann 2014).

Sea-level rise also increases the risk of coastal erosion (Heppell and Brown 2001; Van de Noort 2002; Colette 2007a; Sabbioni *et al.* 2008; Kelly 2009; Daly 2011; Erlandson 2012; Milner 2012; Reeder *et al.* 2012; Bickler *et al.* 2013; Croft 2013; Dawson 2015). For instance, sea-level rise in an area with hard coastal defences, such as sea walls, causes a phenomenon known as 'coastal squeeze', in which areas of saltmarsh in front of the sea walls are lost due to an inability to migrate landwards in response to sea-level rise (Murphy *et al.* 2009). This could also cause the loss of any archaeological remains buried beneath the saltmarsh (Long and Roberts 1997; Trow 2003; Murphy *et al.* 2008, 2009; Westley *et al.* 2011). Coastal defences also lead to a reduction in sediment input into the local sediment cell, which is known to increase erosion along other areas of coastline nearby (Cooper *et al.* 2001; Reeder *et al.* 2012), thus indirectly endangering coastal archaeological sites.

Coastal erosion can lead to the discovery of new sites that would not otherwise have been found (Darvill *et al.* 1998; Chapman 2002; Davidson 2002; Edwards *et al.* 2007; Daly 2011; Milner 2012). For instance, Mesolithic footprints in the Severn Estuary and Low Hauxley, Northumberland, and the site of Seahenge, Norfolk, were revealed by coastal erosion (see Figure 2.4)(Pitts 2011; Milner 2012; Cosgrove 2015). However, the uncovering of archaeological sites, in particular organic remains, can accelerate their decay, as they are exposed to oxygen and microbial and fungal activity, as well as erosion (Long and Roberts 1997). Furthermore, the loss of beaches due to sea-level rise increases the amount of erosion at the bottom of cliff faces, leading to an increased chance of cliff collapse and a loss of any archaeological sites situated on the cliff (Darvill *et al.* 1998; Trow 2003; Bromhead and Ibsen 2006; Kelly 2009; Murphy *et al.* 2009; Westley *et al.* 2011; Daly 2011; Croft 2013). On high-energy coastlines and during storm events, the material from a cliff failure may be transported away very quickly, meaning that any archaeological material is removed before it is discovered (Long and Roberts 1997; Trow 2003). Therefore, the information held within these archaeological sites has the potential to be destroyed without any opportunity for it to be discovered or recorded.

***Figure 2.4**. Human and animal footprints revealed by erosion in the intertidal zone at Low Hauxley, Northumberland. Source: NatureLogBlog.wordpress.com*

The threat of coastal erosion is mainly confined to coastlines with soft bedrock and overlying sediments, including sandstone, boulder clay and alluvial/marine mud (Jones 2002; Trow 2003; Edwards *et al.* 2007; Westley *et al.* 2011; Kelly 2009; Reeder *et al.* 2012; Croft 2013; Dawson 2015). Shorelines with more resistant rock, such as granite cliffs, are not significantly threatened by wave action. However, Trow (2003) states that soft coastlines, for instance estuaries and saltmarshes, are important for archaeology, as they often maintain favourable preservation conditions, and have been known to contain middens, submerged Mesolithic sites, shipwrecks, and submerged forests. Therefore, the coastlines at greatest risk of erosion may be the ones that have the greatest archaeological potential.

2.4.2 Storminess

Serious storms can threaten heritage sites in inland areas. Heavy precipitation events and more frequent droughts may result in flash flooding and a loss of soil structure, and increase the likelihood of instability, soil erosion, and landslides, thus endangering the integrity of any archaeological sites on, or within, affected areas (De Roo 1998; Colette 2007; Herle *et al.* 2009; Holický and Sýkora 2010). In steep or mountainous areas, artefacts can be eroded and scattered across the surface of the slope by sheet erosion (Meylemans *et al.* 2008). Earthwork features are particularly threatened as they are eroded with the loss of surrounding sediment and may leave little trace (*ibid*.). Built structures are also at risk; heavy rains associated with Storms Eva and Frank lead to the collapse of an 18th-century bridge in Tadcaster, North Yorkshire, in 2015 (see Figure 2.5) (Tran *et al.* 2015). Finally, coastal storms can increase the amount of sediment deposited in the intertidal or nearshore zone (Faulkner *et al*. 2005). This has the potential to bury coastal archaeological features and prevent their discovery. The projected increases in magnitude and frequency of storm events due to climate change means that this kind of event, and the associated impacts discussed here, may become more common throughout the 21st century.

Figure 2.5. *Collapsed section of a historic bridge in Tadcaster following heavy rainstorms during Storms Eva and Frank in December 2015. Copyright Giles Rocholl*

2.5 Indirect Impacts

The impact of climate change on archaeology is not limited to direct impacts, and can be caused by the mitigation and adaptive approaches taken by societies in response to climate change. For example, the construction of coastal defences in response to rising sea levels can result in coastal squeeze, causing the loss of saltmarsh and beach, leading to sediment starvation, and increasing erosion along other areas of coastline (see 2.4.1)(Jones 2002; Kelly 2009). Furthermore, the construction of built coastal defences and flood alleviation infrastructure can physically damage the archaeological resource beneath, due to the compaction of soils and heavy machinery used (Cassar and Pender 2003; English Heritage 2006; Wessex Archaeology Ltd 2007; Murphy *et al.* 2009; Flatman

2009; Kelly 2009; Daly 2011; Hall *et al.* 2016). The construction of infrastructure designed for the mitigation of climate change, such as offshore windfarms and tidal barrages, also has the potential to destroy any archaeological site located beneath them, as well as altering local erosion and sedimentation patterns (English Heritage 2006; Wessex Archaeology Ltd 2007; Berghäll and Pesu 2008; Kelly 2009; Murphy *et al.* 2009)

The lack of hard coastal defences can also pose a threat to coastal archaeology. Hard coastal defences are very expensive, so many areas of coastline are subjected to alternative management approaches, namely *managed realignment* or *no active intervention* (Egloff 2006). The *managed realignment* approach promotes the removal of areas of sea wall in order to allow the sea to breach the previously defended area and allow a saltmarsh to develop (Cassar and Pender 2003). Therefore, any archaeology landward of the sea wall, previously defended from coastal processes, is subsequently at risk from erosion or inundation (Cassar and Pender 2003; Bromhead and Ibsen 2006; English Heritage 2006; Kelly 2009; Macphail 2009; Murphy *et al.* 2009). The development of saltmarsh is desirable for biodiversity and conservation, meaning that this approach is often favoured for both economic and environmental reasons (Egloff 2006; Murphy *et al.* 2009). Furthermore, *no active intervention* is an approach taken for many areas of the coastline for which it is not economically beneficial to construct defences. Scheduled monuments and listed buildings are the only cultural heritage assets to be properly considered in shoreline management plans (Cassar and Pender 2003; Trow 2003; Bromhead and Ibsen 2006; Murphy *et al.* 2009; Hunt 2011). However, Long and Roberts (1997) do argue that the construction of coastal defences for towns, cities, and power plants may inadvertently protect some local archaeological sites and historic buildings from erosion.

2.6 Implications for the Historic Landscape

As well as damaging individual archaeological sites and remains, climate change has the potential to significantly impact historic landscapes across the UK. As explained in greater detail in Chapter 3, the historic landscape is a product of past and present human action, and may be characterised by field-boundary morphology, settlement structure, visible archaeological and historical sites, and vegetation structure and location. The impact of climate change on archaeological and historical sites could have a significant impact in particular on the historic character of rural landscapes (Kaslegard 2011). For example, coastal erosion and landslides have resulted in the destruction of many historic and even pre-Roman coastal fortifications on the south east coast of England (Bromhead and Ibsen 2006). The loss of these features threatens the military and defensive character of this historic landscape. Furthermore, changing climatic conditions may lengthen crop growing seasons, and make areas suitable for arable agriculture that were once only used for livestock (Knox *et al.* 2010; King *et al.* 2018). As well as affecting the local economy and traditional ways of life, this could affect the visual character of the landscape as smaller field boundaries are removed and monocrop agriculture replaces livestock. Climate change may also alter the species assemblage or ecosystem structure in areas of woodland or parkland by changing species phenology and suitable ranges (Historic England 2016). This could lead to a collapse of ecosystems, if producer/prey/predator phenological cycles become desynchronised, or if invasive species outcompete native species under future climate conditions (e.g. Stachowicz *et al.* 2002; Mainka and Howard 2010; Chevillot 2017). A change in the location and type of vegetation in a landscape would dramatically impact the overall character. Rural landscapes often have close visual links with traditional industries and local sense of place (Kaslegard 2011). Climate change may lead to changes in historic landscapes that affect local sense of place and the experience of being within the landscape, as well as local economies and ecosystems (*ibid*.).

2.7 Measuring the vulnerability of cultural heritage to climate change

Chapter 7 provides a deeper discussion on the definition of vulnerability and how the vulnerability of cultural heritage to climate change is typically measured. The purpose of this section is to outline the general trends in vulnerability assessments within archaeological research and identify the associated limitations, in order to justify the proposed methodology of this thesis.

Vulnerability indices are a popular method of assessing the risk and potential damage to material cultural heritage from climate change (see Thieler and Hammar-Klose 2000; McLaughlin *et al.* 2002; Boruff *et al.* 2005; Boruff and Cutter 2007; Diez *et al.* 2007; Hegde and Reju 2007; Torresan *et al.* 2008; McLaughlin and Cooper 2010). Indices use a selection of variables to quantify different elements of vulnerability and produce a single vulnerability score (Barnett *et al.* 2008; Balica *et al.* 2012). Risk maps and vulnerability matrices are also frequently used to identify archaeological or historical features with greater exposure to the impacts of climate change or other environmental disasters (Risk maps see: Accardo *et al*. 2003; Grossi *et al*. 2007; Robinson *et al.* 2010; Westley *et al*. 2011; Daire *et al*. 2012; Westley and McNeary 2014; Boinas *et al*. 2015; Vulnerability matrices see: Papathoma-Köhle *et al.* 2017; Berry *et al.* 2019). Different methods and studies incorporate different types of threat, with some including both anthropogenic and natural factors, while others only measure vulnerability to a specific type of threat.

The common theme across methods and frameworks reviewed during this research is that the object of study is individual or groups of sites, buildings or features. This causes several issues, which are discussed in section 7.2.5, such as a lack of coverage in areas that have not been systematically surveyed, a lack of clarity about what constitutes the 'sites' included, and a lack of recognition of the historicity of the landscape as a whole. Even when research covers a stretch of coastline or a landscape, the focal level is still on the individual archaeological sites within the study area, rather than on the historic landscape (e.g. Daire *et al*. 2012; Reeder *et al*. 2012; Chadwick-Moore 2014; Van Rensselaer 2014; Westley and McNeary 2014).

There are several limitations with studying the vulnerability of individual or groups of archaeological sites to climate change. Firstly, it neglects the importance of the context of sites and their relationships with other sites and the surrounding landscape. It implicitly assumes that archaeological data are confined to discontinuous points across a landscape, and therefore obscures the historicity of the liminal spaces between sites and the historical-cultural importance of the landscape as a whole (Turner 2006; Bender 2009a).

This thesis develops a landscape-scale approach to vulnerability assessment using Historic Landscape Characterisation (HLC) (see Chapter 6) in order to address the limitations discussed here and in section 7.2.2. This takes into account the dynamic historic character of the landscape as well as the individual archaeological features or sites within it. It also incorporates the relationships between sites, and between sites and the landscape, and the evolving socio-cultural values associated with landscapes. HLC has been used by Cornwall County Council (2013) to determine the sensitivity of the Cornish historic landscape to the development of solar power farms and wind turbines. There is therefore precedence for combining a HLC with a vulnerability assessment to evaluate and manage the vulnerability of the historic landscape to various threats.

2.8 Summary

This chapter provides a brief appraisal of the different ways in which cultural heritage assets are threatened by the impacts of climate change. As well as affecting individual features and sites, climate change has the potential to cause wider changes to the historic environment, such as altering the character of the historic landscape through land-use and vegetation change. The impacts included here are not exhaustive, and there are many other ways in which climate change may affect archaeology and historic resources. However, this chapter demonstrates the extensive nature of climate change impacts with regard to archaeology, and therefore indicates the complexity of addressing the issue.

Chapter 3

Concepts and Methods for Landscape-Scale Vulnerability Assessment

3.1 Introduction

This chapter describes and justifies the methodological approach used in this research to address the research aims discussed in the Introduction (Chapter 1). The research question guiding this thesis is: *How can the vulnerability of cultural heritage to future climate change be assessed and managed at a landscape scale?* Chapter 3 presents the steps by which a landscape-scale vulnerability framework is constructed. This landscape-scale vulnerability framework was developed to address the lack of recognition of the historic landscape within archaeological vulnerability assessments (see sections 2.7 and 7.2.5), and incorporate the historic landscape in sustainability assessments of coastal and flood-risk management approaches (see Chapter 8).

The conceptual framework underpinning this thesis is described, in order to establish the conceptual and epistemological context of this research (3.2). This is important as it allows the reader to understand the context of the research methods, results and conclusions. Section 3.3 explains the methodological approach adopted, and justifies the choice of methods. Secondly, there is an overview of the methods used to address each research aim in this thesis (3.4). Each of the research aims develops one of the three steps of the Landscape Vulnerability Framework.

3.2 Conceptual Framework

This section explains and justifies the paradigm in which this research was carried out. The paradigm includes the concept of scale and the Hierarchy Theory scalar framework, the concept of the historic landscape, and the theory of sustainability. These ideas actively shape the methods chosen for addressing the research questions.

The concept of scale, including its use in different disciplines as well as archaeology, and the importance of explicitly defining the chosen scale of research is initially discussed. This informs the choice of the Hierarchy Theory scalar framework which underpins this thesis. Section 3.2.2 provides a description of the Hierarchy Theory and an explanation of how it was applied to this research to address the limitations discussed. The concept of the historic landscape is then explained, with reference to how it was used to resolve some of the limitations within archaeological research. Finally, the theory of sustainability and its relevance to this research is explored.

3.2.1 Scale

Scale and its conceptualisation are central to geographic research and theory, and are debated across various natural and social science disciplines. This section provides a brief overview of the different ways that scale is used (both explicitly and implicitly) in different disciplines, followed by an explanation of the Hierarchy Theory scalar framework which was employed in this thesis.

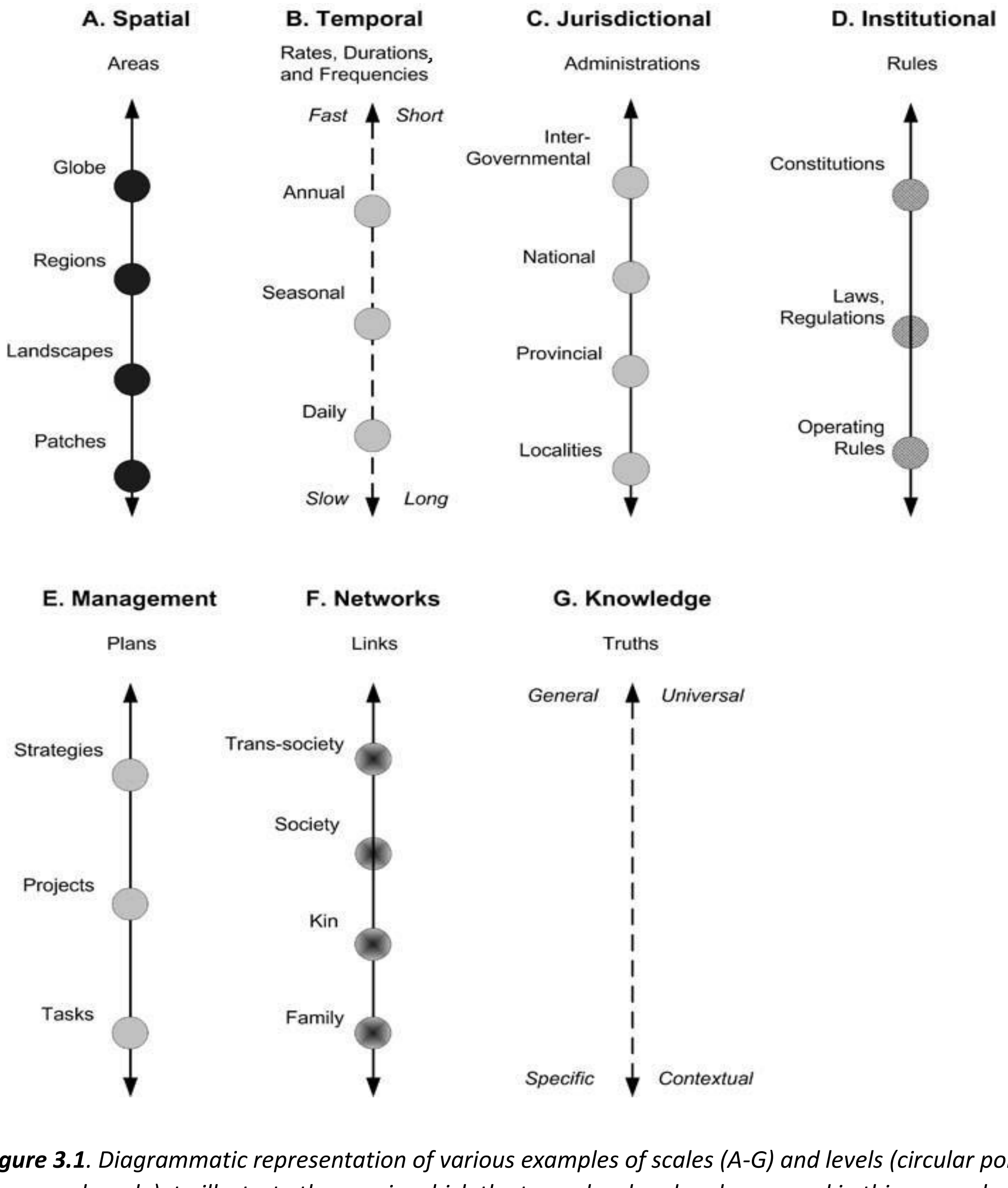


***Figure 3.1**. Diagrammatic representation of various examples of scales (A-G) and levels (circular points along each scale), to illustrate the way in which the terms level and scale are used in this research. Taken from Cash et al. 2006.*

As a brief precursor to the explanation of the scalar framework of this research, there must be a clarification of the ways that the terms *level* and *scale* interact. In much academic literature, these two terms can be used interchangeably with no loss of meaning (i.e. local-scale, local-level). This can result in confusion if this literature interacts with others in which the meaning of level and scale are specified. Within literature tackling the theory of scale in social sciences, levels are defined more precisely as units of analysis along a specific scale, while scale refers to “the spatial, temporal, quantitative or analytical dimensions used to measure and study any phenomenon” (Cash *et al.* 2006, p.2, see also Gibson *et al.* 2000). Sayre (2009) goes further, arguing that scale is not fixed or absolute in nature, but rather represents the way in which phenomena and processes relate to one another. Figure 3.1 provides a diagrammatic representation of this definition of level and scale, in order to clarify its meaning. It is this use of scale and level that is employed within this thesis.

The use of scale in social sciences

Theoretical approaches to scale within the social sciences perceive scale as describing the organisation of social levels, and the interactions between these levels (Reed and Brunyeel 2010). There have been many debates within social theory regarding scale. A foundational discussion within scale theory involves the way that scale is considered to be socially constructed, and the means by which this occurs. For instance, national governments are key in constructing jurisdictional scales of governance (with local councils, county councils, and nation states as levels), and therefore deciding the power and resources allocated to each level of this scale (McCarthy 2005; Termeer *et al.* 2010). This is an example of the way in which the construction of scale can be used politically, in order to determine who receives power and resources, and the power relations between levels of a particular scale (Reed and Brunyeel 2010). Furthermore, ‘scale-framing’ can be used to support certain actors. Infrastructure companies can frame their opponents as being selfishly concerned only with the impact of development on their immediate surroundings (‘NIMBYism’ or ‘Not In My Back Yard-ism’), rather than the larger public benefit that an infrastructure project may provide, in order to discredit their argument (Towers 2000; Termeer *et al.* 2010). In this way, the construction of scale can fix social relations in space, giving meaning and priority to certain processes or actors over others, and thus acting as a potent political tool.

There are also debates which tackle whether scale is an ontologically real property of social life, or whether it is imposed as a framework upon the subject of study by researchers (e.g. Marston *et al.* 2005; Sayre 2009; Herod 2011). Many scholars have built upon scale theory, and added to its intricacies, for instance the relational theory of scale, which suggests that scales are organised not by set levels, but by the relations between levels (e.g. Brenner 1998; Howitt 1998).

The use of scale in physical and natural sciences

Within the biophysical sciences, the term 'scale' can be used to refer to the 'operational scale', which describes the phenomenon being studied or the scale at which a process operates. It is also used to refer to the way in which a process or phenomenon is observed – the 'observational scale' (Sayre 2005).

The operational scale refers to the scale at which a process or phenomenon operates, for instance its temporal and/or spatial range and magnitude (Sayre 2009; Reed and Brunyeel 2010). For example, the Coriolis Force has an ontologically real level on the operational scale, as it affects the way that low pressure weather systems rotate in the northern and southern hemispheres, but does not (contrary to popular belief) influence lower level processes such as the way that the water spins down a drain (Sayre 2009; Shakur 2014), which is controlled by factors such as basin design and the direction of water flow. However, the operational scale of other processes can span across several different spatial and temporal levels. The process of climate change through the build-up of GHGs operates at a global level. It is contributed to by processes at lower spatial levels such as deforestation, population dynamics and resource use, and impacts conditions across a variety of spatial and temporal levels, such as changing weather patterns, seasonal variation, and long-term temperature trends (Wilbanks and Kates 1999). As these processes do not operate at a single spatial or temporal level, they cannot be defined as having a single operational level or scale. In fact, McMaster and Sheppard (2004) argue that, in some cases, a process has no specific operational scale, and so the operational scale by which the process is defined is still socially constructed. Dungan *et al.* (2002) argue that not only should the physical structure of the system be considered, but that the processes that act upon the system should also be included, for instance those that occur at higher spatial levels, as they can form the context and constraints of the system in focus. This is examined in greater depth in the discussion of Hierarchy Theory (3.2.2).

The observational scale of a study incorporates both the spatial extent of the study, for instance whether it encapsulates a wide landscape or focuses on a single organism, and the resolution of the study, i.e. the level of detail that is captured. Typically, studies that have a wider spatial extent ('large-scale') tend to have a lower resolution, while 'small-scale' studies often have a higher resolution. The observational scale can also include the temporal extent and resolution of the study, for instance whether the study incorporates days, years, or millennia, and the density of sampling points across the time period (Goodchild 2011). It is important to choose an observational scale that is appropriate for the variable being measured, but the choice of observational scale can influence the results and conclusions drawn from the study. This is because the scale of sampling and analysis can affect the patterns that are observed or not observed within the data (Lam 2004; Sayre 2009).

This can be seen in models designed to predict the potential impact of climate change on agricultural productivity. At a global level, there does not appear to be a significant impact on overall productivity, as losses in some areas are offset by improving conditions in other areas, and the CO_2 fertilisation effect. However, studies at regional levels indicate that the impact of climate change on agriculture may be most severe for the most vulnerable populations, such as migrant workers, pastoralists, small holders and wage labourers (Wilbanks and Kates 1999). This reveals that the social and economic impacts appear more severe and unequitable when assessed at a lower spatial level. Research over a larger spatial level can reveal processes of interdependence that may not be evident on smaller spatial levels, but result in generalisations in the data, which can cause smaller, complex processes to be obscured (Turner 1989; Turner *et al.* 1990; Cash and Moser 2000). On the other hand, studies at lower levels on the spatial scale can illuminate the way in which global processes influence, or manifest in, a specific locality. Walsh *et al.* (2004) suggest that research into human-environment interactions, for instance climate change impacts and adaptation, should include several observational levels, due to the different levels upon which different processes operate. Furthermore, if research focuses specifically on processes operating at a single level, the analysis and results may overstate the importance of the processes, phenomena and actors operating at this level, while relevant processes that occur on different spatial or temporal levels may be missed (see also Wilbanks and Kates 1999). There is further examination of multi-level approaches in the discussion of the Hierarchy Theory (3.2.2).

The use of scale in archaeology

The concept of scale is not widely discussed in archaeological research, and although some scholars have addressed the issue, the focus remains on the observational scale (i.e. the appropriate scales to use in research projects) or the cartographic use of the term, rather than the operational scale (i.e. the scales of the processes that created the archaeological resource) (Lock and Molyneaux 2006b). This is surprising as, in accepting that scale is a social construct, it is also accepted that past societies may have constructed scales and scale relations differently compared to present societies (Lock and Molyneaux 2006a, b). Fairclough (2006) explores a wide range of scales in the context of archaeology, including spatial, temporal, and cartographic scales, scales of perception, use, objectives and application. However, these are concerned only with the observational scales, and still do not address the operational scales of the creation or development of the archaeological record.

Many archaeological research projects do not explicitly discuss the scale they have chosen or the reasons behind the choice. Those that do generally use ‘scale’ to mean the spatial extent, resolution or scope of the subject matter, often interchangeably (e.g. Barker *et al.* 1997; Panich and Schneider

2015; Picornell-Gelabert and Servera-Vives 2017). When mentioned within the methodology of a report, 'scale' is mainly used to refer to different levels on a specific (usually spatial) scale (e.g. Linse 1993; Bevan and Conolly 2004; Olson *et al.* 2013). Stein (1993) states that the scale used in research is often dictated by the discipline within which the research takes place, and that scale is considered "twice while conducting [archaeological] research; once while describing data and again while interpreting data." (p.1). This does not account for the consideration of scale when deciding what data to collect. This corroborates with a point made by Harris (2006), that researchers often choose a level and scale of study unconsciously or unquestioningly.

The importance of defining scale

It is important to explicitly mention scale in the explanation of the conceptual framework, as the scale of observation influences the results of the research project. A focus on the spatial or jurisdictional scales may not accommodate the cultural factors influencing the vulnerability of a community, while projects using a temporal scale of observation may focus on processes occurring in the short, medium, and long term, but neglect to notice processes or impacts occurring at a higher or lower spatial level. Not only does the resolution and spatial extent of the study influence results, but the choice of scale can also affect the way that research is planned, the methods used, the way that data is interpreted, and therefore the conclusions drawn (Lam 2004). It is therefore important to explicitly consider, and justify, the choice of scale of a research project. To address the aforementioned issues, this project uses the methodological framework of Hierarchy Theory to define the scale of the research. Hierarchy Theory provides a framework for simplifying systems for study, and can facilitate the acknowledgement of higher and lower level processes than the object of focus, while reducing the complexity of the entire system to a more manageable state (Wu 1999; McMaster and Sheppard 2004).

There are a multitude of meanings associated with 'scale', which has led to conflicting uses and confusion between, and even within, disciplines (McCarthy 2005; Sayre 2009). Several conceptual papers have aimed to clarify the meaning of scale, and the correct terminology that should be used (see Dungan *et al.* 2002; Cash *et al.* 2006). As a common term within both academic and lay language, a strict definition may be difficult to establish. However, it is important for research papers to explicitly establish the definition of scale that they use throughout, as well as the observational scale of the study.

Many issues that occur as a result of scale are often related to scale mismatches. Scale mismatches occur when the levels on the operational scale of a phenomenon or process do not align with the levels on the institutional or jurisdictional scale that aims to control it. Coastal erosion is increasing as a result of global climate change, and vulnerability to coastal erosion is increasing due to population growth and increased habitation of marginal areas. However, agencies tasked with addressing the risk of coastal erosion are often local or county councils, which have neither the resources nor the authority to address the driving forces of the problem (Wilbanks and Kates 1999). This is known as an *institutional fit problem* (Cash and Moser 2000). There are also *scale discordance problems*, in which the levels on the scale of assessment and knowledge creation do not match up with the levels on the scale of the management system. For instance, climate change projections are generally being undertaken on a global level, and for decadal time periods, due to the resolution of available climate models. However, adaptation to climate change is undertaken at the local level, and is often focussed on shorter-term, incremental changes. The spatial and temporal levels at which the knowledge is required are not the levels at which new knowledge is being created (Wilbanks and Kates 1999; Cash and Moser 2000). As a result, many of the difficulties faced by policymakers are caused by issues of scale. Scale discordance problems can be seen in the vulnerability assessment and management of cultural heritage. As explained in section 2.7, vulnerability assessments in archaeology are predominantly site-based, but cultural heritage and the processes of environmental change that threaten it are extensive and landscape-wide. Addressing the vulnerability of each individual site may highlight only the environmental processes affecting extant archaeological features, and neglect to consider other processes that affect the wider landscape.

3.2.2 Hierarchy Theory

Hierarchy Theory is a framework often used in ecology, that clarifies and simplifies the interactions between phenomena and processes at different spatial and/or temporal levels (Wu 2013). It states that natural systems exist within hierarchical scales, and that the phenomena and processes at a chosen level (focal level) are influenced by both the level above, and the level below (Figure 3.2). The higher level provides the context in which the focal level exists, and imposes constraints upon any processes that occur therein, while the lower level provides mechanisms through which the focal level processes occur, as well as imposing bottom-up constraints (Allen and Starr 1982; Cash and Moser 2000; Sayre 2005, 2009). As well as the vertical structure, Hierarchy Theory suggests that natural systems have a horizontal structure composed of *holons* (from the Greek *holos*, for whole, and *on*, meaning part) (McMaster and Sheppard 2004). *Holons* are individual entities which, combined, form part of the level above, but act as single entities with respect to lower levels (*ibid*.). For example, each archaeological site is a *holon* on the site level. Each site is made up of several contexts at a lower spatial level, but collectively these sites form part of a higher level, the regional archaeological resource.

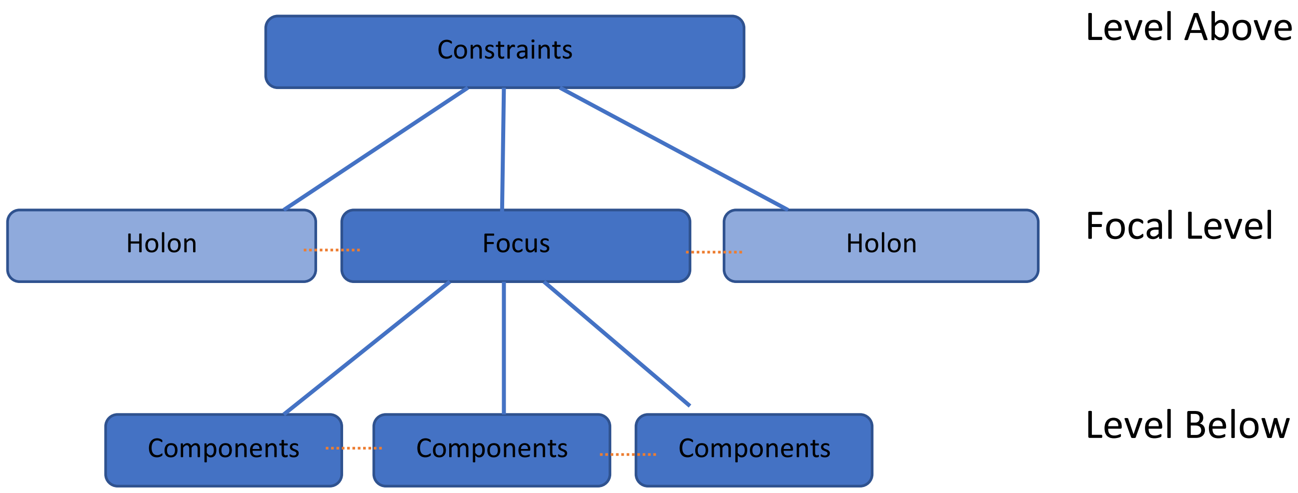


Figure 3.2. *Representation of relationships between levels in a system, as described by the Hierarchy Theory. Diagram developed from that of Darin Jensen. Source: Sayre 2009.*

The incorporation of more levels within the scope of a research project can provide a greater comprehension of the processes at work. For example, understanding precipitation patterns requires an understanding of large-scale, long-term climatic processes, as well as local-level topography (Cash and Moser 2000). Sayre (2009) argues that acknowledging processes and phenomena at a higher level can illuminate patterns and processes that would not have been evident if the attention remained on the focal level alone. The use of Hierarchy Theory to structure this research addresses the issue mentioned in 3.2.1, that the choice of observational scale can influence the results of a study.

Some criticisms of Hierarchy Theory include the argument that it oversimplifies interactions between processes at different levels, as processes occurring at lower levels may not necessarily nest neatly within higher levels of the hierarchy (Wu 1999; Sayre 2005). Furthermore, it assumes that all the relevant processes and phenomena can be clearly divided into spatial or temporal levels (McMaster and Sheppard 2004). These criticisms are particularly salient for social processes, as political, social and economic institutions can be created and altered more easily than biophysical processes (Sayre 2005). Cumming (2016) also states that hierarchical models imply that ecological interactions only occur between levels adjacent to one another, and can therefore obscure interactions between lower and higher levels.

Hierarchy Theory was used in this research despite these limitations, as the structure it provides facilitates the study of archaeological sites as they exist within Landscape Character Areas (LCAs) and the historic landscape as a whole. Moreover, for this project the processes occurring at the lower levels (in archaeological sites) do nest within the higher spatial levels (LCAs and historic landscape), as the LCAs were defined in part from the nature of the sites within them (see Chapter 6). Finally, although the LCAs are socially constructed (and therefore epistemological rather than ontological), they remain at a spatial level between that of archaeological sites and that of historic landscapes. Therefore, Hierarchy Theory is an appropriate scalar framework by which to structure the approaches used in this thesis.

In this research, the focal level is the LCA, as defined by Historic Landscape Characterisation (HLC) (Chapter 6). The upper level is the study area as a whole, and the lower level is the archaeological sites and features within the landscape that characterise each LCA (see Figure 3.2). Each LCA is a *holon* which influences the overall character of the study area. The spatial scale was chosen over the jurisdictional, cultural or sectoral scales as the most appropriate for this study, as the processes resulting from climate change cannot be defined by jurisdictional, cultural or sectoral boundaries. However, there is a cultural element interwoven into the subject matter: although the upper level (the Dysynni valley landscape) and lower level (archaeological sites) used within this project can be considered ontologically 'real', their limits are produced through disciplinary conventions and traditions, and decisions taken by heritage managers. Furthermore, LCAs were defined spatially within this project, even though the methods for doing so are based on a subjective interpretation of their historical attributes. Delineating the extent of this study as spatial is therefore more appropriate, as the subjects of research are fixed entities, despite being socially constructed. It is acknowledged that the outcomes of this research may be most useful for heritage management purposes if the focus was on the jurisdictional scale. However, it is recognised that the management of natural systems is more effective when a holistic, integrated approach is taken. This is because natural systems and phenomena such as river catchments, flood plains and climate change do not fit into political borders (Termeer *et al.* 2010). The current accepted approach to coastal management is organised by sediment cells and sub-cells (a length of coastline in which coarse sediment input, output and processes are mainly self-contained) rather than by administrative boundaries (Motyka and Brampton 1993; Defra 2006; SCOPAC 2019). Therefore, precedent exists for using scales in management that do not directly fit the jurisdictional scale.

3.2.3 The Historic Landscape

The *historic landscape* is central to the approach taken in this thesis with regards to conceptualising the archaeology and cultural heritage of the study area. The underpinning philosophy is that the historic landscape is not a physical object or defined geographical area, but rather it is "an artefact of past land-use, social structures and political decisions" (Fairclough *et al.* 2002, p.70). This philosophy is based on the idea that present-day landscapes are the result of human decisions and activities in the past, such as agricultural regimes, urbanisation, woodland management, field boundary morphologies, patterns of land ownership, and mineral extraction (e.g. Fairclough *et al.* 2002; Fairclough 2003a, 2003b, 2006). As the historic landscape is a social construct, it is subjective and dynamic, as the relationship between the area and the humans within it changes (Fairclough 2003b; Fairclough 2006a). This idea challenges the common view that landscapes that have been significantly modified by human activity, particularly in the past few decades, are not as valuable as those that remain relatively unchanged since the Middle Ages or prehistory (Fairclough 2003b; Bradley *et al.* 2004). The changes that occurred in the late-20th century, for instance the expansion of urban areas and infrastructure, are seen by many to have had a negative impact on landscapes (Natural England 2010). Moreover, aspects of the cultural landscape such as traditional practices and non-modern ways of life are often romanticised through an idea that there was once a harmony between nature and culture that no-longer exists (Fairclough 2003b, p.31). Fairclough (2003b) argues that this gives value only to antiquated land-use practices and ancient remains within the landscape, and devalues modern practices and evidence of more recent land-use. In contrast, the historic landscape concept does not consider the 20th-century impacts as negative, but rather as another episode of historical activity which adds another layer of historicity to landscapes (Bradley *et al.* 2004). This thesis employs this theoretical standpoint because it does not exclude any elements of cultural influence on landscapes, from Bronze Age cairns to 20th-century military remains, when assessing the historic nature of the area and evaluating conservation approaches.

The historic landscape is spatially continuous and thus recognises the presence of humans in the landscape around their settlements and monuments during the past, rather than isolating archaeological sites from their surroundings (Clark *et al.* 2004). It also considers sites to be meaningful as they exist within the context of the landscape, rather than their importance and meaning being separate from the landscape. Therefore, this thesis and the framework developed within it consider the impact of climate change on the historic landscape comprising the sites within it, rather than on the archaeological and historical sites of a landscape in isolation.

3.2.4 Sustainability

The third research aim of this thesis is shaped by the concept of sustainability, namely the potential options for the sustainable management of the historic environment under scenarios of climate change. 'Sustainability' is conceptualised in a variety of ways by different scholars and within different disciplines, so no single definition or conceptualisation of sustainability can be applied to all situations (Heinen 1994; White 2013). The definition used in this thesis is that sustainability is the consideration, use and safeguarding of environmental, social and economic systems in a way that is equitable across both present and future generations (see Brundtland and Khalid 1987; Bell and Morse 2008; Stocker *et al.* 2012; Sabaté and Warren 2015; Sánchez-Arcilla *et al.* 2016).

Sustainability is considered by some to be a wicked problem (e.g. Norton 2005), defined by characteristics such as the fact that there are no 'true' or 'false' solutions, the fact that different stakeholders may have different understandings of the problem and potential solutions, and that there is no stopping rule, meaning that the problem is never fully solved, only managed (Rittel and Webber 1973). Furthermore, climate change is defined as a super wicked problem (see Levin *et al.* 2009), because as well as the other wicked problem characteristics, it also is time-critical, there is no central authority to its management, and those seeking to solve the problem are also those causing it (Levin *et al.* 2012).

In aiming for a wicked problem solution to the impacts of a super wicked problem, there may not be one single best solution, or any management approaches that are able to satisfy all the criteria of sustainability. However, explicitly approaching the issue of coastal landscape heritage management through the lens of sustainability in this thesis ensures that the three 'pillars' (environment, society and economy), and intra- and inter-generational equality are all consciously considered.

There are several criticisms of the idea of sustainability, for instance the idea that economic growth is necessary for both environmental protection and sustainability. This is based on the current neoliberal economic world view, that economic growth will lead to more equality and prosperity worldwide (Mitcham 1995). It also assumes a western perspective of anthropocentrism and conflict between societal needs and environmental needs (Parodi 2015). The dominance of this western perspective can hinder the adoption of sustainability policies in developing countries, as 'needs' may be construed differently by different societies and cultures. Therefore, the policies and ideas outlined in sustainability policy and strategy (e.g. Brundtland Report, Brundtland and Khalid 1987) may not be applicable to the human 'needs' in many regions (Kopfmüller 2015). Although this thesis, and the vulnerability framework developed within it, are based on the concept of sustainability, it is important for these criticisms to be acknowledged. In order to address the western-centric limitation, efforts were made to ensure that the methodology and framework developed in this thesis is sufficiently customisable so that they can be adjusted for different environmental, social, economic and political conditions that influence the way that historic landscapes and cultural heritage are understood, perceived and managed.

3.2.5 Summary

This section discussed the three main conceptual elements of the methodological approach that underpins this research. These elements are interconnected in a number of ways, for instance the use of the historic landscape concept requires the scale and levels of cultural heritage to be altered from information levels within spatially explicit sites, to features within spatially continuous landscape character areas. Even though the higher spatial level (landscape) may be the same, the organisation of archaeology into lower levels is different. Studies that make such changes to the way that archaeology is organised and perceived within their research must be explicit in their reasoning and new scalar framework, in order to avoid misunderstandings and misuse of their data and results.

Sustainability relates to issues of scale, as by definition it requires the management of resources across three different institutional scales (economic, social, environmental), which are each organised with different jurisdictional and temporal levels. It also requires the consideration of various levels on the spatial scale, and both short-term and long-term resource use at various spatial and jurisdictional levels (local, regional, national, international/global). The pursuit of sustainability inevitably engenders issues of scale mismatch, so it is important to be cognizant of the complexity of scale issues in order to address them explicitly and effectively.

Finally, sustainability is a crucial consideration when managing the historic landscape: a key element of the historic landscape is its time-depth and the fact it gives equal value to remains from all generations. Furthermore, the elements that characterise the historic landscape include the impacts of present and past economic systems and human action, as well as environmental processes. Employing the concept of sustainability in the management of historic landscapes is important to make sure all elements and temporal levels are considered.

The methods, results and outputs of this thesis were informed by the conceptual and methodological approach outlined in this section. This was explored in detail in order to make the research process and conclusions of this study as transparent as possible.

3.3 Overview of Methods

This thesis used a mixed-methods approach, utilising both quantitative and qualitative data collection methods. The following section discusses and justifies the methodology with reference to how the chosen methods address each of the research aims. Detailed descriptions of each stage of the methodology are also presented in the relevant chapters. Following the introduction (Chapter 1), justification of research (Chapter 2), conceptual framework (Chapter 3), overview of the study area (Chapter 4), and landscape analysis (Chapter 5), the main body of the thesis is divided into three chapters, each of which is dedicated to one research aim (See Figure 1.4). The conceptual framework described above was instrumental in shaping the methods chosen for this thesis: HLC is based on the concept of the historic landscape. The concept of sustainability was addressed by creating a sustainability assessment, which measured and compared different management approaches based on the factors needed to satisfy sustainability.

3.3.1 Landscape Analysis and Characterisation

The first research aim, addressed by Chapter 6, is the need to characterise the historic landscape of the study area, by analysing the known archaeological resource, identifying additional cultural heritage remains, and using the data generated to inform HLC.

The known archaeological resource is defined as the records held in the National Monuments Record of Wales (NMRW) and the Historic Environment Record (HER) databases, any information held in archives such as The National Archives and The National Library of Wales (NLW), and the results of Level 1 surveys carried out by University of Sheffield Landscape MA students. These records formed the lower observational level within the Hierarchy Theory scalar framework employed in this research, as they influence the character of different areas of the historic landscape. Although the main focus of this thesis is on the historic landscape and landscape character areas, the level of archaeological features and sites is the most commonly used focal level within heritage management, so it was appropriate to include consideration of this spatial level. Additional cultural heritage remains were identified through the analysis of aerial photographs and the deployment of geophysical survey in areas with potential for sub-surface remains. The information collated and collected about the archaeological resource of the study area was combined with historic and modern maps to inform a HLC of the study area. This is a method of landscape analysis and interpretation, that represents the current landscape as the cumulative outcome of past human activities and identifies areas of similar historic character (see Chapter 6). Each area of similar character (LCA) is a *holon* at the focal level of the hierarchy theory as it applies to this thesis (see 3.2.3).

3.3.2 Development of a Landscape Vulnerability Assessment tool

Once the historic landscape has been characterised for the study area, the second research aim is to develop a methodology for assessing the vulnerability of the historic landscape to climate change and its associated impacts (see Chapter 7). This requires an exploration of climate change and sea-level rise models for the coming century, and a review of other vulnerability assessment methods used in archaeology. Based on this review, the method chosen was a vulnerability index (VI). This review also showed that other vulnerability assessments used in archaeology predominantly concentrated on 'sites' as the focal level of analysis. Therefore, in order to maintain the focus on the historic landscape rather than on individual features or sites, a new landscape-level VI was created. The VI methodology developed is then applied to the Dysynni valley study area.

The temporal extent of this study and the climate change impacts included is the 21st century because the vast majority of integrated model assessments within climate change research focus solely on this period, and the IPCC RCP emission scenarios also only encompass the 21st century (Meinshausen *et al.* 2011; Collins *et al.* 2013). The uncertainties inherent in climate models, future GHG emissions, and the reaction of the climate to radiative forcing means that the range of potential outcomes in the longer-term is so great as to be unhelpful to decision-makers. For instance, the IPCC models project anthropogenic radiative forcing between 0 and 12Wm^{-2} by 2300, which would result in global surface temperature change between +0 and +12.6°C, depending on the RCP (Collins *et al.* 2013). Tackling a longer timeframe in this project would suffer from a lack of robust research into potential climatic changes and impacts and too wide a range of eventualities for usefully informing coastal or archaeological management (Hawkins *et al.* 2014).

Although trialled using the Dysynni valley study area, this VI is designed to be applicable to other landscapes, so that the overall Landscape Vulnerability Framework developed in this thesis can be replicated for other historic landscapes in the UK and beyond.

3.3.3 Development of a Sustainability Assessment tool

In response to the results of Chapter 7, which identifies the most vulnerable landscape character areas to climate change, the most suitable methods of managing the threat to cultural heritage must be assessed. Chapter 8 develops a tool that assesses both the sustainability of potential coastal management approaches, and the impact that they would have on the historic landscape. In order to incorporate the various elements of sustainability, the assessment tool chosen is a Multi-Attribute Value Theory (MAVT) method (see section 8.2). MAVT is a tool used for multi-criteria decision analysis, in which alternative options are compared based on various criteria, in relation to one or more objectives. This allows both quantitative and qualitative factors, and conflicting objectives, to be incorporated into the same assessment (Wang *et al.* 2009). Section 8.2 provides a justification of this choice of tool based on a review of the most commonly used sustainability assessment tools.

This sustainability assessment tool was trialled on the Dysynni valley study area, by using it to compare the sustainability of the current management approaches along the coast with other sustainable coastal and landscape management options. Unlike traditional sustainability assessments, this tool was designed to include specific mention of cultural heritage and the historic landscape, alongside economic, social and environmental considerations.

3.4 Summary

Overall, the aim of this thesis is to develop a framework (a Landscape Vulnerability Framework) for assessing the vulnerability of the historic landscape to climate change and identifying the most sustainable approach to managing the identified risk. This framework is designed to be applicable to coastal landscapes across the UK and beyond, and is also easily customisable for application to inland or other types of landscape.

The conceptual framework throughout the thesis is defined by the three concepts discussed above in 3.2: the explicit structuring of the subject into a hierarchical framework in order to clearly incorporate elements from all spatial levels; the conceptualisation of archaeological/cultural heritage as spatially continuous and layered across the landscape; and the need to include economic, social and environmental variables, and both inter- and intra-generational equity, in the management of the historic landscape. All three parts of the thesis, as discussed above, are underpinned by this conceptual approach. Ecological and environmental vulnerability assessments are often undertaken using a patch-matrix approach, rather than focusing on discrete points within a landscape (e.g. Thuiller *et al.* 2005; Berry *et al.* 2006; Vos *et al.* 2008). Using Hierarchy Theory and applying it to the historic landscape provides a way to recalibrate the scale of archaeological management and assessment so that it is more in line with other systems and the impacts of climate change. Furthermore, focussing on the idea of sustainability and including economic, social and environmental considerations makes this landscape vulnerability framework more compatible with the mainstream climate change impact and adaptation reports, in which archaeology and heritage get little mention (e.g. IPCC 2014a, b; ASC 2016; Defra 2018).

Chapter 4

Dysynni Valley, Gwynedd: an introduction to the case study

4.1 Introduction

The Dysynni valley historic landscape was chosen as a study area in order to trial and exemplify the framework being developed in this thesis. The Dysynni valley is a designated Landscape of Special Historic Importance in Cardigan Bay, in the county of Gwynedd, North Wales. The majority of the study area lies within the boundaries of Snowdonia National Park, with only the town of Tywyn lying outside the park. The extent of the study area for this thesis is outlined in Figure 4.1. This was defined by the Ordnance Survey national grid boundary for SH50 and SH60 to the north and east, the coastline to the west, and the Dyfi estuary and wetlands to the south and south east. This region has a long and rich history of human settlement, but most known archaeological sites in this landscape are confined to the upland areas. This is partly due to the disruption caused by centuries of agricultural activity in the lowlands, as well as a relative lack of archaeological survey in these areas. However, complex cropmarks, field boundary morphology and the location of find-spots indicate that there remains a wealth of archaeological information on the valley floor. Following a justification of the case study choice (4.1.1), this chapter reviews the current state of knowledge of the environment, history and archaeology of the study area and surrounding landscape. The geological and environmental background of the Dysynni valley are first discussed (4.2 and 4.3). Subsequently, the known archaeological information is detailed in chronological order, followed by information regarding the current research and management of the resource (4.4 and 4.5). Further research into archives and archaeological datasets were used to supplement this information in Chapter 5 as part of the landscape analysis. Figure 4.2 provides a map including the main sites of interest mentioned within this report.

4.1.1 Case study choice

The Dysynni valley was chosen as the study area for several reasons. In order to test the methodology on a full range of climate change impacts, the study area had to be vulnerable to climate change and there must also be accessible data about the natural and historic environment. The combination of low-lying valleys and steep slopes in west Wales allows the incorporation of many different climate change factors. Having a varied and dynamic coastline, including natural dune systems, saltmarsh, mudflats, both shingle and sand beaches, estuaries, and lagoons, means that the framework developed can be tested on many different coastal systems. It was also important to have an area with a long history of human occupation, so that the results and framework generated could be meaningful for cultural heritage management. Other areas that could have been chosen for their vulnerability to climate change include the Holderness Coast, East Riding of Yorkshire, which is particularly vulnerable to coastal erosion, or The Fens in eastern England, which are vulnerable to sea-level rise. However, the topographic and biotypic variability in west Wales provides a greater insight into the way that different types of cultural heritage are vulnerable to climate change.

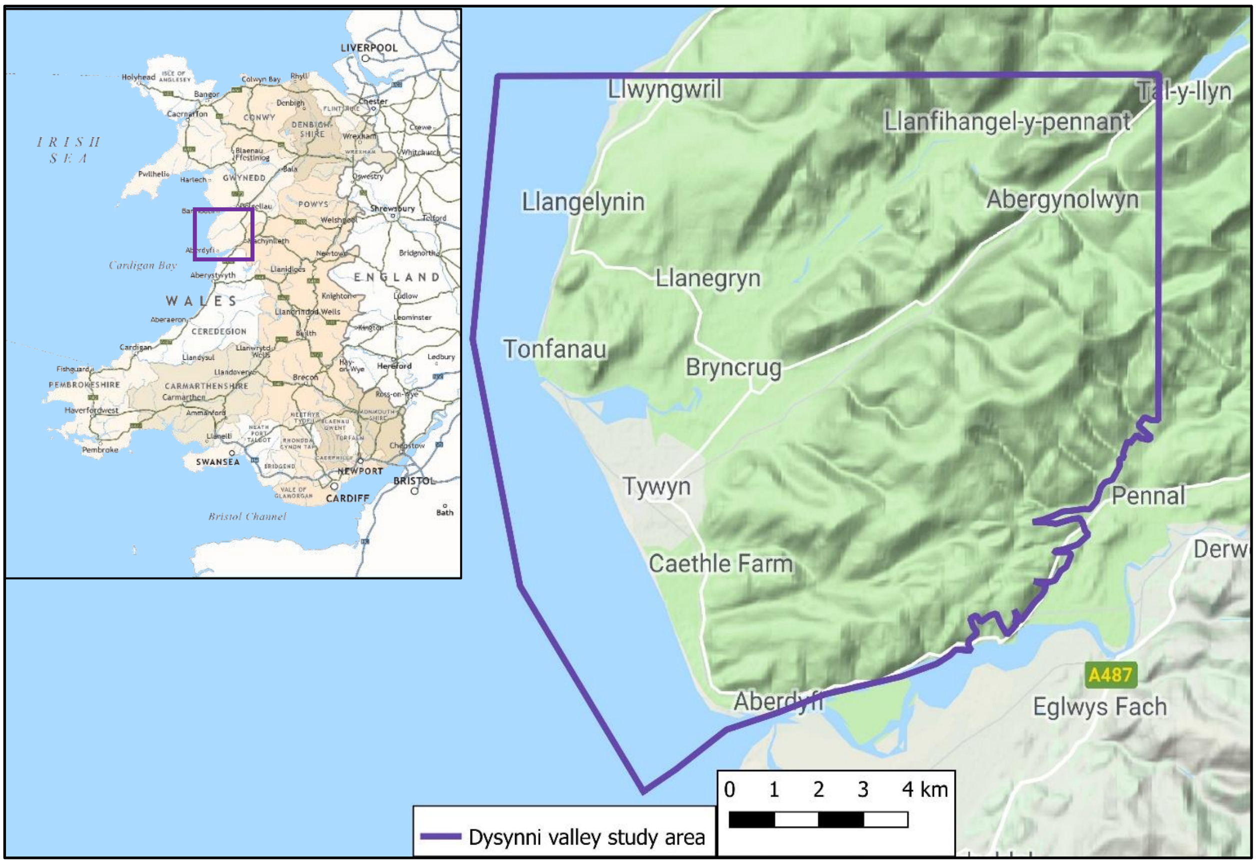


Figure 4.1. *Dysynni valley study area in Gwynedd, Wales. Copyright Maproom 2019 (left) and Google Maps 2019 (right)*

The University of Sheffield Department of Archaeology was already undertaking archaeological survey in west Wales, in the Dysynni valley, including landscape and geophysical survey. This meant that the results of geophysical surveys undertaken in previous years but not yet published were available. It also meant that MA Landscape Archaeology students were available in the study area to help with geophysical surveys during the field season, allowing a greater area to be covered than would have been otherwise possible.

As discussed below (4.3), the valley floor of the River Dysynni is low-lying and susceptible to flooding. Additionally, there are extremely steep areas which are susceptible to erosion and rockfall.

Using this study area allows the Landscape Vulnerability Framework to be tested on several different environmental settings and topographies within the same landscape.

Finally, the Dysynni valley is relatively rural and all land-use is extensive and low impact, so archaeological features from a range of periods are extant across the landscape. This facilitates the identification of historical elements and the characterisation of the historic landscape in Chapter 6.

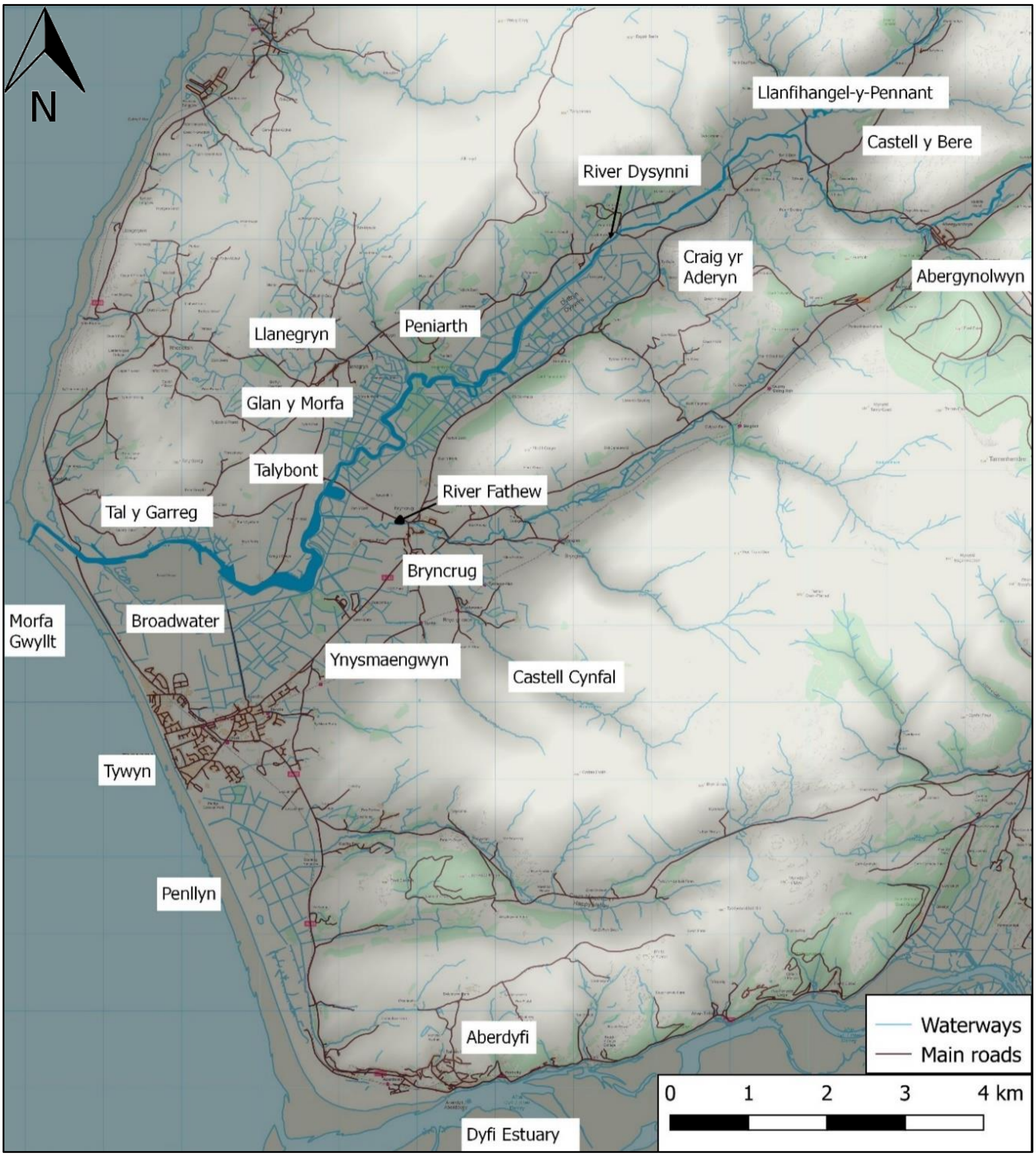


Figure 4.2: *Locations in the Dysynni valley mentioned in this chapter on an Ordnance Survey Vector Map. Elevation is overlain on the map to indicate topography. The brown lines indicate main roads, and the blue lines indicate waterways such as the River Dysynni, streams or drainage ditches. Crown copyright and database right 2019 Ordnance Survey 100025252*

4.2 Geology

4.2.1 Bedrock

The bedrock geology in the Dysynni valley floor is dominated by sedimentary formations, mainly mudstone and mudstone mixes (see Figure 4.3). A ribbon of igneous formations, including felsic tuff, rhyolite and basalt, stretches inland from Morfa Gwyllt, although it has been divided by a fault plane. Sedimentary rocks are softer and more susceptible to coastal erosion than igneous rocks (National Grid for Learning 2008). The predominance of this type of geology indicates that the coastline in the study area may be at risk from coastal erosion.

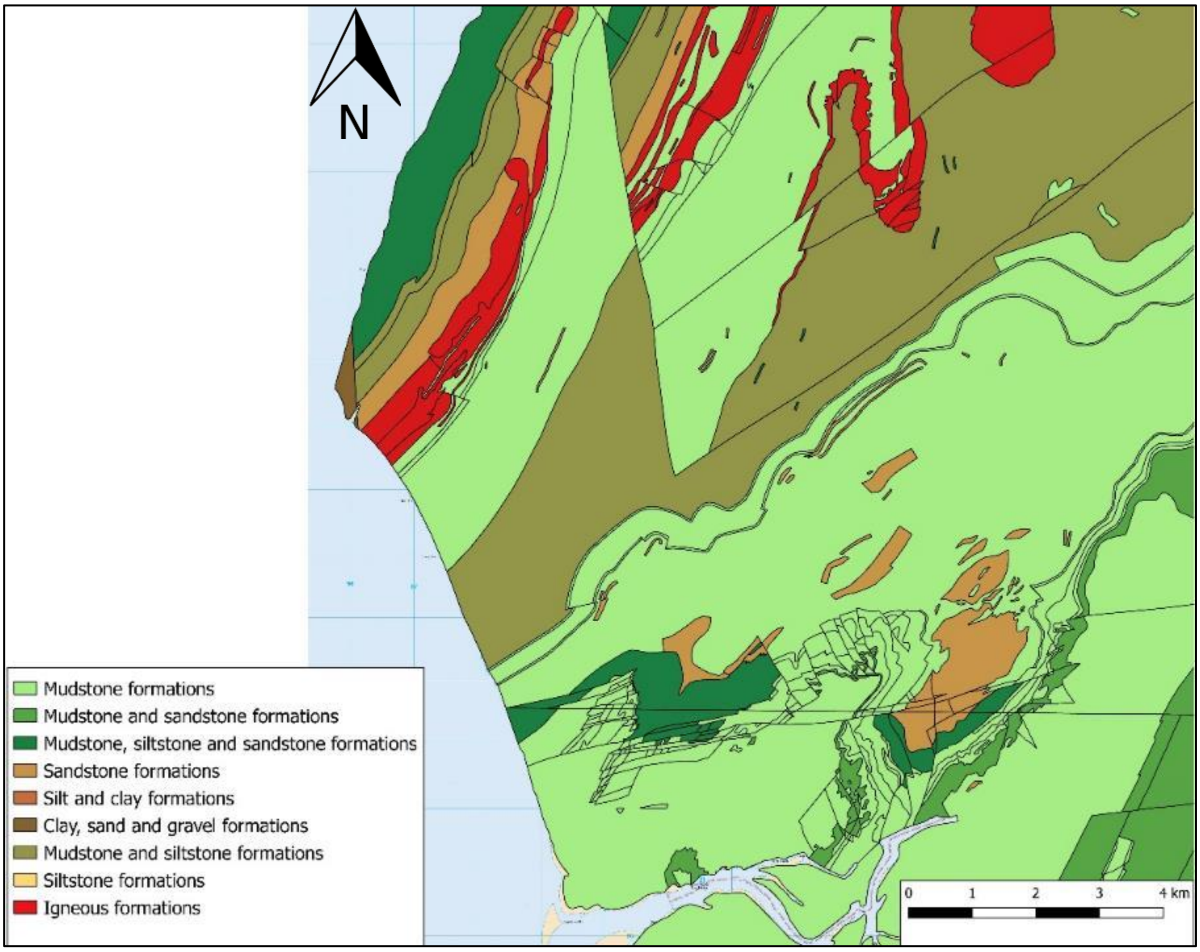


***Figure 4.3**. Bedrock Geology in the Dysynni valley from the British Geological Survey (DiGMapGB-50 2010). Geological Map Data BGS Copyright UKRI 2019. Crown copyright and database right 2019 Ordnance Survey 100025252*

4.2.2 Superficial deposits

Along the shoreline from the mouth of the Dysynni in the north, to the Dyfi Estuary in the south, is a band of coastal deposits (see Figure 4.4), including storm beach and tidal deposits, that extends inland south of Tywyn. This configuration of superficial deposits indicates that this area may have been in the intertidal zone or part of a delta system at some point during the Holocene (BGS 2019). Blown sand deposits also band the coastline, although do not stretch as far inland as the coastal, storm beach and tidal deposits (see Figure 4.4).

The land from the coast at Broadwater, stretching inland along the Dysynni valley bottom to Castell y Bere, is dominated by alluvium and river terrace deposits, likely deposited by the river and estuary system during the Holocene (Thomas and Chiverrell 2003). Small areas to the north and south of Broadwater, and south of Tywyn, are formed of Devensian glacial till, which was deposited when glaciers in the valley melted at the end of the Devensian Glaciation (Entwhisle and Wildman 2010). In fact, the U-shaped nature of the Dysynni valley was likely created due to glacial erosion (Watson 1962; Blundell *et al*. 1969; Snowdonia National Park Authority (SNPA) 2016). There are also peat

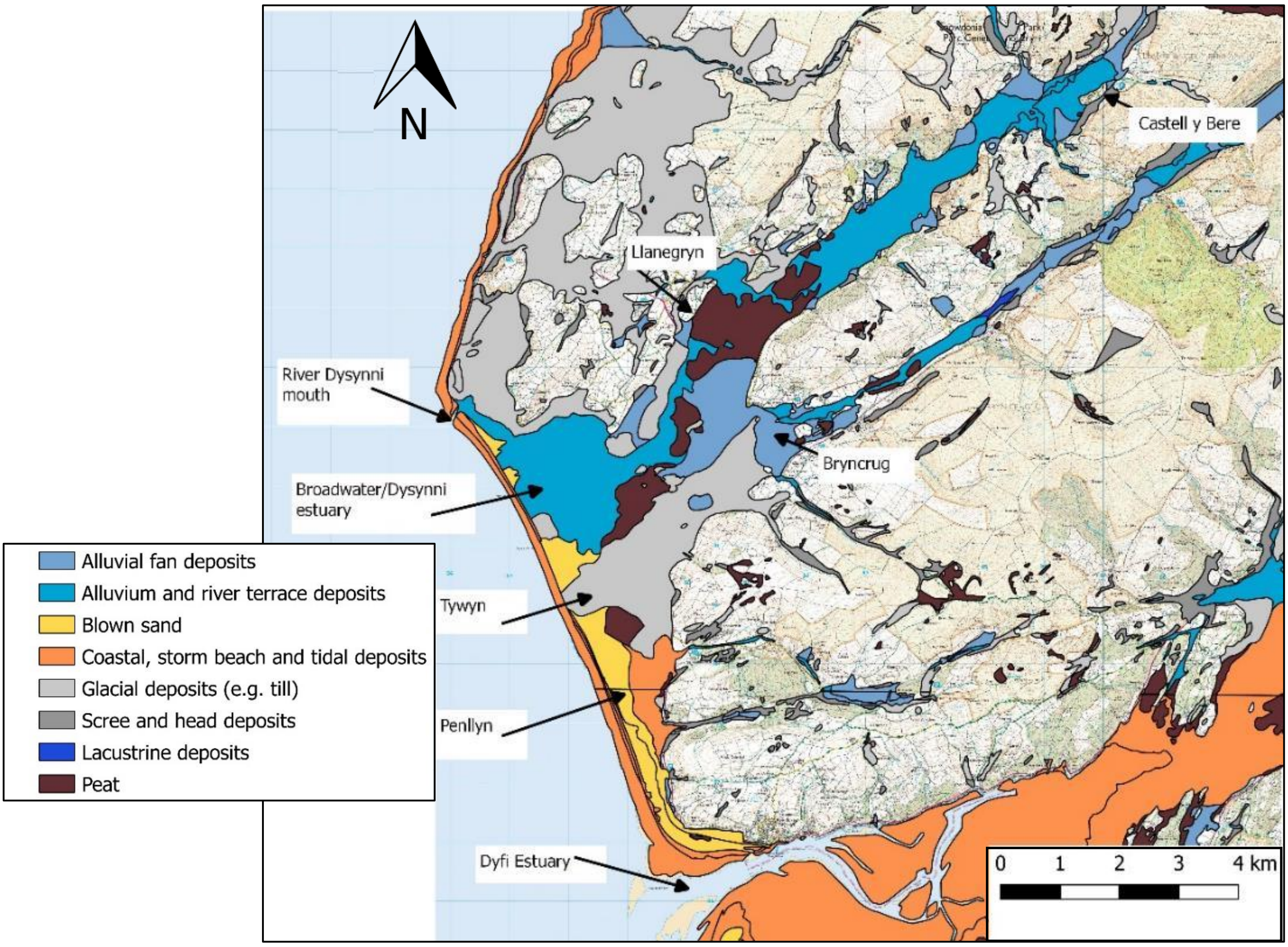


Figure 4.4. *Superficial geological deposits in the Dysynni valley from the British Geological Survey (DiGMapGB-50 2010). Geological Map Data BGS Copyright UKRI 2019. Crown copyright and database right 2019 Ordnance Survey 100025252*

deposits located directly north and south of Tywyn and west of Bryncrug, while a larger deposit of peat stretches across the Dysynni Valley floor near Llanegryn (see Figure 4.4).

To the northwest and southeast of Bryncrug is a large alluvial fan deposit, indicating that the River Fathew may have been much larger in the past. Smaller alluvial fan deposits can also be seen on the edge of the valley bottom further inland in the Dysynni Valley, near Craig yr Aderyn and Castell y Bere. The dominant superficial deposits around Castell y Bere are river terrace deposits (see Figure 4.4), which indicates that there was a more extensive and dynamic river system in the Dysynni valley during the Holocene than at present (Griffiths *et al*. 2013).

4.3 Environment

The Dysynni estuary and surrounding coastline consists mainly of a low-lying coastal plain, while the Dysynni valley is a typical U-shaped valley, with a flat, wide valley floor and steep sides. The plain lies below 10m aOD (above Ordnance Datum) up to 10km inland along the river valley. As a result, the floodplain is vulnerable to storm surges, high rainfall events, and other flooding mechanisms. Prior to extensive drainage and land improvement schemes in the 18th and 19th centuries, much of the land in the valley was unproductive marshland (Smith 2004a; Frost 2012). This is indicated by the fact that there is an area of land north of Tywyn called 'Morfa', which translates to 'marsh' or 'saltmarsh', while Penllyn farm, south of Tywyn, translates to "head of the lake". This lake can be seen on tithe maps from the mid-19th century.

Other historical reference to past environmental change in the valley includes Craig yr Aderyn, or 'Birds Rock', which is a hill rising from the south side of the valley floor, approximately 8km inland. Craig yr Aderyn is a Site of Special Scientific Interest (SSSI) as it houses the only regular inland breeding colony of cormorants in Wales (McInnes and Benstead 2013). It is suggested that Craig yr Aderyn was once closer to the coastline, which is why cormorants initially nested there, and that they continued to nest there despite the retreating shoreline (*ibid*.).

Finally, there is a submerged forest and peat bed located in the intertidal zone of the coast of Borth, around 7km south of the study area (Godwin and Newton 1938). Radiocarbon dating of the peat deposits show that it dates to c.6000-4700 cal. BP (Wilks 1979). This shows that sea level was previously lower than at present, so palaeoenvironmental and archaeological evidence could be preserved within the submerged forest and peat beds. It is possible that the peat beds extend further north than the current known extent, and are covered by sand (Smith 2004a). This is supported by the presence of both well-humified peat and woody peat beneath Penllyn Farm, as shown by the results of coring undertaken by both the British Geological Survey (BGS) (Leng and

Pratt 1987) and by Caitlin Nagle (pers.comm.). However, any offshore peat beds at Tywyn may have been subject to an increase in erosion since the construction of the sea wall there in the 19th Century, and so may not remain extant.

The study area is also considered important for biodiversity, and includes several Biodiversity Action Plan priority habitats such as saltmarsh, lagoons, mudflats, reedbeds, and the SSSI Broadwater (JNCC 2016; SNPA 2016; Welsh Government 2016). Broadwater, the saltwater lagoon near the mouth of the River Dysynni and the surrounding dunes and marshland, is designated a SSSI due to the range of habitats it includes, and the plant and animal species it supports. There are several species of both breeding and wintering birds at Broadwater, such as Coot and Sedge Warbler (breeding) and Mallard, Teal and Wigeon (wintering) (Countryside Council for Wales (CCW) 1983; Natural Resources Wales (NRW) 2007; Vanstone *et al*. 2012). Rare plants, such as the Welsh mudwort, pyramidal orchid, autumn ladies tresses, and bur-marigold can also be found in this SSSI (NRW 2007). The Snowdonia National Park Authority (SNPA 2016) acknowledges the threat of climate change to these estuarine ecosystems, although the Park makes no mention of the potential archaeological and historical sites that could also be affected. The area encompassing the Dyfi Estuary and coastal dune system to the north also has several designations relating to its ecological status; it is a National Nature Reserve (NNR), an SSSI, a Ramsar wetland site, a Special Protection Area (SPA), and a UNESCO Biosphere Reserve

Upland areas in the Dysynni valley are dominated by acid grassland, heath and bracken, and raised bog habitats, which are used for sheep grazing (SNPA 2014a). Few areas of natural woodland are supported, but large areas of the hills are used for conifer plantations for timber production (*ibid*.). In addition to forestry, the main land use in the study area is pastoral farming. Sheep farming is most common on the steep slopes and higher upland areas, and both sheep and cattle are farmed in the lowlands and on coastal grazing marsh (*ibid*.).

4.4 Archaeological and Historical Background

This section provides an overview of the state of research prior to the undertaking of this thesis. Aerial mapping and geophysical surveys have identified additional features in the study area, as detailed in Chapter 5. Further information on the features mentioned in this section is available in Appendix 1 Table Ap1.1.

4.4.1 Mesolithic (10,000BC – 4,000 BC)

The main archaeological remains dating to the Mesolithic are the intertidal peats and submerged forest (see Figure 4.5), and the associated finds. These include a Mesolithic flint pick, flint flakes, and an antler tool (Sambrook and Williams 1999, p. 26). There is also a high potential for Mesolithic artefacts or features to be preserved within the peat beds beneath Penllyn Farm, based on the high level of preservation of wood in cores from this area observed by Nagle (pers.comm.).

4.4.2 Neolithic (4,000 BC – 2,200 BC)

Within the intertidal peats a hearth was recorded and dated to c.5900 cal. BP (Godwin and Willis 1961; Heyworth 1985), indicating that the area may have continued to be in use during this period. Two Neolithic stone axes were discovered in 1871 300m south of Llanegryn (Frost 2012). Other than this, there is little known archaeological evidence dating to the Neolithic.

Figure 4.5: *Tree stump preserved amongst the submerged forest bed dating to at least 5400-3900 cal. BP (Sambrook and Williams 1996)*

4.4.3 Bronze Age (2,600 BC-700 BC)

There is significantly more archaeological evidence of the Bronze Age in the study area and surrounding landscape than the Neolithic. For instance, there are several known Bronze Age standing stones, such as the Waun Fach stone near Llanegryn (Smith 2001). There are also several Bronze Age find-spots, including several bronze axes and spearheads (Smith 2005). The majority of these are found at higher altitudes in the hills surrounding the valley, for instance the cairn found at the highest peak of Craig yr Aderyn. However, a group of Early Bronze Age burials and burial urns were also discovered on the eastern edge of Tywyn, only 1.5km inland (Anwyl 1909, p.162).

4.4.4 Iron Age (800 BC – AD 43)

There is a wealth of Iron Age evidence in and around the study area, primarily in the form of hillforts. For instance, there are two Iron Age hillforts located on the southwest slope of Tal y Garreg, a hill on the north side of the Dysynni valley (Smith 2008). There is also an Iron Age stone-walled hillfort on Craig yr Aderyn, at 233m aOD, with extensive views along the Dysynni valley (*ibid.*). Several enclosures have been identified as cropmarks in aerial photographs near Bryncrug, and are thought to date to later prehistory (Wiles 2007a).

4.4.5 Roman (AD 43 – AD 410)

There are several find-spots of Roman artefacts in or around the study area; pottery, a plumb bob and part of a lead bar all thought to be Roman were discovered during an excavation on Craig yr Aderyn during the 19th Century (Ffoulkes 1874, cited in Driver 2013). Roman coins have also been found in six findspots, according to Guest and Wells (2007). One of these was a single find, three were group finds, and two were hoards (*ibid.*). One of the group finds, from the well of Castell y Bere, indicates that the site was used prior to the construction of the medieval castle. There are also the remains of a Roman fort in a strategic position overlooking the Dyfi Valley at Cefn Caer, slightly east of the study area (SNPA 2016). There is evidence of a Roman road running from the coast near Llwyngwril towards the northeast along the south side of the Mawddach Estuary (Bowen and Gresham 1967). Bowen and Gresham (1967) also posit that there may have been a Roman road connecting the fort at Cefn Caer to the road at Llwyngwril, either directly over the hills and past Castell y Bere, or in the lowlands along the coast and crossing the Dysynni at Domen Dreiniog (see 4.4.7). This combination of evidence indicates that there was undoubtedly activity in the study area during the Roman period.

4.4.6 Early medieval (AD 410- AD 1066)

There is a significant amount of archaeological and historical evidence dating to the early medieval period within the study area. Several inscribed stones have been found in or near Tywyn, including Croes Faen and the Pascentius Stone dating to the 5th-7th centuries (Longley and Richards 1974). It is thought that St. Cadfans Church Stone, dating to the 9th century, is the earliest documented instance of written Welsh, which makes it very valuable for the study of early Welsh history and the history of the Welsh language (Edwards 2013).

Viking raids of Tywyn during the 960s and 970s AD were recorded in Brut y Tywysogion, a monastic chronicle documenting the 7th-14th centuries, a version of which is held within the Peniarth Estate Manuscripts collection. This suggests that there was a settlement or monastic community located at Tywyn that was large enough to be considered worth raiding (Longley and Richards 1974).

A survey and excavation at Llanegryn undertaken ahead of the construction of a primary school revealed six hearths mainly dated to between the 8th-11th centuries (Cooke 2014). The hearths were probably used for charcoal making, evidenced by the lack of any charred plant remains or any indication of industrial processes such as slag (*ibid*.).

Cropmarks of several square features were identified in aerial photographs between Tywyn and Ynysmaengwyn. These features are thought to be an early medieval square barrow cemetery, and are located near the site of the Croes Faen stone (RCAHMW 2012a).

4.4.7 Medieval (AD 1066 – AD 1540)

Two castles, Castell y Bere and Castell Cynfal, were constructed during the medieval period in the study area. Castell Cynfal, now a motte located on a ridge on the south side of the Dysynni valley, would also have included a timber castle (Beverly Smith and Beverly Smith 2001; Wiles 2007b). It is uncertain how far the castle or complex extended, and it was only in use for a short time; constructed by Cadwaladr ap Gruffudd ap Cynan in 1147, but captured and destroyed in the same year by his nephews Hywel and Cynan (Beverly Smith and Beverly Smith 2001; GAT 2017a).

Like Castell Cynfal, Castell y Bere was also built by the Welsh, and was conquered and abandoned shortly after its construction in the 13th century. It is located near Llanfihangel-y-Pennant, and is situated on top of a natural mound of bedrock surrounded by flat pasture land (see Figure 4.6). The function of Castell y Bere is uncertain, for instance whether it was for military or administrative purposes (Beverly Smith and Beverley Smith 2001). Finds of Roman coins and pottery from the well within Castell y Bere suggest that the site was occupied prior to the construction of the castle (Bowen and Gresham 1967). There is documentary evidence dating to the late 13th century that suggests that a borough, or burgh, was constructed by royal charter near the castle (Morris 1901). However, there is no reference to the burgh in any historical document later than 1295, which has been attributed to the destruction and abandonment of the castle in 1294-5, and the assumed abandonment of the burgh (Lewis 1912; Taylor 1974). It has been suggested that the location of Castell y Bere indicates that the River Dysynni, currently narrow with a low discharge near the remains, may have been navigable during the medieval period, greatly increasing the access to trade routes from this site (Smith 2004a).

Llanegryn Parish Church of St Egryn and St Mary was also constructed in the 13th century, and was referenced in a document dating to 1254 (Beverly Smith and Beverly Smith 2001; Frost 2012). An earlier pillar with an incised cross was built into the south wall of the church, and the building was extended during the 19th century (Beverly Smith and Beverly Smith 2001). The church therefore incorporates architectural styles and cultural heritage from several historical periods.

During the medieval period, land in Wales was divided into administrative areas called *commotes*, which were controlled by a central royal court, or *llys* (Cadw 1990). Talybont Castle Mound, also known as Domen Ddreiniog, is thought to have been associated with a *llys*. It is located at a former bridging point of the Dysynni, at a meander which would provide defence for the site (Frost 2012; GAT 2017b).

Figure 4.6. *View from the ruins of Castell y Bere across the flat valley floor towards the coast. The Iron Age hillfort atop Craig yr Aderyn can be seen from here.*

4.4.8 Post-Medieval (AD 1540- AD 1901)

Several large stately houses with estates were built in or near the study area. For instance the Peniarth Estate, now a Grade II listed building, was established in 1412 and enlarged in the 1700s. (Frost 2012). The Peniarth Estate Records and Manuscripts, now held in NLW, comprise 106 boxes and 547 manuscripts, and include documentary material from as early as 1362.

The Ynysymaengwyn Estate, also constructed in the 15th century, was demolished in the 1960s after falling into disrepair (Frost 2012). Both the Peniarth and Ynysymaengwyn Estates invested in significant drainage and land improvement in the Dysynni valley in the 18th and 19th Centuries, to turn the lowlands of the valley into productive farmland (Smith 2004a; Frost 2012). The previous nature of much of the Dysynni valley as wetland is indicated in placenames. For instance, Penllyn ('head of the lake') Farm is no longer situated near any large water body, while the Glan y Morfa ('next to coastal marsh') Bach and Mawr farms, are located 4.5km inland, and 2.8km from Broadwater, the nearest large wetland area. Gwynedd Archaeological Trust (GAT 2017c) speculate that Ynysymaengwyn would have been within the tidal reach of the Dysynni prior to this land improvement, which would have provided greater access to communication and trade routes.

There are numerous sites in the hills surrounding the Dysynni valley lowlands related to industrial activity, including quarries, mines, and related buildings. It is likely that these were important for transporting resources during the Industrial period (SNPA 2016). Talyllyn Railway is a narrow-gauge railway established in 1865 to carry slate from the Bryneglwys quarries by Nant Gwernol Station, Abergynolwyn to the standard-gauge railway at Tywyn (GAT 2017d). The development of this railway for goods transportation indicates that the resources sourced in the study area were important for regional development. The railway was the first narrow-gauge railway in Britain to carry passengers by steam, and remains open as a tourist attraction (*ibid.*).

4.4.9 Contemporary (AD 1901-present)

During the 20th Century there was significant military activity in the study area, particularly during the Second World War. Practice trenches and a rifle range can be found near Tywyn, with more practice trenches further up the coast near Barmouth (Kenney and Hopewell 2015). Near the coast

Figure 4.7. Two of the line of Second World War pillboxes between Tywyn and Aberdyfi

between the Dysynni and Mawddach estuaries is a Prisoner of War camp also dating to the Second World War (*ibid*.). The remains of an RAF airfield and camp and 12 known air crash sites are located in the valley, and a line of pillboxes stretch along the coast to the south of Tywyn (see Figure 4.7) (GAT 2012; Steele 2012; Kenney and Hopewell 2015). Evidently, this area is important for the archaeological study of the Second World War, and much of the archaeological remains for this period are located in the coastal or intertidal zone, increasing their exposure to climate change.

4.5 Archaeology and Cultural Heritage Management

4.5.1 Organisations with jurisdiction

The majority of the heritage management in the Dysynni landscape is led and undertaken by four organisations; Cadw, Gwynedd Archaeological Trust (GAT), SNPA, and the Royal Commission on the Ancient and Historical Monuments of Wales (RCAHMW). Other than Tywyn, the study area lies within Snowdonia National Park, and is therefore under the jurisdiction of the SNPA. This is a central planning authority made of representatives from local and Welsh governments. Any consent or planning permission for listed buildings within Snowdonia must be sought from SNPA rather than Gwynedd Council.

Cadw is the historic environment service of the Welsh Government. They maintain and protect heritage assets including landscapes, archaeological sites, and historic buildings, and make them accessible to members of the public. They are also responsible for the designation of heritage assets such as scheduled monuments, listed buildings and conservation areas, which provide statutory protection. In Wales, county archaeological trusts exist to provide archaeological and heritage services such as research, excavation, survey, publishing reports, and education. For the Dysynni valley, GAT provides this service. GAT undertakes archaeological research commissioned by other organisations, for instance archaeological desk-based assessments (DBAs) for development projects (see Smith 2004a; Meek 2015), research projects funded by Cadw (see Longley and Richards 1999; Davidson *et al.* 2002; Kenney and Hopewell 2015), and conservation area appraisals for SNPA (see Davidson 2011).

GAT also curates the HER, a comprehensive database supported by geographic information system (GIS) mapping, which contains information on historical and archaeological sites, monuments, buildings, and landscapes. It facilitates data sharing between organisations and is dynamic, meaning new information can be added to the record. Another database of heritage assets is the NMRW, which is curated by the RCAHMW. RCAHMW is a government-sponsored body which creates, curates and provides archaeological information for governmental decision-makers, researchers and the public.

4.5.2 Recent research

Several of the research projects carried out in the Dysynni valley and surrounding region have been funded or commissioned by Cadw. The main aim of these projects has been to compile accurate records of different types of archaeological remains in the Dysynni valley and wider area, such as early medieval burial and ecclesiastical sites (Longley and Richards 1999; Davidson *et al.* 2002), medieval and post-medieval agricultural features (Kenney 2014), military aircraft crash sites (GAT 2012; Steele 2012), military landscapes (Kenney and Hopewell 2015), and slate industry transport routes (Davidson and Gwyn 2014).

There has also been a number of commercial archaeological assessments and surveys, for instance for development projects such as a new primary school (Roseveare 2012; Wessex Archaeology 2012, 2014), a residential development in Tywyn (Smith 2013), a solar farm (Meek 2015), and a multi-user path between Tywyn and Bryncrug (Knight 2011; Blackburn 2011). In the DBAs for the latter example, Knight (2011) recommended that strip, map and sample excavations should be undertaken at several known features near Croes Faen, such as the Croes Faen standing stone, and the Croes Faen square barrow cemetery cropmarks. However, these were not undertaken due to heavy snow, which created unfavourable working conditions (Blackburn 2011). The construction went ahead without the strip, map and sample excavations, rather than delaying the development until more suitable conditions permitted the investigations to be undertaken. In this case the development time-line was prioritised over the potential archaeology in the area, and an opportunity to further the understanding of the archaeological record in the study area was potentially lost.

There have been a few sensitivity or threat-related assessments undertaken in north west Wales. SNPA carried out a sensitivity analysis of each of the landscape blocks in Snowdonia, which focussed on threats to the character of the landscape such as wind energy developments, mobile masts and caravan parks (SNPA 2014b). This assessment determined that the Dysynni valley landform, skylines and key views, scenic quality, character, and tranquillity had high sensitivity to wind energy developments, mobile masts and static caravan or chalet parks.

At a much larger spatial level, the CHERISH (Climate, Heritage and Environment of Reefs, Islands and Headlands) Project is assessing the potential impacts of climate change on coastal cultural heritage in Wales and Ireland. This five-year project (2017-2021) is funded by the EU through the Ireland Wales Co-operation Programme, and is led in partnership by the RCAHMW, the Discovery Programme Ireland, Aberystwyth University, and Geological Survey Ireland (RCAHMW 2018). Case study areas in both Ireland and Wales have been chosen for detailed survey, mapping and monitoring. Detailed data of key heritage assets will provide a baseline for monitoring future rates of erosion (CHERISH 2018). One of the case study areas is Ynyslas National Nature Reserve, on the southern edge of the Dyfi estuary, but none of the work CHERISH is undertaking currently is directly related to the Dysynni valley and coastline (*ibid*.). However, the wider conclusions of the project may influence management decisions about coastal heritage in the future.

The RCAHMW also funded the Uplands Archaeology Initiative, or the Welsh Uplands Initiative, a project that promoted the survey of upland areas across Wales in order to identify new sites and enhance the databases of known sites (Hughes 2003).

4.6 Environmental Management

This section provides a brief overview of the environmental, coastal and flood-risk management in the Dysynni valley. A more in-depth discussion can be found in section 8.3. As a low-lying coastal area, the Dysynni valley has long been prone to waterlogging and flooding. The Dysynni Low-Level Drain (DLLD) and extensive drainage ditch system, developed in the 18th-19th centuries, is critical for maintaining the pastoral farmland on the valley floor (Dunderdale and Morris 1996; Smith 2005).

There is also a long history of coastal defence construction in the Dysynni valley. The original promenade and sea wall on the Tywyn coastal frontage was constructed in the late 19th century. An additional promenade was built further north, near Bryn-y-Mor, but was destroyed in a coastal storm in 1935 (Atkins 2009). A modern sea wall and promenade were built it its place around 1980 (Smith 2004). The most recent coastal defence project was completed in 2011, and included a new recurve sea wall, wooden and rock groynes, rock armour, and a detached breakwater (see section 8.3.1). It was developed to address the damage and undercutting of the previous defences (Atkins 2009).

Dredging has been carried out in the River Dysynni to lower the channel bed and reduce flood-risk in the surrounding floodplain (DredgingToday 2015; ITV 2015). As part of regional shoreline management policy, Aberdyfi harbour is also dredged to deepen the channel and make the estuary more navigable (Earlie *et al*. 2012a, b). The sand removed during this dredging is deposited on the beach and sand dunes to the west and north of Aberdyfi to combat shoreline retreat by widening the beach and stabilise the dunes (*ibid*.). The sand dunes west of Aberdyfi provide coastal protection for Aberdyfi Golf Club, which is important for the local economy and tourist industry (Wales Online 2013).

4.7 Summary

This chapter provided a brief overview of the Dysynni valley, the study area used to trial and exemplify the framework developed throughout this thesis. The Dysynni valley contains many areas that are environmentally and ecologically important, and is rich in evidence for human occupation with a high potential for further archaeological discovery. The nature of the Dysynni valley, as low-lying and overlain by soft alluvial deposits, means that the coastal effects of climate change such as sea-level rise and storm surges may impact archaeological and historical sites located several kilometres inland. However, few studies into the vulnerability or sensitivity of the local archaeological resource have been carried out, and relatively little archaeological research has been undertaken in the Dysynni lowlands, so archaeological sites may be exposed to the effects of climate change before they have been discovered and researched properly.

Several different organisations have jurisdiction over, or interest in, the heritage management of the study area. This can cause some confusion or overlap of information, for instance in duplicated records across different heritage resource databases (e.g. the HER and NMRW). This duplication indicates that some assets are being recorded and studied twice, which is inefficient and can be misleading if the two databases are combined without care.

As much of the archaeological research in the study area has been in the form of desk-based and archaeological assessments for development projects, new archaeological information is often only discovered prior to destruction. Furthermore, often the research undertaken cannot be as thorough as would be desired due to time constraints or working conditions (see Blackburn 2011). This study area provides a unique opportunity to develop indices of susceptibility to environmental change for sites that have not, as yet, been researched or protected in any way.

There is a long history of coastal defence and flood alleviation schemes in the Dysynni valley and coastline, indicating that the area has already been subject to the processes that are set to exacerbate due to climate change. Difficulties arise once a defence structure such as Tywyn sea wall or the DLLD has been established, as the maintenance and renewal costs can make it challenging to continue the same level of protection that has become expected (see section 8.1).

Chapter 5
Landscape Analysis

5.1 Introduction

Chapter 5 addresses some of the objectives of the first research aim of this thesis: *Identify a method of analysing and characterising the archaeological resource on a landscape level*. Namely, research objectives 1a (*Collect information on the known archaeological resource in the Dysynni valley*) and 1b (*Use aerial photography and geophysical surveys to enrich the archaeological record of the Dysynni valley*). In doing so, this chapter deepens the existing knowledge base of the cultural heritage in the Dysynni valley through a landscape analysis using a range of sources. This chapter focusses on collecting information on the components of the lower level of the historic landscape as organised in the Hierarchy Theory. These archaeological features inform the character of the landscape at both the focal level (LCAs) and the overall historic landscape.

A range of methods were chosen for the collection and synthesis of data relating to the study area, in particular with relation to past land use and the archaeological resource. Firstly, archival research was undertaken to discover historical documents pertaining to the study area, such as maps, land ownership, and management information. Secondly, archaeological databases containing all recorded archaeological feature and historical building data in the study area were compiled and studied. Next, aerial photographs taken over the 20^{th}-21^{st} centuries were studied to identify any previously unknown cropmark features. Finally, geophysical surveys were undertaken to ground-truth some of the cropmarks identified in aerial photographs, and survey the areas around known archaeological features. The main purpose of this data collection and synthesis was to provide a strong foundation for the HLC (see Chapter 6). All archaeological remains, historical buildings, and landscape features identified through this landscape analysis are used as Landscape Character Features (LCFs), the lower level of the historic landscape within the Hierarchy Theory framework. LCFs are features that give character to, or influence the character of, the historic landscape and different LCAs.

Several methods were used for the landscape analysis because each method measures different variables, so the results of all methods combined provides a more complete picture of the cultural heritage of the study area compared to using a single approach (Islas and Vergara 2012). This makes the results of the analysis more informative, as well as more robust and reliable (Barber *et al.* 2000; Langdon *et al.* 2003; Birks 2005).

5.2 Methodology

5.2.1 Archival research

Archival research was carried out in order to identify and study any historical documents, particularly maps and photographs, relating to the Dysynni valley. First, online searches were carried out for records in the following archives: The National Archives, The National Library of Wales (NLW), Coflein (the RCAHMW online catalogue), The British Library, Bangor University Archives, and the Rhagorol (Gwynedd Council) online catalogue (The National Archives 2019; NLW 2019a; Coflein 2019; British Library 2019; Prifysgol Bangor University 2019; Gwynedd Council 2019). The following place-name search terms were used in the initial online search: 'Dysynni'; 'Tywyn'; 'Towyn'; 'Dyfi'; 'Dovey'; 'Aberdyfi'; 'Aberdovey'; 'Bryncrug'; 'Peniarth'; 'Ynysmaengwyn'; 'Ynysymaengwyn'; 'Broadwater'; 'Castell y Bere'; 'Llanegryn'; 'Llangelynin'; 'Llanfihangel-y-pennant'; 'Talyllyn'; 'Penllyn'; 'Tonfanau'; 'Croes Faen'; 'Cardigan Bay'; 'Gwynedd'; 'Merioneth'; 'Merionethshire'; 'Meirionydd'. Based on the results of these searches, both the National Archives, Kew, and the NLW Archives, Aberystwyth, were visited to view the map and documentary sources identified in the online catalogue search.

During the archive visits, detailed notes and photographs were taken of historical documents and all relevant maps found. In The National Archives, there were no restrictions on the taking of photographs, however in NLW all maps had to be kept within plastic sleeves, so any photographs taken were affected by glare from the sleeve.

5.2.2 Historic Environment Record and National Monuments Record Wales databases

Another source of archive data used were the NMRW and the HER databases. The NMRW is an archive of recorded historical and archaeological sites throughout Wales, held by RCAHMW. The HER in Wales are held by regional archaeological trusts, and contain a register of archaeological sites located within their local authority boundaries. Shapefiles of the HER and NMRW sites located in the Dysynni valley and surrounding landscape were provided by GAT, the Dyfed Archaeological Trust (DAT) and the RCAHMW as point-data for use in GIS, including attribute information such as the name, type and period of each record.

Data processing

The HER data was provided in Microsoft Excel Worksheet (.xlsx) format, while the NMRW data was provided in Microsoft Access Database (.accdb) format. To facilitate the processing and analysis of the site data, both sources were compiled into a Microsoft Access Database. As the HER and NMRW databases had been organised in different ways, some database fields were changed or omitted in the new database. An overview of each database to which I had access is available in Appendix 1, Table Ap1.2, including the information included within each database, and the information included within the final compiled database.

A new field, 'elevation', was added to the newly created database, in order to include more spatial information on each record. To satisfy the 'elevation' field, GIS was used to extract the height values in metres aOD for the NMRW and HER point data from LiDAR data provided by the Welsh Government. This information was exported into a Microsoft Excel Spreadsheet format, and imported into the Microsoft Access Database. The LiDAR dataset used has a 1m resolution, and a vertical height error of ±5cm (NRW 2015a).

In GIS, the point data shapefile was first 'clipped' to match the extend of the study area, as many records were located outside the defined boundary. Through an inspection of the compiled database, it was evident that some records had been duplicated, as they were included in both the HER and NMRW databases. Duplicates were identified through a query that searched for identical co-ordinate values. Some entries had the same co-ordinate values but were different features, for instance if the features were in very close proximity. Altogether, 504 of the 3775 entries were identified as duplicates and one version of each (252 records) were removed from the database. It is possible that more of the records in the HER and NMRW could be duplicates but with different co-ordinates, for instance if the record location was entered more precisely in one database than another. Further records which appeared to be duplicates based on the name and description were removed during the process of this research. Some of these were discovered through systematic searches, and others were identified fortuitously. Records in the HER and NMRW databases that were recorded only as 'Documentary Evidence', and had either no description or which specifically stated that no known extant features existed, were also removed from the compiled database. This is because the main focus of this thesis is the way that the historic landscape, as it exists today, is vulnerable to climate change. The aim of using site databases was to record features that had a physical presence in the study area and would therefore be materially affected by climate change. Furthermore, the position of features located through documentary evidence alone may be inaccurate or may refer to a much wider area than is indicated by point data. Following the processing described above, 1529 records remained in the database.

The information within the compiled database was collected and recorded over many years by different people, so there were several inconsistencies in the categories given to records. For example, 'Anti Tank Block' and 'Anti Tank Obstacle' were both included in the 'Type' field, while 'Post-Medieval,Modern', 'Post-Medieval/Modern' and 'POST-MEDIEVAL;Modern' were all used in the ‘period’ field. To improve the usability of the new database and facilitate the analysis of the data within it, the entries for some fields such as these were aggregated. Table Ap1.3 in Appendix 1 details the changes made to the labelling system within the database. These changes were made with reference to the Historic England Monument Type Thesaurus, to ensure that the terminology followed a consistent and reliable standard (Historic England 2014).

5.2.3 Aerial photographs

Aerial photographs are a commonly used source in archaeological survey, as they can often reveal features such as cropmarks and shadow marks that are not visible from ground level (Winton and Horne 2010). The British Academy (2001) estimate that up to 50% of archaeological sites in Britain have been identified through aerial photography. This may be from archaeological reconnaissance surveys, or from aerial photography taken initially for another purpose such as military reconnaissance or for cartographic surveys (Winton and Horne 2010; Hanson and Oltean 2013). Aerial photography can be used to determine which areas should be prioritised for ground-based geophysical survey, but it can also be used for monitoring change to the historic environment (Bewley 2006; Jones 2008).

Over 530 images of the study area were found across five collections of aerial photographs held by RCAHMW archive, located in NLW, Aberystwyth. The collections studied comprised The Cambridge University Collection of Aerial Photography (CUCAP), RCAHMW Black and White Oblique Aerial Photographs, RCAHMW Colour Oblique Digital Aerial Photographs, Royal Air Force Vertical Aerial Photographs, and the Ordnance Survey Aerial Photography Collection. Each of the images was studied, and copies were taken of those that featured potential cropmarks, in total 58 photographs (see Figure 5.1). Some of these cropmarks had already been recorded in the NMRW record and the HER record, but had not been mapped. Following the study of aerial photographs at RCAHMW, additional cropmarks were identified in the Dysynni during reconnaissance flights by Glyn Davies and Jonathan Brentnall during the dry summer of 2018. Theses cropmarks were added to the collection in this study (see AP_2018_4244, Figure 5.1D).

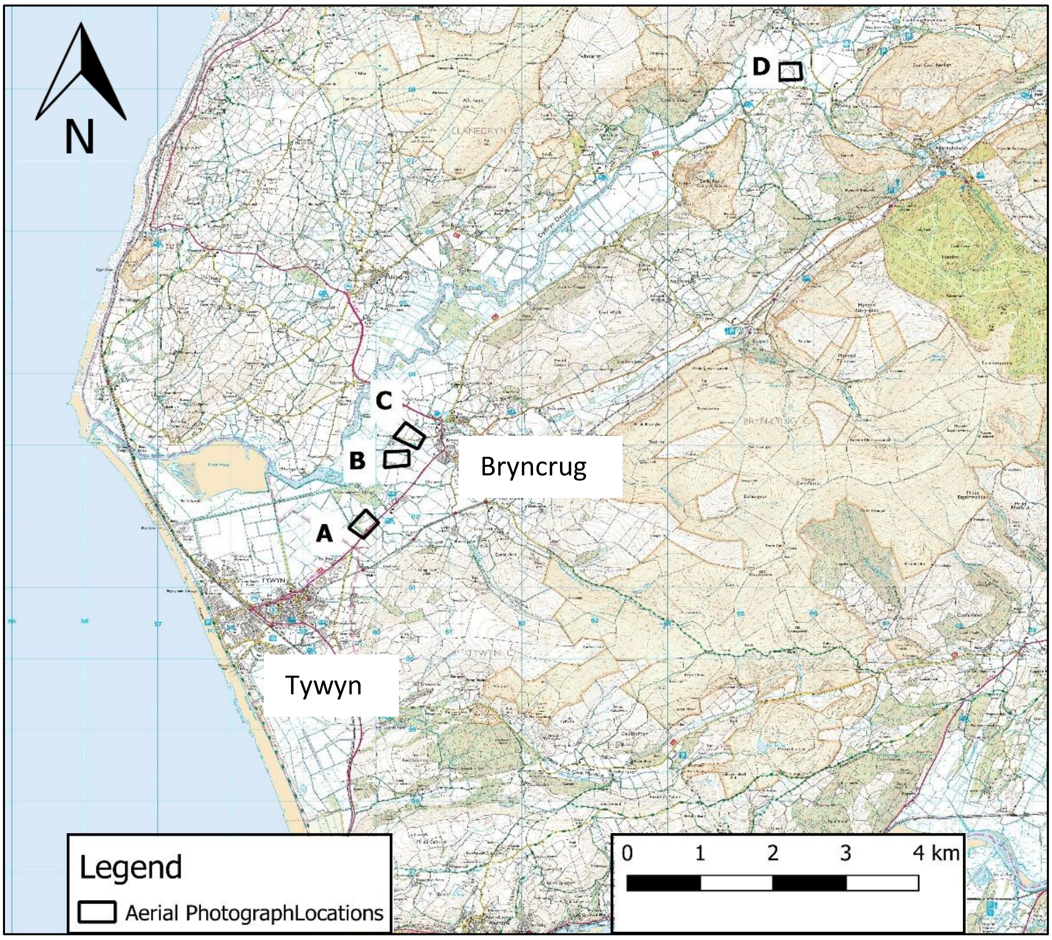
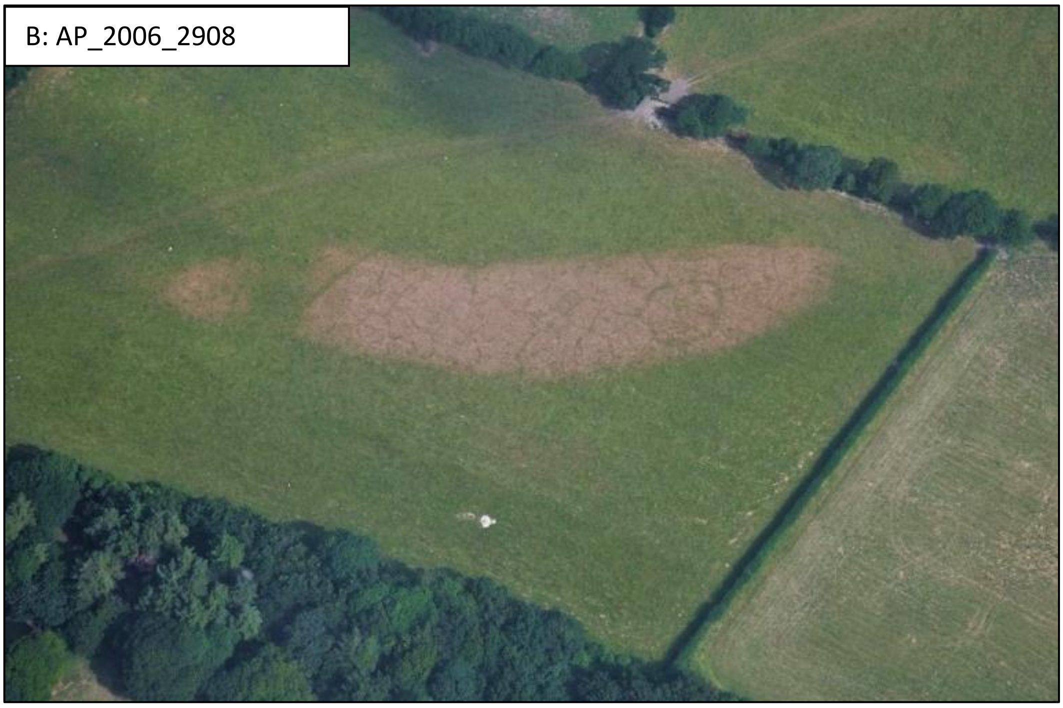


Figure 5.1. *Examples of aerial photographs from the Dysynni valley (A-D), and a map of their locations. All images are Crown copyright and are reproduced with the permission of Royal Commission on the Ancient and Historical Monuments of Wales (RCAHMW), under delegated authority from The Keeper of Public Records*. Map *Crown copyright and database right 2019 Ordnance Survey 100025252*



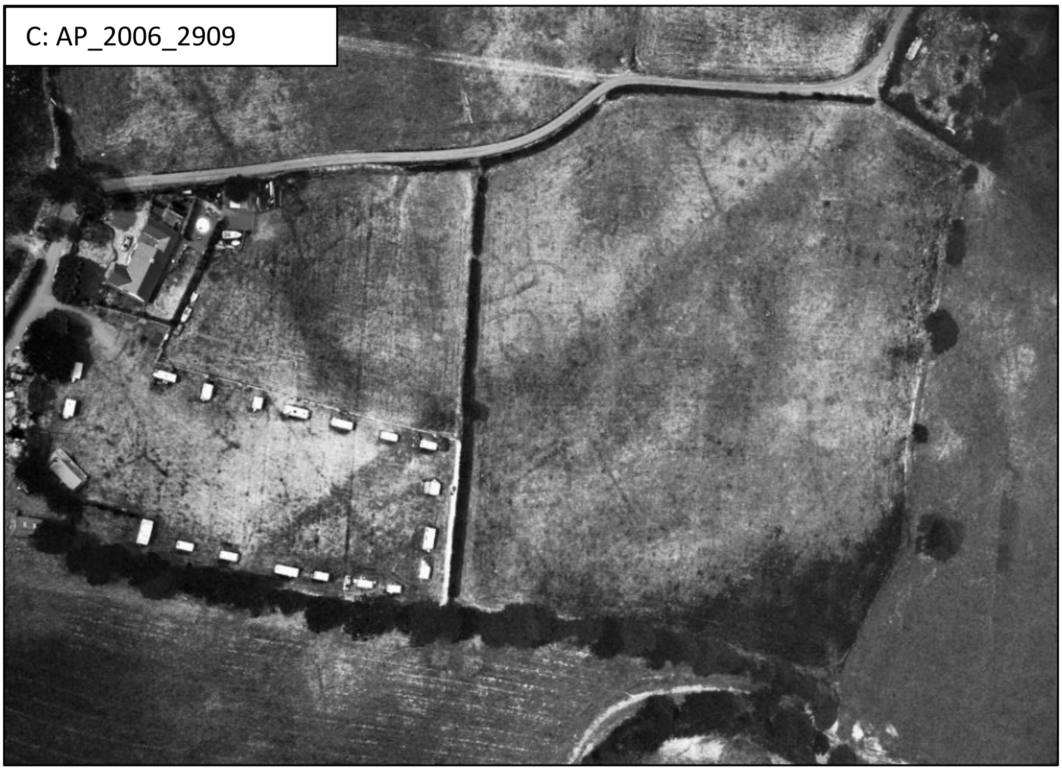


Figure 5.1 cont.

Figure 5.1 cont.

Figure 5.1A shows square cropmarks, c.12m in diameter, relating to a medieval square barrow cemetery near Croes Faen (Blackburn 2011). The cropmark in Figure 5.1B is a circular feature around 18m in diameter, with an associated curvilinear feature. Figure 5.1C shows a number of features within a single field, including several intersecting circular features, and a square double-ditched enclosure. The feature identified in Figure 5.1D appears to be a double-ditched enclosure around 30m in diameter, with a larger surrounding wall that has at least two clear entrances.

QGIS, an open-source GIS software was used to georeference and georectify the copies of the aerial photographs onto the Dysynni landscape, using identifiable features such as field-shapes and roads. The vertical aerial photographs could be georectified relatively accurately, but the oblique aerial photographs were more susceptible to warping, particularly if there were too few reference points. Therefore, when a cropmark was featured in more than one aerial photograph, the aerial photograph that was most accurately georectified was used to determine the location of the feature. Subsequently, the features identified in each aerial photograph were rendered in QGIS as a vector layer (see Figure 5.6).

The slight warping of the georectified aerial photographs may have introduced a small degree of error in the position of the georectified cropmark features. However, when compared to the location of the features also identified in geophysical surveys, the errors were no more (and often much less) than 5m in the context of features up to 75m in diameter and fields several hectares in size. While this is at the higher end of the acceptable error margin suggested by Dr Toby Driver of the RCAHMW (pers. comms.), it is sufficient for informing decisions on where to locate further geophysical surveys, and provides a relatively accurate map of georectified features within the wider landscape.

The purpose of identifying cropmarks and potential features in the study area was twofold. Firstly, the aim was to gather as much information as possible about the history and past land-use of the study area, by identifying features that were not yet recorded in the NMRW and HER databases. Secondly, the presence of features in aerial photographs was used to decide where geophysical surveys should be carried out, in order to ground-truth the results and gain a greater understanding of the features identified.

5.2.4 Geophysical surveys

Geophysical surveys are used as above-ground sensing techniques to identify any potential subterranean features. Some geophysical survey technologies are classified as 'passive' techniques because they measure what is already there. For instance, magnetic gradiometry (or magnetometry), undertaken using a gradiometer, measures anomalies in the near-surface magnetic field compared to the Earth's magnetic field (Gaffney and Gater 2003). Features such as ditches, pits, and hearths and other burnt features are well detected by gradiometry, however it does not easily detect built features unless they are constructed from fired brick (*ibid*.). Other geophysical techniques are classified as 'active' techniques, as they induce a phenomenon to be measured. Earth resistance, or electrical resistivity, survey puts an electric current through the ground in order to measure the electronic resistance of subsurface features (Jones 2008). Resistivity survey identifies masonry and building foundations, as these features increase the subsurface resistance (*ibid*.). However, resistivity is affected by the saturation of the soil, so the results generated can vary with season and soil type (Gaffney and Gater 2003). Jones (2008) suggests that, as different geophysical techniques identify different types of features, two or more methods should be used in conjunction with one another. Therefore, both gradiometry and electrical resistivity techniques were used on areas in which features were identified as cropmarks in aerial photographs, and in surrounding fields. The purpose of this was to ground-truth the cropmarks identified in the aerial photographs and identify details that were not visible on aerial photographs (either due to lack of aerial photograph coverage or unsuitable conditions for features to create cropmarks). This helps to inform the HLC, as well as improve our understanding of the history of human occupation in the valley.

Geophysical surveys were carried out by MA Landscape Archaeology students from the University of Sheffield in fieldwork during the spring each year from 2014 to 2018. Both gradiometry and resistivity were used, because they identify different types of feature. Fluxgate gradiometer survey was used on all fields surveyed, while resistivity was employed less frequently, and often over a smaller area within the survey grid. This is because resistivity surveys are more time consuming, and the results of resistivity surveys that were undertaken were very similar to the gradiometry results. Over the five years, 20 fields were surveyed, covering around 32 hectares (0.32km^2) in total.

The areas surveyed were chosen based on the results of preliminary archive research and analysis of aerial photographs. Surveys focussed on the areas around Bryncrug and Croes Faen, where the aerial photographs revealed a wealth of features. Three fields at Croes Faen were also selected for geophysical survey despite having no cropmarks identified there, to determine whether the square barrow cropmark features (see Figure 5.1A) extended further than the areas visible in the aerial photographs. Additionally, the remains of a 2m high potential Bronze Age standing stone or medieval cross-shaft stone stood at the southern point of field A3 (see Figure 5.2) until 1840, when It was moved nearer Tywyn (Knight 2011; Vousden 2013). Cadw speculate that it could be associated with nearby burial or ritual deposits (Knight 2011).

Some fields around Castell y Bere were also targeted for geophysical survey. The main reason for this was the documentary evidence dating to the late 13th century that suggests that a borough, or burgh, was constructed by royal charter near the castle (Morris 1901). No references to the burgh have been found in any document post-dating 1295, which has been attributed to the destruction and abandonment of the castle in 1294-5, and the assumed abandonment of the burgh (Lewis 1912; Taylor 1974). The aim of geophysical surveys around Castell y Bere is to identify features relating to the burgh, or those relating to infrastructure associated with the burgh, such as roads.

The surveys were located using a survey-grade GNSS (Global Navigation Satellite System) with a horizontal accuracy of at least 0.1m. Figure 5.2 shows the location of the surveys carried out each year. The geophysical data was processed following the methodology suggested in the 'Data Processing' chapter of the Geoplot 3 manual (Geoscan Research 2004). The same processing tools were carried out in the same order for each plot, although this order differed between gradiometry and resistivity data. This process is outlined below, firstly for gradiometer processing, and secondly for resistivity.

Following processing, the geophysical survey results were georeferenced using QGIS and the GPS data collected, so that they could be viewed within the context of the landscape (see Figure 5.2).

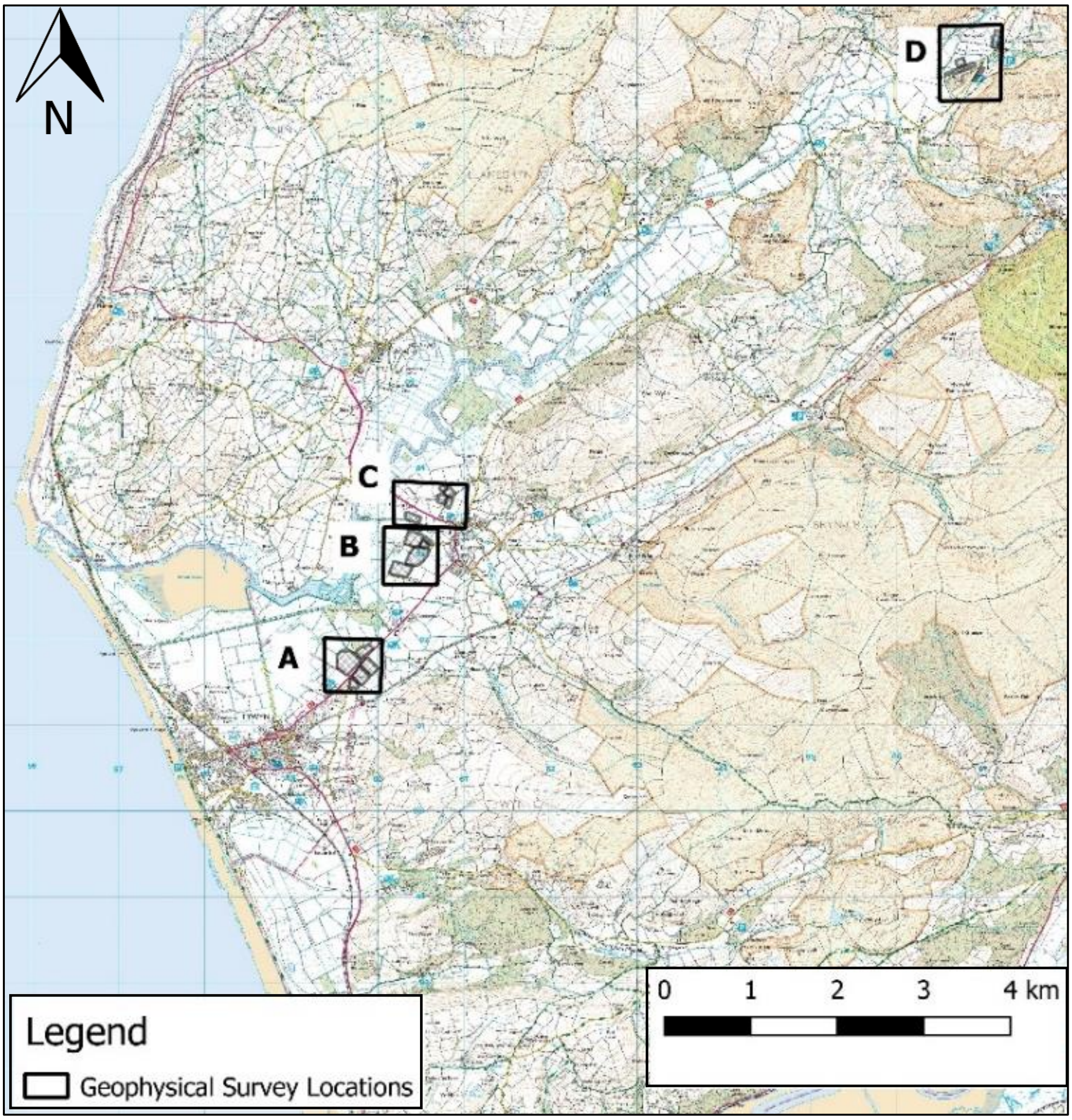
Gradiometer Processing

1. Clip Function, with a threshold of ± 3.0 Standard Deviations (SD) from the mean, to remove highly magnetic features
2. Zero Mean Grid (ZMG) and/or Zero Mean Traverse (ZMT) Functions. ZMG for correcting grid edge discontinuities. ZMT for further correcting edge discontinuities, slope errors or traverse stripe errors.
3. Destagger Function, to address stagger errors. For plots collected with a single sensor, the 2-4-6-8 setting was used, while plots collected using gradiometers with two sensors were destaggered using the —34—78 function.
4. Clip Function, with a threshold of ± 3.0 Standard Deviations (SD) from the mean, to further remove magnetic anomalies.
5. Despike Function, with a window of a window of X=Y=1m, to remove the effect of smaller anomalies.
6. Low Pass Filter Function, with X radius = 0.5m and Y radius = 1m, to improve the visibility of weak features, and smooth the gradiometer data.
7. Interpolation, using the Sin(x)/x expansion method, to increase the resolution from 0.25 x 1m to 0.25 x 0.25m. This gave the data a smoother appearance and increased the visibility of large but faint features.

Resistivity Processing

Resistivity data require processing in a slightly different order, as the results present differently to that of gradiometer data.

1. Clip Function, with a threshold of ± 3.0 SD, to remove noise spikes in the data.
2. Despike Function, with a threshold of ± 3.0 SD, to remove any remaining data spikes. For data plots with small levels of spiking, a window of X=Y=3m was used, while for plots with more significant anomaly spikes, a window of X=Y=1m was used.
3. Edge Match Function, to correct grid edge discontinuities.
4. High Pass Filter Function, with a window size of X=Y=10m, to remove the geological background and enhance archaeological features.
5. Low Pass Filter function, with a window of X=Y=1 readings, to smooth the appearance of the data and increase the visibility of faint archaeological features.
6. Interpolation, using the Sin(x)/x expansion method, to increase the resolution from 1 x 1m to 0.25 x 0.25m and enhance the appearance of large archaeological features.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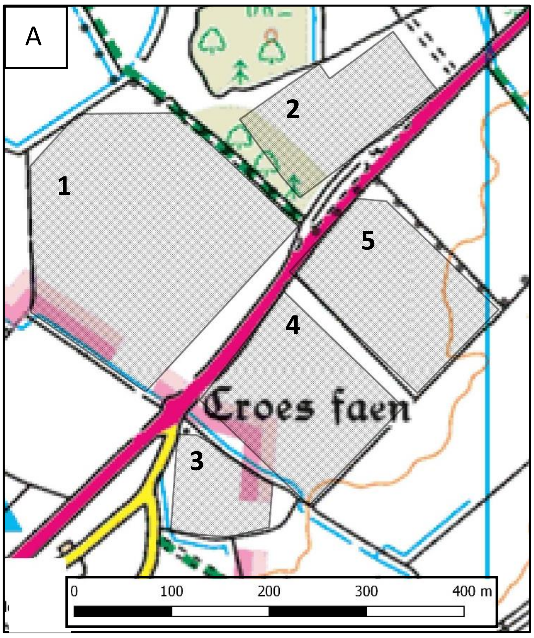
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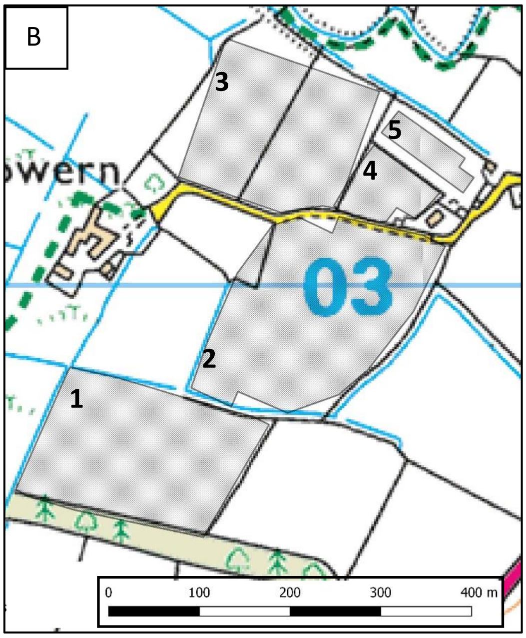
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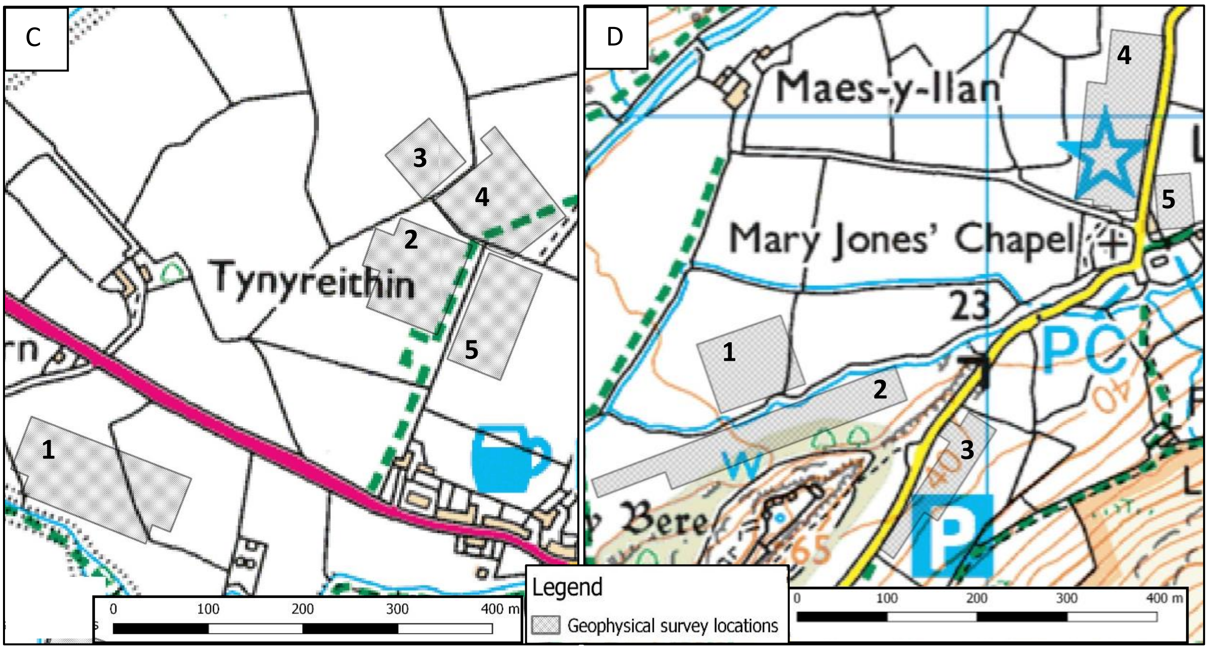


***Figure 5.2**: Location of each of the geophysical surveys undertaken in the Dysynni valley. Gradiometry was carried out for all of these plots, but resistivity was only applied to A2, B3-5, D1-2. Crown copyright and database right 2019 Ordnance Survey 100025252*

5.3 Results and Analysis

5.3.1 Archive results

The National Archive

The search of The National Archives found several records relating to the study area, eight of which held information regarding the landscape or past land use, including maps. Detailed descriptions of each record are provided in Appendix 1 Table Ap1.4. The majority (n=6) of the records found in The National Archives relate to the Dysynni Valley Drainage District and the management of drainage channels in the early 20th century. These records indicate that, despite the land improvement schemes in the 18th and 19th centuries, issues associated with drainage and waterlogging have been occurring for the past century at least. For instance, Merioneth Rivers Catchment Board (1952) includes correspondence from 1948 between Colonel J. Williams Wynne of Peniarth and C. H. Wake of the Dysynni Catchment Board, stating that the financial deficit of the Peniarth Estate was too great to maintain the drainage ditches on the land. Furthermore, several other records refer to decisions to change the official boundaries of the 'main river' in order to relieve the financial burden of drainage works on landowners. Records 2, 4 and 8 (see Table Ap1.4; Ministry of Agriculture and Fisheries 1950; River Dysynni Catchment Board 1950; Ministry of Agriculture and Fisheries 1949) all refer to ‘maining’ tributaries or drainage channels, which means changing their official status to be part of the ‘main river’ (see Figure 5.3). This would mean that any drainage works required would be carried out by the local authority, who had jurisdiction and responsibility over the main river, as stipulated in the Land Drainage Act 1930 (Dobson and Hull 1931). If watercourses were not part of the main river, then the responsibility for any drainage works rested on the landowners, who could receive grant-aid of only up to 50% of the total cost of drainage, under the Agriculture Act 1937 (Deb 1940). Therefore, although the Peniarth and Ynysymaengwyn land drainage schemes (see section 4.4.8) provided more land for agriculture in the valley, they also created a new financial burden and ongoing maintenance requirement for landowners and farmers in the valley.

__Figure 5.3.__ Section of the map Ministry of Agriculture and Fisheries (1950) included in record MAF 77/257 in The National Archives. The brown line indicates the River Dysynni main channel, and the green lines indicate channels added to the main channel designation. The blue line defines the boundary of the Dysynni Catchment Area. Source: Ministry for Agriculture and Fisheries

The National Library of Wales

The only records found in NLW that were relevant to the study area were maps, and are described in Appendix 1 Table Ap1.5. Historic maps such as these can provide an insight into the form of the landscape, and the structure of land divisions, several centuries ago. For instance, the map *Lands at Aber Dysynni* (1833 – Record 9) displays the land divisions and form of the river near the mouth of the Dysynni, which can be compared with the current morphology of the river mouth. This map shows that at least one of the present sluices that form part of the drainage system already existed by 1833, and that Broadwater was not considered an estuary or lagoon feature, but rather a terrestrial area that was frequently flooded. If the map in Record 9 (*Lands at Aber Dysynni* 1833) was drawn accurately, it also shows that the sand bar that currently partially blocks the mouth of the Dysynni and causes it to flow northwest for several hundred metres before reaching the sea did not exist in 1833. Furthermore, there is no railway bridge or railway line marked on this map, suggesting that the current railway line north of Tywyn was not in the same location when the map was drawn, or that there was not yet a railway line in place as Tywyn train station only opened in 1863. Morris (1743 - Record 13) also indicates the way in which the landscape morphology may have been different in the past. In the 1743 map of Aberdyfi Harbour by Lewis Morris, the mouth of the Dyfi is blocked by a bar, which diverts the river channel to the north, so it meets the sea in front of the current golf course. The river channel is also more well defined on this map than on modern maps, suggesting that the Dyfi estuary has developed into a braided river channel in recent centuries. This record also depicts an area of 'low marsh' where Aberdyfi golf course is currently located.

Aberystwith and Welsh Coast Railway (1865 - Record 11) provides a plan for a proposed new railway line that would have been built on a viaduct spanning the Dyfi estuary. The viaduct and railway line were not built, however no records were found discussing the reasoning behind this. Record 11 also shows a railway line across the sand on the south side of the Dyfi estuary, linking to a ferry crossing the River Dyfi. It is not evident whether this railway line to the ferry was in use at the time, or whether it was also just a proposal.

A problem with working with historic maps is exemplified by *Lands at Towyn (*c.1820 - Record 12), which is a simple map showing the shape, location, size and cost of fields owned by John Edwards Esqr. in Towyn parish. As the map only shows the relevant fields, and does not include any other landscape features or long sections of road, it was impossible to georeference in GIS and compare to modern maps. This is also the case for Record 10 (*Aberdyfi Harbour Cartographic Material* c.1880), which is difficult to situate against a modern map, as there is little information included about which features the lines on the map relate to.

5.3.2 Historic Environment Record and National Monuments Record Wales results

When displayed visually in GIS, it is evident that the majority of HER and NMRW records are concentrated in upland areas in the Dysynni valley, in Tywyn and Aberdyfi urban areas, and along the coastline. In contrast, there are very few recorded features located in the lowland areas (see Figure 5.4). The high number of upland features reflects the local importance of extractive industries during the Industrial Revolution, and the subsequent wealth of historic industrial remains, such as mines, quarries and associated features, in the upland areas. Furthermore, many of the records in the uplands are related to extensive pastoral agriculture, such as sheepfolds and abandoned farmsteads, as well as prehistoric sites which have been relatively undisturbed by the continuing low-intensity land use. In the lowlands, more intensive agriculture and drainage means that archaeological remains are more likely to have been disturbed. Finally, there has been more archaeological survey undertaken in the upland areas compared to the lowlands, meaning that the distribution of the HER and NMRW records is not necessarily representative of the distribution of archaeological remains. For instance, the Welsh Uplands Initiative, or Upland Archaeology Initiative was a rapid reconnaissance project funded by RCAHMW during the 1990s. Its aim was to generate a more compete record of Welsh upland heritage by identifying new sites and their locations (Hughes 2003). Across Wales, this initiative led to an 11-fold increase in the number of archaeological sites recorded in the searched areas (*ibid*.). MA Landscape Archaeology students from the University of Sheffield have also undertaken Level 1 walkover surveys in upland areas of the Dysynni valley, in particular near Craig yr Aderyn. The sites identified during these surveys were added to the database of HER and NMRW records used in this thesis.

Many of the records in Aberdyfi and Tywyn refer to historic buildings, hence the high density of records in these urban areas compared to the lower density in rural areas. The HER and NMRW records in the Dysynni valley cover all time periods from the Bronze Age and potentially earlier, to the modern period. Post-medieval records are the most common, with almost half of the total records attributed to this period.

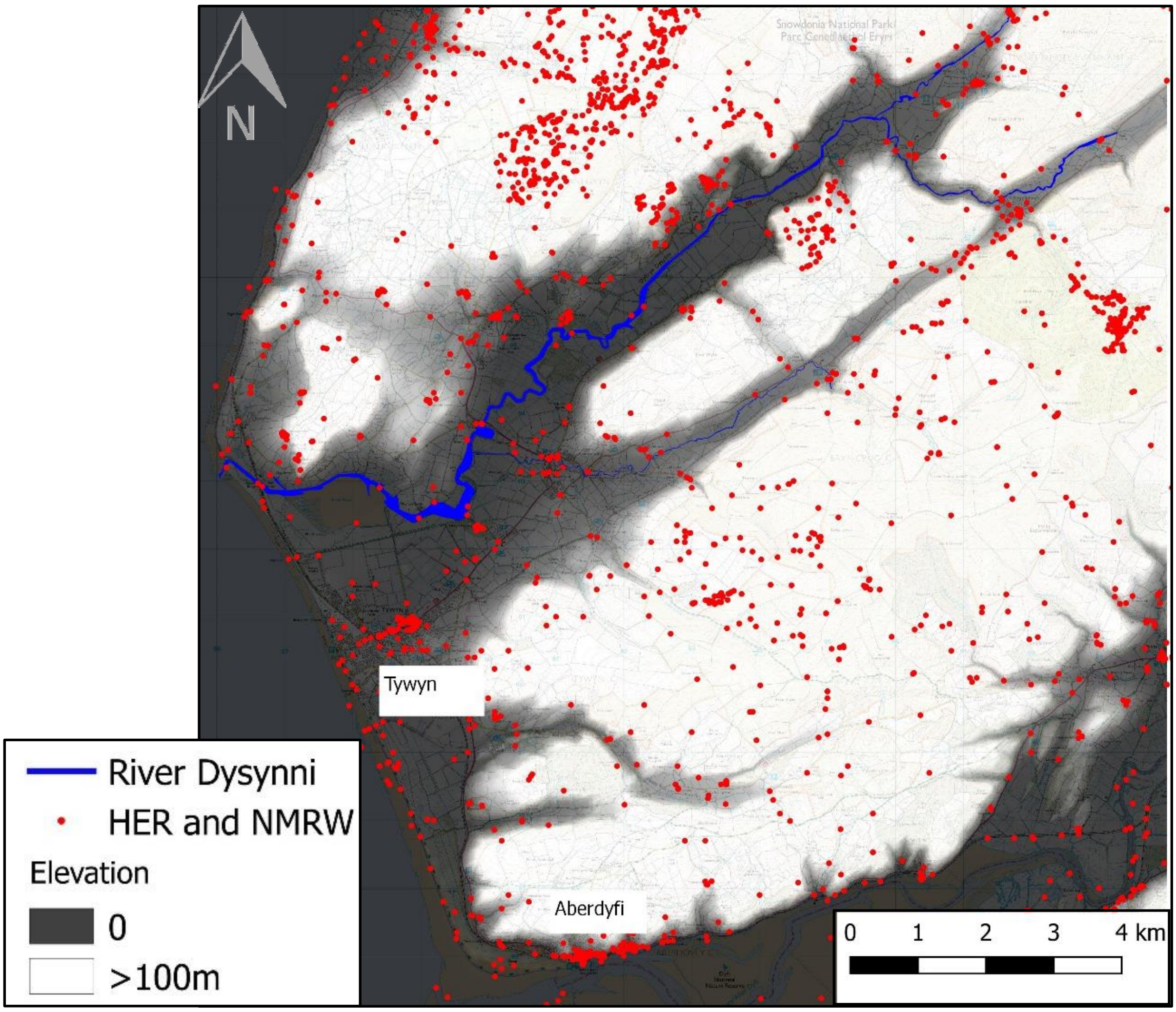


Figure 5.4. *HER and NMRW records in the Dysynni valley, including elevation information (aOD). Crown copyright and database right 2019 Ordnance Survey 100025252*

5.3.3 Aerial photography results

The study of aerial photographs of the Dysynni valley revealed several new, previously unidentified cropmark features, and several features that had already been identified by the RCAHMW but not yet mapped. Figure 5.5 shows all vectorised features identified in the study of aerial photographs, classified by source collection. Figure 5.6 shows some of the features identified in greater detail alongside the georectified image in which they were identified. Table Ap1.7 and Figure Ap1.1 in Appendix 1 provide a description and location of all of the newly identified cropmark features in the Dysynni valley.

The features identified in the aerial photographs are mainly distributed across low lying areas, for instance near Tywyn, Penllyn, and Bryncrug. There are some located in the upland or hilly areas north of the Dysynni estuary, however these are more widely dispersed than those in the lowlands.

This pattern contrasts with the distribution of HER and NMRW records, which are mainly clustered in upland areas. The distribution of features identified in the aerial photographs may be because the conditions required to reveal cropmarks are more likely to occur in flat grassland compared to hilly areas or rough ground (Cornwall County Council Historic Environment Service 2007). It may also reflect a preferential bias for taking aerial photographs over some areas rather than others by some of the surveyors. For instance, Cowley (2002) found that aerial reconnaissance surveys in Scotland tended to target areas of known potential for cropmarks over areas of unknown potential or areas without known cropmarks. Dr Toby Driver (pers. comms.) acknowledged that he focussed on areas that he was confident would yield results during his reconnaissance work in 2018, due to time limits. Therefore, it is possible that the distribution of cropmarks identified in the study area is influenced by the original survey methodology as well as by the distribution of known archaeological remains.

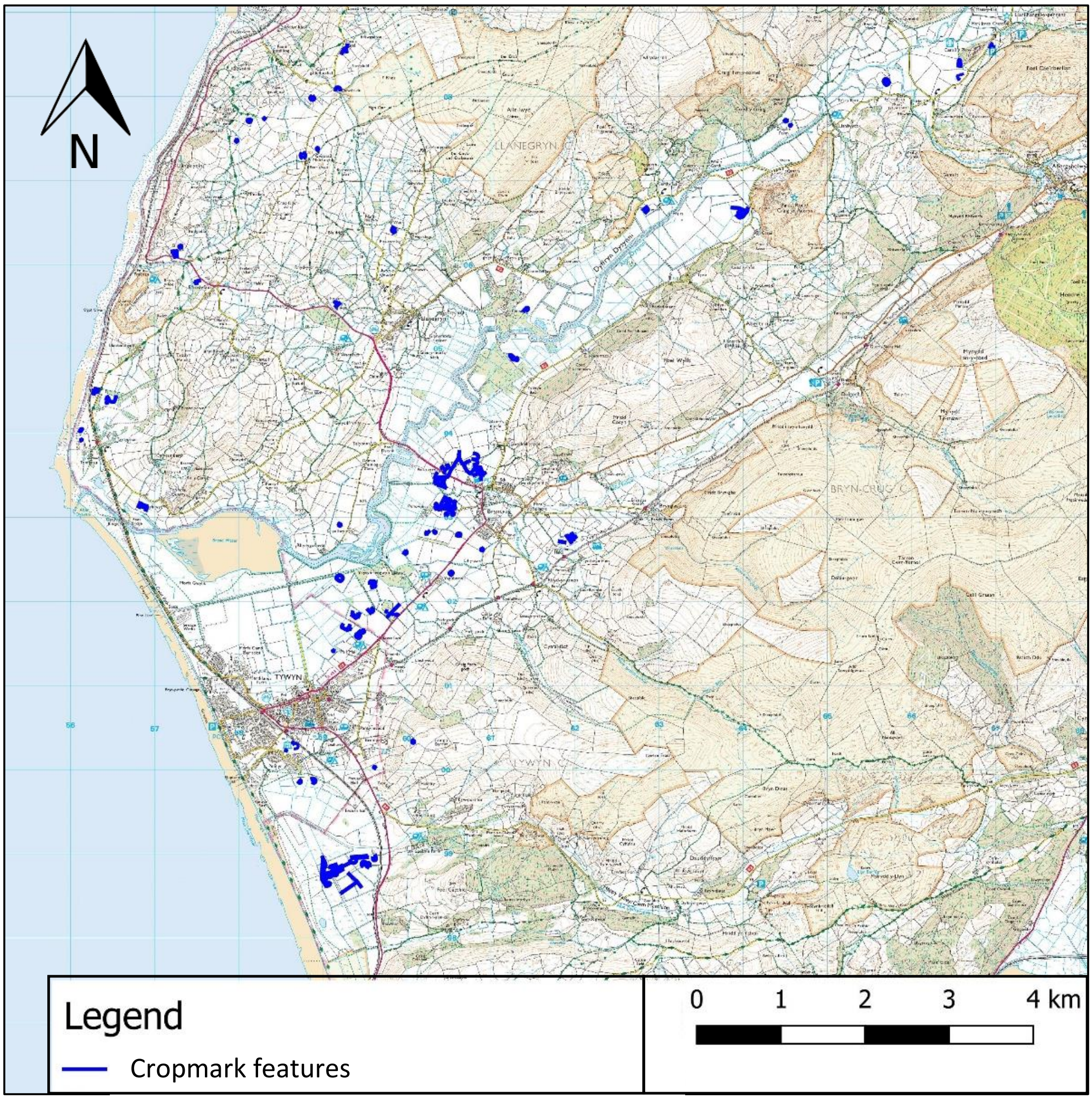


Figure 5.5. *All cropmarks identified in aerial photographs, vectorised in QGIS. Crown copyright and database right 2019 Ordnance Survey 100025252*

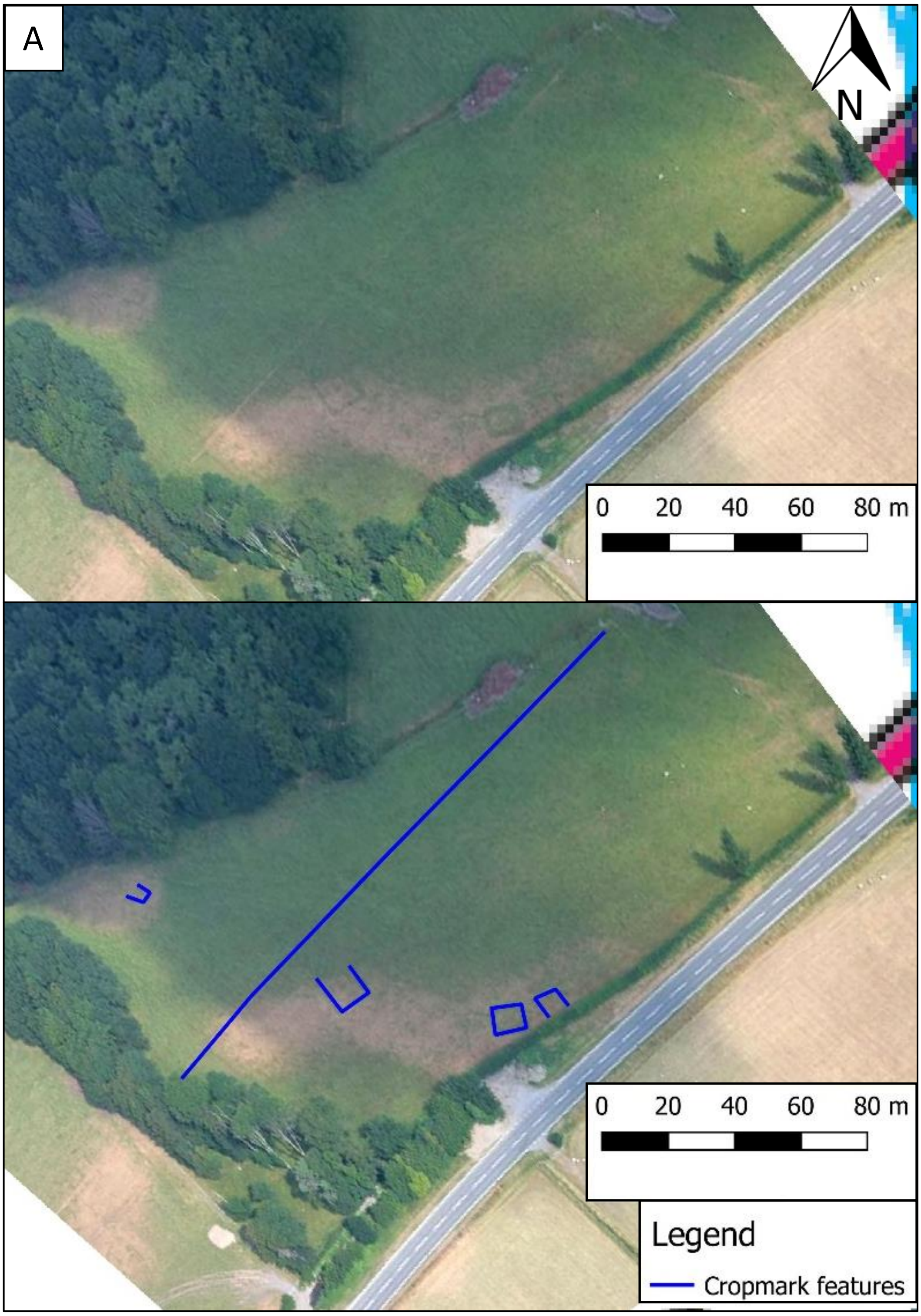


Figure 5.6. *Examples of vectorised cropmarks from aerial photographs AP_2006_2905 (A) and AP_2006_2910 (B). All images are Crown copyright and are reproduced with the permission of Royal Commission on the Ancient and Historical Monuments of Wales (RCAHMW), under delegated authority from The Keeper of Public Records.*

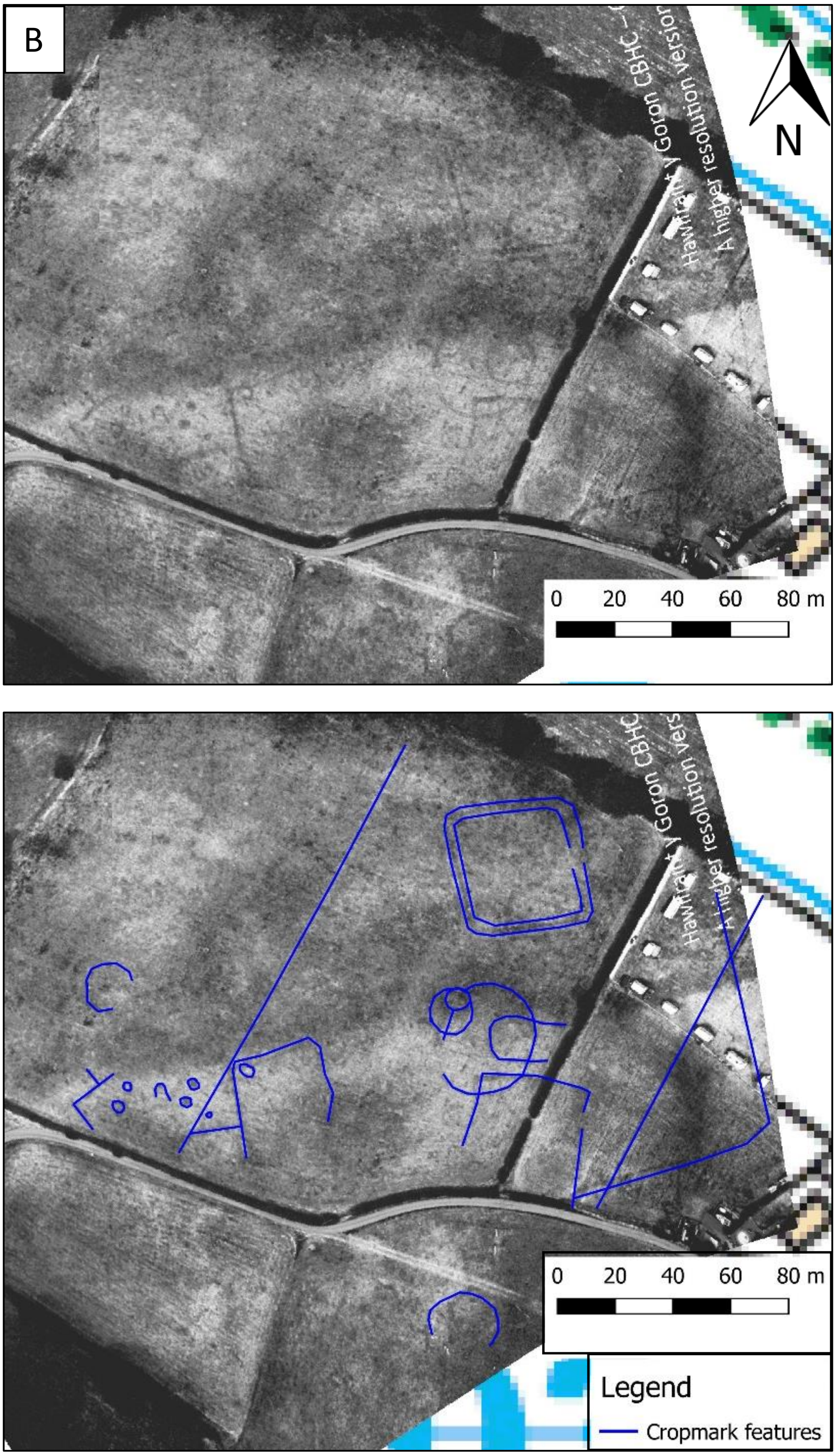


Figure 5.6 cont.

The majority of cropmarks identified in aerial photographs were simple circular or curvilinear features, but there were also examples of more complex features, including rectangular features intersected or surrounded by linear features (see Figure 5.6). This indicates that the cropmarks are likely to date from a range of time periods, suggesting that there has been extensive and varied human use and habitation of the Dysynni valley in the past. Furthermore, the location of the cropmarks indicates that, although much of the lowlands were marshland before the land improvement schemes (see Chapter 4), the land may have been habitable at some point before it became wet.

5.3.4 Geophysical survey results

As explained in the methodology, the geophysical surveys were mainly carried out in areas where crop marks had been identified. In most cases, the geophysical surveys confirmed the presence of features first identified in the aerial photographs, and in some cases increased the known extent of features. This confirmed the evidence for complex, potentially multi-period structures and land use in areas of the lowlands. See Table Ap1.7 for a concise overview and description of features identified in the geophysical surveys.

Survey results from Croes Faen (area A in Figure 5.2) confirmed the presence of several square features, thought to be a square barrow cemetery, identified in AP_2006_2905 (See Figure 5.7A) (Knight 2011). At Bryncrug (area B in Figure 5.2), survey results confirmed the presence of a square, double-ditched enclosure identified in AP_2006_2910 (Figure 5.6) as well as several intersecting circular and linear features (see Figure 5.7B).

In field B2 at Bryncrug (see Figure 5.2), the gradiometer survey did not detect features that matched the circular cropmark in the north of that field from AP_2006_2910 (Figure 5.6), but it revealed two curvilinear features that were not visible in aerial photographs (see Figure 5.8), and a modern pipeline in the north of the field. Figure 5.8 also shows that the cropmark identified in AP_2006_2908 (see Figure 5.1) was confirmed in the geophysical survey of field B1.

The dominant features revealed by gradiometer surveys in fields A3, A4 and A5 were considered to be modern pipeline features, based on the strength of the signal (Figure 5.9). In terms of potential archaeological features, fields A3 and A4 contained only a couple of faint linear features, while no archaeological features were revealed in field A5 (see Figure 5.9). This suggests that the Croes Faen standing stone was not associated with nearby buried features to the north east at least, although there may be associated deposits in unsurveyed fields to the south and west of field A3 (Figure 5.4).

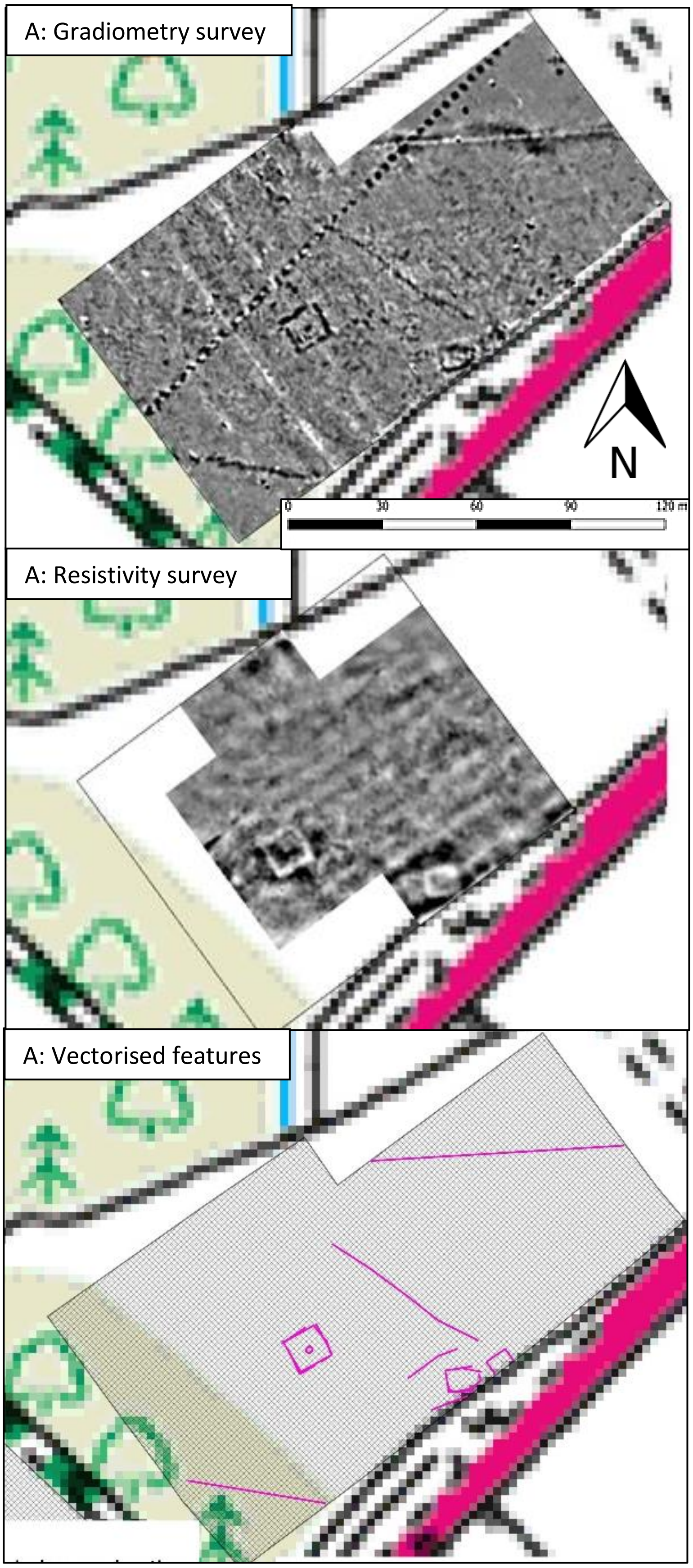


Figure 5.7A: *Geophysical survey plots near Croes Faen (area A, field 2). Both resistivity and gradiometry were undertaken and were used to render the subterranean features as a vector file in QGIS. Crown copyright and database right 2019 Ordnance Survey 100025252*

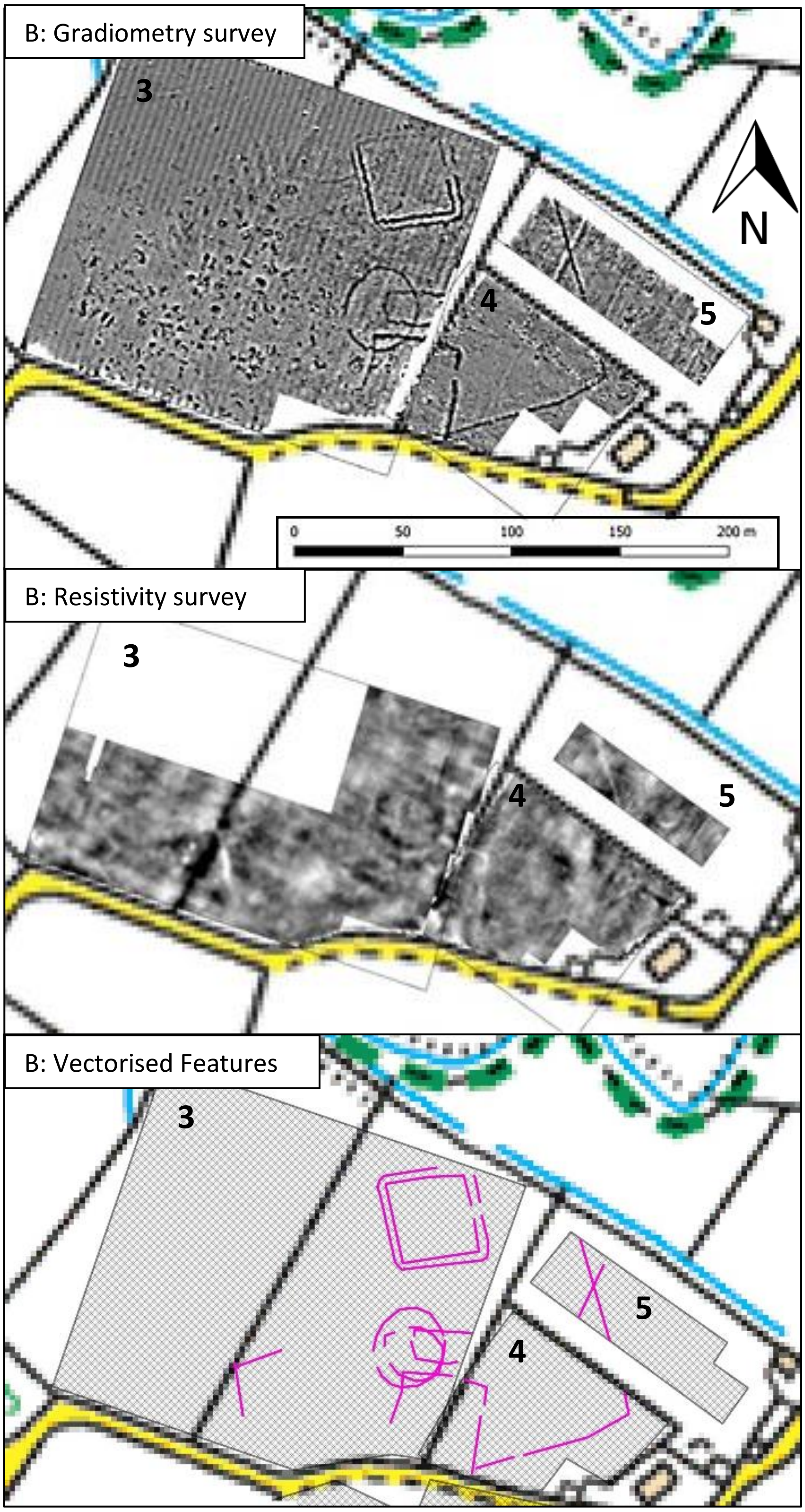


Figure 5.7B: *Geophysical survey plots near Bryncrug (area B, fields 3, 4 and 5). Both resistivity and gradiometry were undertaken and were used to render the subterranean features as a vector file in QGIS. Crown copyright and database right 2019 Ordnance Survey 100025252*

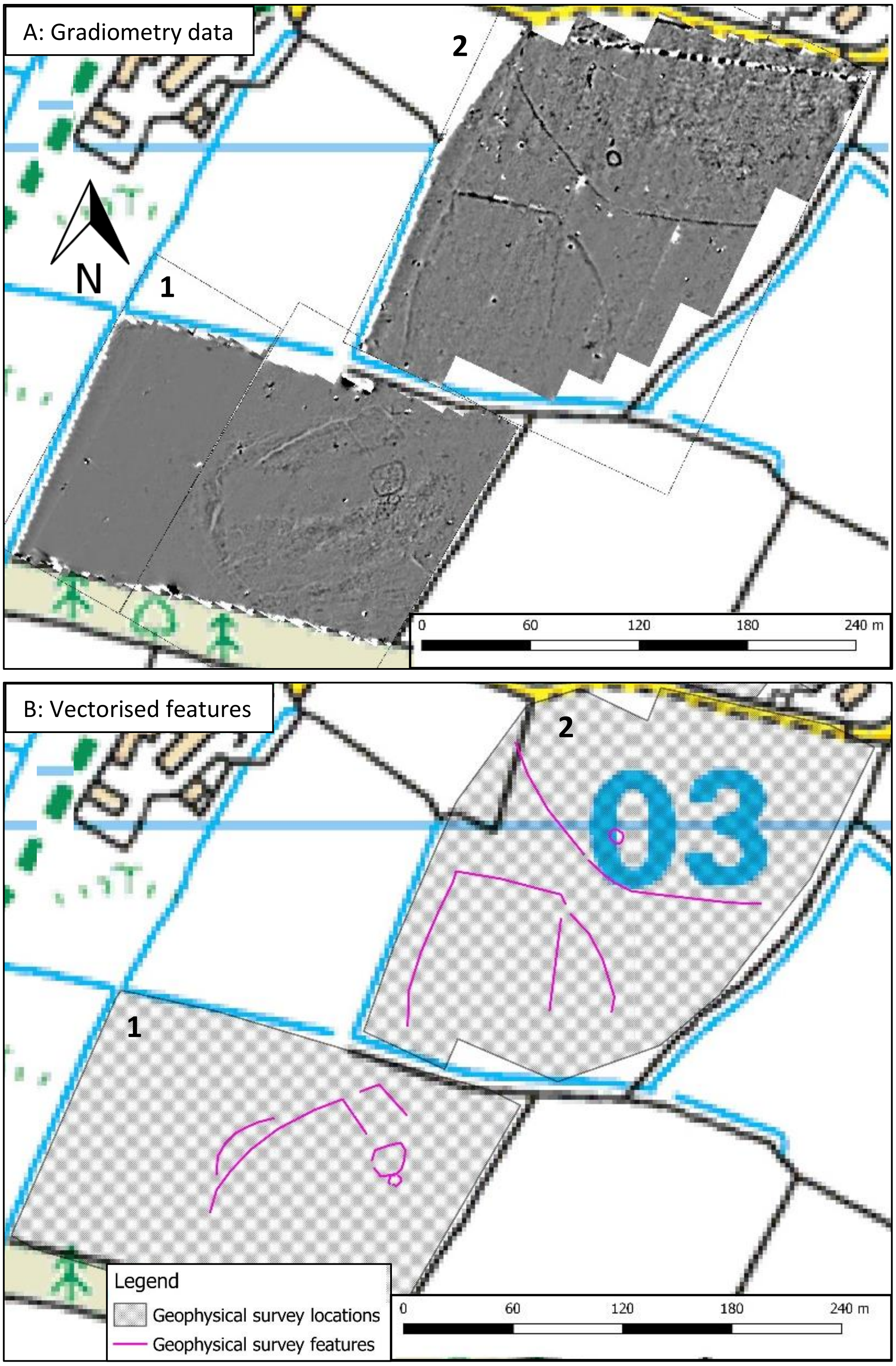


Figure 5.8. *Processed gradiometry data (A) and vectorised geophysical survey results (B) from near Bryncrug (area B fields 1 and 2). Crown copyright and database right 2019 Ordnance Survey 100025252*

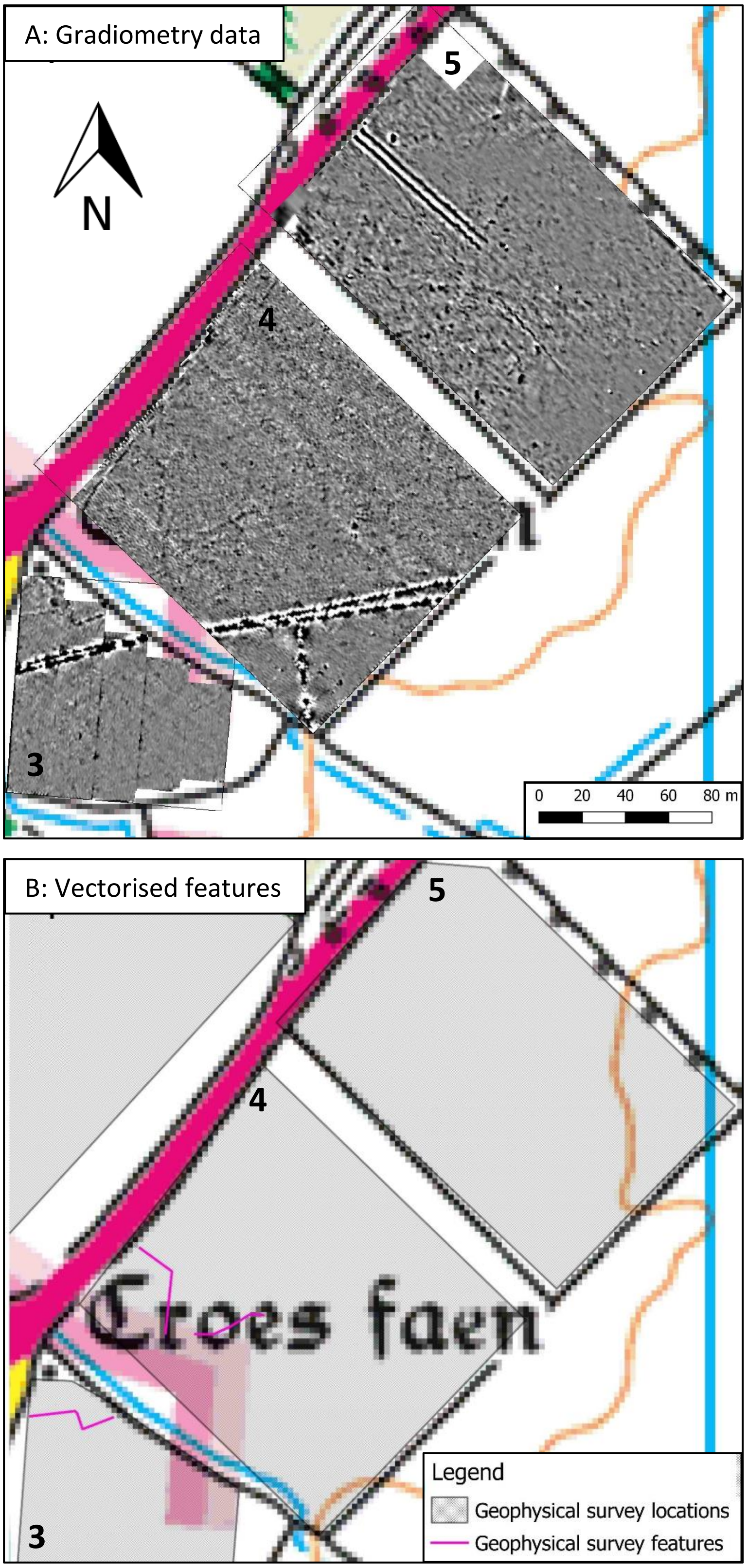


Figure 5.9. *Processed gradiometry data (A) and vectorised geophysical survey results (B) from near Croes Faen (area A, fields 3, 4 and 5), having discounted the modern features. Crown copyright and database right 2019 Ordnance Survey 100025252*

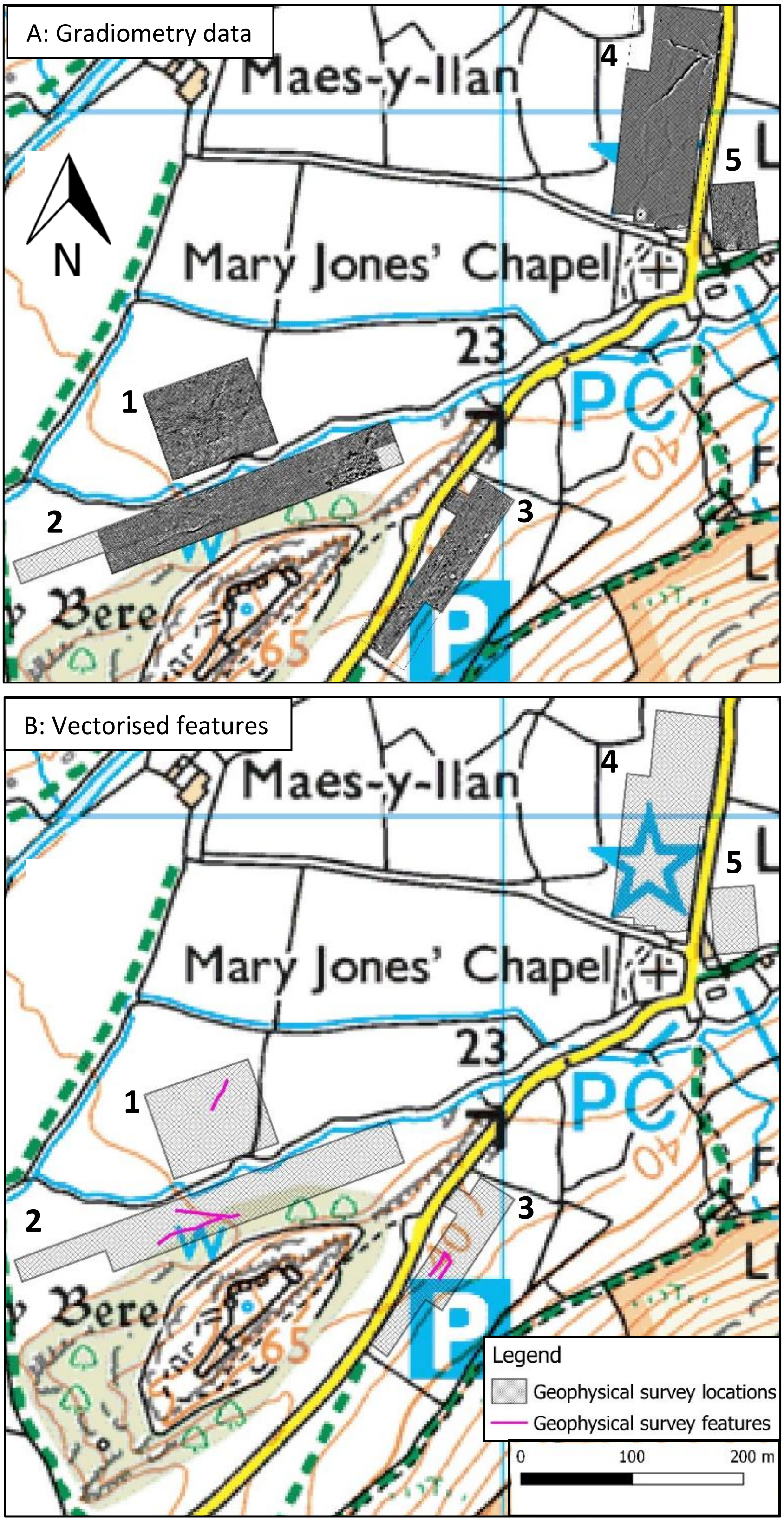


Figure 5.10. *Processed gradiometry data (A) and vectorised geophysical survey results (B) from near Castell y Bere (area D fields 1-5). Crown copyright and database right 2019 Ordnance Survey 100025252*

Little was revealed by the surveys undertaken at Castell y Bere; only a few short linear features appeared in the geophysical survey results of fields D1-3 (see Figure 5.10). The strong features in field D4 were not considered to be potential archaeological features. The strength of the circular feature in the south of the field (~200nT) indicates that is likely a modern piece of iron. Thornhill (2016) suggests that the branching shape of the linear feature in the north of the field indicates that it may be a hydrological or geological feature. This is supported by the fact that the location of the feature is at the boundary between alluvial fan deposits and river terrace deposits (Thornhill 2016).

5.4 Landscape analysis discussion

This section provides an overview of the methods and results of the landscape analysis carried out for the Dysynni valley, the study area for this thesis. This includes a period-by-period narrative of land-use and landscape development in the study area. Archive research, analysis of aerial photographs, and geophysical surveys were undertaken in order to gain a greater understanding of the archaeological resource.

5.4.1 Landscape development over time in the Dysynni valley

Chapter 4.4 provided a brief summary of the archaeological and historical background of the study area based on available archaeological reports, which established that there is evidence for human activity in the Dysynni valley throughout history and prehistory. This section provides a more detailed narrative on the development of the Dysynni valley landscape based on the results of the aerial photograph study, geophysical surveys, and archive research.

Prehistoric, Roman and early medieval (10,000BC – AD 1066)

In addition to the cropmarks identified near Croes Faen and Bryncrug by the RCAHMW (see Figure 5.1), further cropmarks provisionally dated to the prehistoric or early medieval period were discovered through detailed study of available aerial photographs (see 5.2.1.3). The majority of new cropmarks identified are individual, circular enclosures in both lowland and upland areas, suggesting widespread use or occupation of the study area during prehistory. The cropmark complexes near Bryncrug identified by RCAHMW (see Figure 5.1C and Appendix 1 Table Ap1.6) comprise several different features of varying morphology (linear, curvilinear, circular, rectilinear) which overlap. Circular enclosures are more likely to be prehistoric in date (Bronze Age or Iron Age), while the rectilinear enclosures and in particular the square, double-ditched enclosure are more likely to date to the Roman period (Royal Commission on the Historical Monuments of England 1989). This indicates that there were multiple periods of use or occupation in some lowland areas of the valley.

There is little data available for mean sea-level along this stretch of coastline for the past c.4000 years (see Wilks 1979; Heyworth and Kidson 1982), so the tidal reach and river dynamics during this period are not yet certain for the study area. However, the cropmarks identified thus far have all been concentrated in areas at least 4m aOD, on small rises above the floodplain. A possibility is that the most low-lying areas of the Dysynni valley may have been marshland or active floodplain, and were thus uninhabitable during the prehistoric to early medieval period. Habitation would therefore be concentrated on the small islands within the marsh, and in upland areas (in which there are plentiful prehistoric remains). This would explain the high concentration of cropmarks in slightly raised areas, and the lack of cropmark evidence in the lowest-lying areas or near the river channel. Alternatively, the lack of cropmark evidence in the most low-lying areas may be due to higher soil water content or waterlogging, meaning that the drought conditions required to reveal cropmarks have not been reached. There is also the possibility that the construction of the drainage ditches and channelisation of the River Dysynni disturbed or damaged subterranean prehistoric remains in the floodplain.

Previous available information, such as the location of HER and NMRW records, suggested that the bulk of prehistoric and early medieval remains were in sloped and upland areas in the Dysynni valley, and that there was little evidence for occupation of the valley floor during this time. Further study of aerial photographs, and ground-truthing of cropmark complexes using geophysical survey, has revealed that the valley floor may also have been utilised during several periods during prehistory to the early medieval period. This supports the suggestion by Sjöberg (2014) that the occupants of the hillforts in the area were also using lowland areas and could have had transhumant lifestyles, rather than constraining their activity to the uplands, as indicated by the fact that the Iron Age hillforts in the area predominantly overlook river valleys and have easy access to coastal routes and resources.

Medieval (AD 1066 – AD 1540)

From the HER and NMRW records, very few (n=53) are dated to the medieval period. Of these, only two are located below 10m aOD (a fish trap, NPRN 409087; and Talybont Castle Mound, NPRN 302714). This indicates that, although Tywyn was inhabited, the areas of the Dysynni floodplain that were previously habitable lowlands became uninhabitable during the medieval period. This may have occurred due to a 0.2m rise in sea-level during the Medieval Warm Period (Grinstead *et al*. 2009) or other factors causing an increase in waterlogging in the lowlands.

Despite the lack of extensive settlement evidence and potential worsening of land quality, the construction of large defensive structures such as Castell y Bere and Castell Cynfal during the medieval period indicates that this area was considered valuable and worth defending. Talybont castle mound has been associated with a *llys* (royal court), which would have had administrative control over the surrounding area and would have been supported by local produce (Fowkes and Wiliam 1960; Cadw 1990; Building History 2008), suggesting that the surrounding landscape was productive enough to support this royal court.

Post-medieval (AD 1540 – AD 1901)

During the post-medieval period, much of the landscape development and land-use change in the study area was engineered by the Peniarth and Ynysmaengwyn estates, which were both established in the late 15th century. As mentioned in section 4.4, both estates funded significant drainage and land improvement projects during the 18th and 19th centuries (Smith 2004a; Frost 2012). The outcome of these projects was that the marshland and floodplain on the valley floor became available for pastoral agriculture. The drainage ditches and field-systems that were created during these projects still dominate the lowland areas of the Dysynni valley at present, indicating that these works played a large part in the current character of the landscape. The establishment of lowland grazing land also allowed more cattle to be farmed, as rougher upland moors are more suitable for sheep (Prifysgol Bangor University 2015). Lowland pastures can also often be farmed more intensively with higher stocking rates, and therefore generate greater economic outputs, while hill and upland farming systems have lower stocking rates (*ibid*.). GAT (2016) state that the land improvement projects “transformed [Tywyn] from a small and wretched settlement into a sub-regional centre with pretensions to becoming a holiday resort”.

John Corbett, of the Ynysmaengwyn estate also invested significantly in Tywyn in the late 19th century, funding the development of a sewage system, the establishment of a school, and the construction of a promenade, market hall, and assembly room (now a cinema) (GAT 2016).

A Tithe map dating to the early 19th century, found during online archive research, indicated the presence of a large lake called Penllyn Pool near Penllyn farm, south of Tywyn (see Figure 5.11; NLW 2019b). Presently, the area is criss-crossed by drainage ditches, but at the time of the Tithe map this area had not yet been drained. As indicated in Figure 5.11, field boundaries extend into the area of the lake, suggesting that the lake was seasonal or an area frequently flooded, rather than a permanent body of water. The presence of Penllyn Pool in the Tithe map explains the name of Penllyn farm, which means ‘head-of-the-lake’ farm.

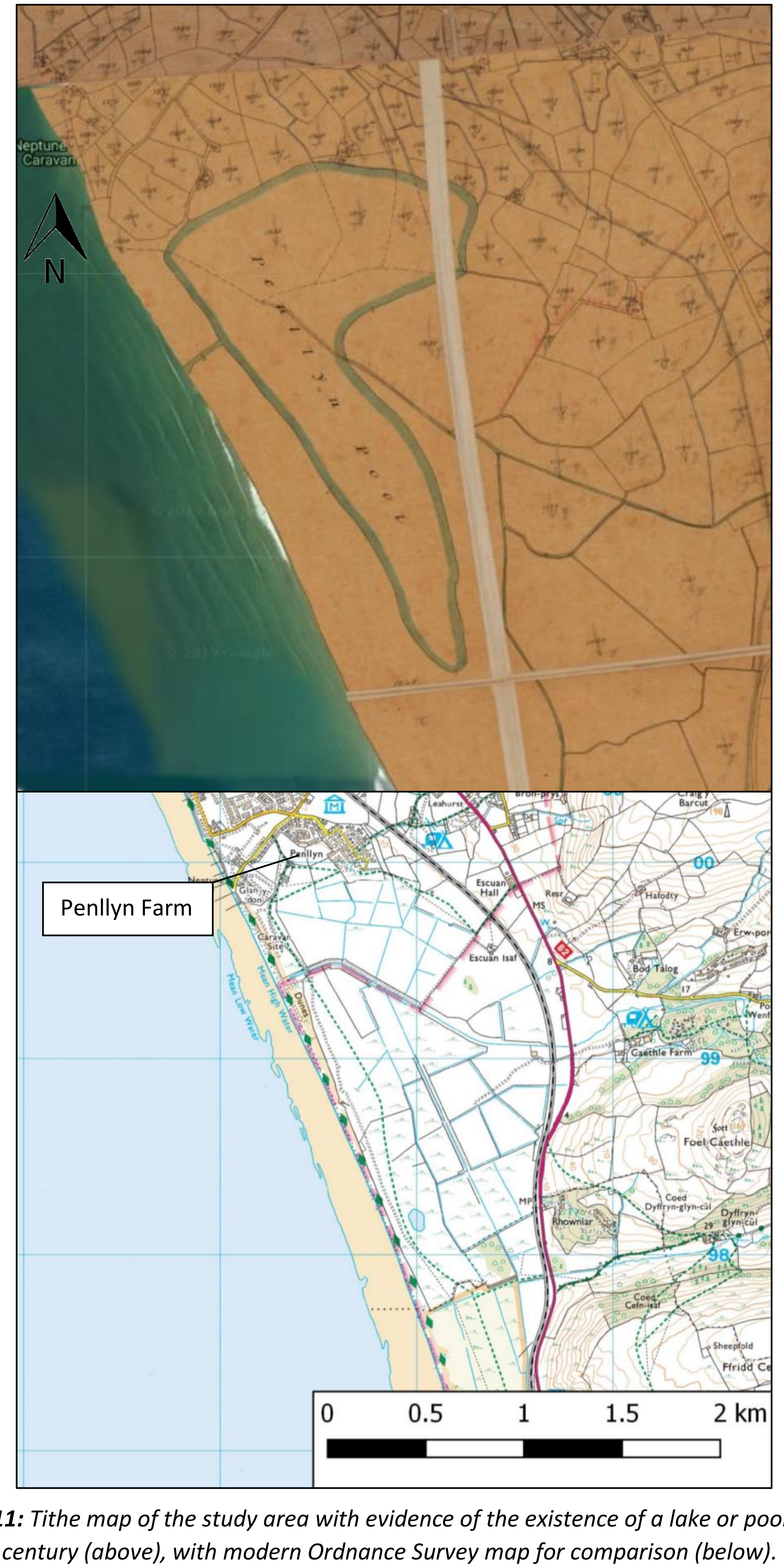


Figure 5.11: *Tithe map of the study area with evidence of the existence of a lake or pool at Penllyn in the early 19th century (above), with modern Ordnance Survey map for comparison (below). Copyright The National Library of Wales and Crown copyright and database right 2019 Ordnance Survey 100025252*

As described in 5.3.1, the archive source *Aberyswith and Welsh Coast Railway* (1865) (Appendix 1 Table Ap1.5) details a plan from 1865 for a proposed viaduct and railway line across the Dyfi estuary, which would have significantly shortened the time taken to reach Aberystwyth. Although these plans were not undertaken, they were created only two years after the trainline was built through Tywyn. This indicates that there was significant investment in the industry and transport links in the study area during the 19th century, perhaps due to both the industrial revolution and extractive industries in the Dysynni valley, and the booming tourist industry during the Victorian period.

Several areas of the Dysynni valley still have noticeable remnants of extractive industries such as mining and quarrying, which were most active during the post-medieval period; of the c.250 HER and NMRW records relating directly to extractive industries (quarry and mine features), over 200 are post-medieval in date.

Evidently, the post-medieval period was a time of significant change in the character of the study area, mainly through the patronage of wealthy landowners, as well as the boom in tourism and the wealth of slate and metal ore in the surrounding hills.

Modern (AD 1901 – present)

Despite the extensive land-improvement projects, all of the archive sources found for the 20th century discuss ongoing issues with waterlogging and ineffective drains. These issues may have been caused by changing sea-level during the post-medieval to modern period. From the 17th to mid-19th centuries, global sea-level was around 0.2m below the mean sea-level for 1980-1999 (Grinstead *et al.* 2010). Subsequent sea-level rise of around 0.2m by the end of the 20th century may have increased the tidal reach up the Dysynni valley, and reduced the ability of the drainage system to prevent waterlogging. The National Rivers Authority stated that, even with the Dysynni Low Level Drain, the drainage was considered bad or very bad in most areas in the wet season, and in around one-quarter of the land during a dry season (Dunderdale and Morris 1996). Additionally, Records 3, 4, and 8 (see Appendix 1 Table Ap1.4; Merioneth Rivers Catchment Board 1952; River Dysynni Catchment Board 1950; Ministry of Agriculture and Fisheries 1949) discuss the maintenance requirements of the drainage system, and that the associated costs prohibited it being carried out more frequently. Indeed, in 2017, the Farmers' Union of Wales raised attention to the loss of productive land in the Dysynni valley due to high water levels in drainage ditches, but NRW state that the costs are too great to undertake maintenance more than once a year (Wales Farmer 2017).

The lower sea level during the post-medieval period compared to the medieval and modern periods may have facilitated the establishment of drainage infrastructure in the Dysynni valley and the transformation of marsh into productive land. Subsequent rise in sea-level (and even more rapid rates of sea-level rise in the future) may have negated some of the benefit of the drainage system. However, as many farmers now depend on these low-lying areas for their income, the local authorities are now tied into an expensive maintenance scheme.

As discussed in section 4.4, there are significant military remains dating to the First and Second World Wars, such as the remnants of an RAF base, a rifle range, and a line of Pillboxes positioned on the beach between Tywyn and Aberdyfi. Some of these pillboxes are badly eroded and collapsed, while others still remain relatively unscathed. Although the RAF airfield is now out of use, the Dysynni valley is still a popular training-ground for pilots from RAF Valley Angelsey (Mawddach Estuary 2014). Frequent Hawk and Texan flights low in the valley maintain some of the military character of the area even as the physical remains decline (RAF 2019).

5.5 Conclusion

The results of the landscape analysis indicate that different sources of archaeological and cultural heritage data have widely different distributions. While there are many more HER and NRMW records located in urban and upland areas, the majority of features identified in aerial photographs were in low lying areas. Therefore, the absence of records in some areas from one source of data does not necessarily indicate an absence of archaeological information. Research undertaken for this chapter has revealed that there is much greater archaeological potential in the lowland areas than the current distribution of known features would indicate. It has also revealed that different areas of the landscape are characterised by different types of archaeological feature as well as by the remnants of different types of land use.

The archive research was particularly revealing in terms of the way that the land improvement and drainage schemes led to longer-term changes to land management in the valley. For instance, the required upkeep of the drainage works put a large financial burden on landowners, many of whom had to put some parts of their land (or the waterways within their land) into the control of the local authority. This reinforces the character of much of the lowlands, as dominated by larger-scale, modern field-systems that were created en masse in a centralised scheme (and are now managed centrally), compared to the slopes and upland areas which have smaller, more irregular fields that developed gradually. A large number of the known archaeological features in the study area date to the post-medieval and modern period, which indicates an increase in activity in the study area during the Industrial Revolution, for instance in relation to extractive industries and the tourism boom during the 18th-19th centuries.

The landscape analysis undertaken for this thesis used a range of methods. If this methodology was applied to a different landscape, other methods could be used in addition to, or instead of, the methods used here. Methods and techniques that were not employed for this landscape analysis, but that could be used in the analysis of other landscapes for the purpose of characterisation, include LiDAR, fieldwalking, excavation, interviews and participatory mapping, and other geophysical survey methods such as ground penetrating radar

In Chapter 6, the results of this landscape analysis are used to inform a HLC. Developing a deeper understanding of the study area through a multi-source analysis is important because HLC involves the characterisation and qualification of the time-depth of the landscape, which is dependent on a range of factors.

Chapter 6

Landscape Characterisation

6.1 Introduction

Chapter 6 addresses research objective 1c (*Use Historic Landscape Characterisation to characterise the historic landscape of the Dysynni valley*). HLC is the mechanism through which the focal-level LCAs are defined in this thesis.

HLC was used to generate a landscape-wide, comprehensive representation of the cultural heritage in the area using LCAs (see 6.2). HLC was chosen as a characterisation method as it provides a way to combine and holistically display the information held in disparate records and across different spatial levels, for instance HER and NMRW records (point data), cropmarks and geophysical survey features (field-level), and historical archives relating to historic land management (landscape-level) (see Chapter 5). This allows all elements of the historic landscape to be analysed together, whether in vulnerability assessments, planning decisions, or landscape management schemes. For the purpose of this HLC, all features at a spatial level below LCAs are defined as LCFs, as they are features that influence the character both of LCAs and the historic landscape as a whole. This includes but is not limited to HER and NMRW database records, historic and modern buildings, earthworks, patches of parkland, ancient and modern woodland, and field-boundary systems. In this thesis, using Hierarchy Theory and HLC expands the spatial scope of archaeological analysis to include the wider landscape. This was used to address the problems caused by site-focussed vulnerability assessments (see section 2.7 and 7.2) by creating a spatially continuous, landscape-level structure that can be used in vulnerability assessments. In turn, the HLC was used to inform the sustainable management of the vulnerable historic landscape in the face of climate change (see Chapter 8). Figure 6.1 demonstrates how HLC fits into the Hierarchy Theory framework.

Chapter 6 first provides an in-depth overview of HLC, and a literature review of the most common methods and uses for HLC projects (6.2). Secondly, the HLC methods used in this thesis are described and then applied to the Dysynni valley, including a description of each LCA-type used (6.3).

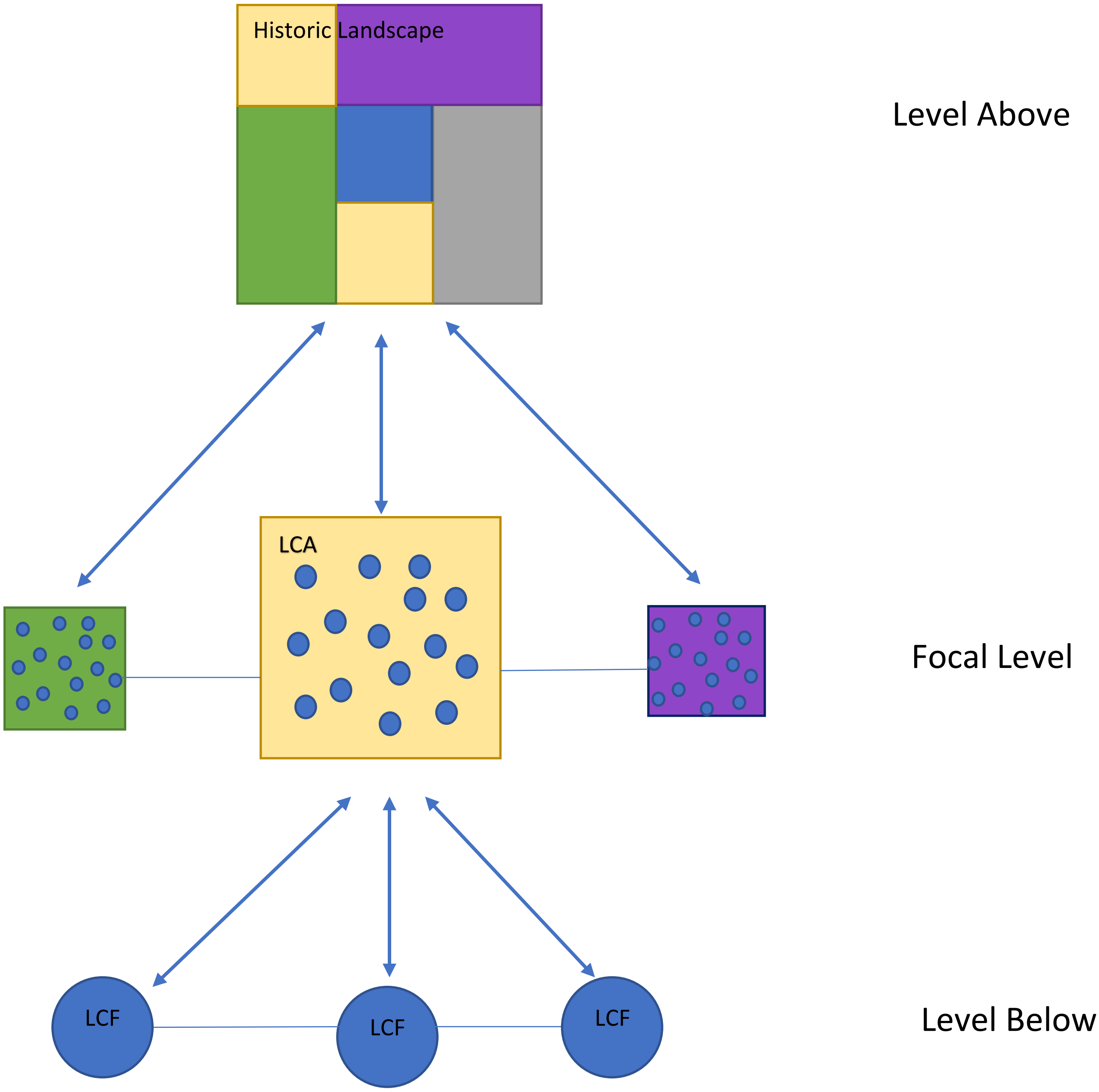


Figure 6.1. *Visual representation of how HLC fits into the Hierarchy Theory framework in this thesis. The Landscape Character Features (LCFs) in the landscape are holons that form one of the levels below the focal level. The focal level is the Landscape Character Areas within the landscape, while the level above is the historic landscape as a whole. This diagram represents the way that objects influence one another both between and within spatial levels.*

6.2 Introduction to Historic Landscape Characterisation

HLC is a method of landscape analysis, developed as a tool for conservation management, that presents the time-depth of a landscape, and represents the current landscape as the cumulative outcome of past human activities. HLC evolved from and developed further the methodologies of Landscape Character Assessment, and can be used as a complementary technique to studying landscapes (Turner 2006). Landscape Character Assessment is used by environmental public bodies to map different character type areas, based on criteria such as topographic features, flora and fauna and land-use. This was supposed to be a holistic, catch-all method of studying and assessing landscapes as it included cultural and historical sites as well as environmental criteria (Fairclough and Herring 2016). However, it prioritises the visual and aesthetic aspects of the landscape and gives less priority to other aspects, such as cultural land uses and temporal change (Fairclough and Herring 2016; Olwig *et al*. 2016). As a result, HLC was developed to focus predominantly on the historicity of the landscape.

The basic premise of HLC is that the structure of a landscape is the result of human activity during different periods of history, which can often be seen in settlements, field boundaries, and the location of industry that survive in the present landscape, even after the land uses have changed (Fairclough *et al.* 2002; Rippon 2013). The location of LCAs (e.g. ancient enclosures, modern enclosures, ancient woodland, modern woodland, settlement), can be used to inform planning processes within the landscape, and foster a greater understanding of the cultural heritage within the landscape (Fairclough 2003b; Lang *et al.* 2009; Bradley *et al.* 2004).

England and Wales have slightly different methods for assessing landscape character (Fairclough and Herring 2016). Since the early 1990s, Historic England supported the creation of HLCs for almost all of England by commissioning their creation from each county or local authority (Historic England 2019). Characterisation of landscape types is also encouraged in Europe by the European Landscape Convention (ELC). Different approaches are used in different countries, due to different perceptions of landscape, and different historical and archaeological traditions (Fairclough and Herring 2016). This makes it difficult to compare the character of landscapes in different areas of the UK and Europe (*ibid*). This thesis uses the English HLC method, in which areas of land are characterised into pre-defined, thematic LCAs. In contrast, in Welsh HLC projects each LCA is uniquely defined, which obscures the trends in historic land-uses across the landscape and prevents comparison between landscapes. An HLC for the Dysynni valley has already been carried out by GAT, using the Welsh methods (see Figure 6.2). This approach was considered unsuitable for use in this thesis because the LCA types used included 'Dysynni lowlands' 'Tywyn', 'Intermediate slopes', and 'Upper slopes', which are not useful for characterising the historic elements of the landscape or defining past land use (Gwyn and Davidson 2009). There are areas of very similar character in different areas of the valley, suggesting that similar activities and land-use took place in a variety of locations. By creating different LCA types for different areas of the landscape, it implies that past activities and land use in one area were separate and distinct from those in another area. Furthermore, Welsh LCAs are much larger and at a coarser resolution, whereas English LCAs are at a higher resolution, and can be affected by individual fields and features. Therefore, the English method is the most suitable for the purpose of this research, and is the focus of this chapter.

Characterisation into LCAs involves the simplification of land uses, in order for more general trends and patterns to be identified. This is carried out using GIS software, which facilitates the mapping of LCA types (Bender *et al.* 2005). The first HLC projects were carried out in England in 1993-4, and many were initially paper-based, as GIS was not widely used until the late 1990s (McClure and Griffiths 2002; Herring 2009). While the technologies used in HLC projects have progressed substantially, the underlying principles of HLC remain the same. LCAs are represented using polygons to form a 'patch-matrix', so that all areas within the landscape are characterised (Bender 2009a) (see Figure 6.3). This differs from a traditional approach to historical elements in the landscape, involving the designation of individual sites, which removes features from their context and obscures the historical-cultural importance of the landscape as a whole (Turner 2006; Bender 2009a). HLC views all aspects of the landscape as important, and values all equally, rather than focussing on individual historical or archaeological features or prioritising ancient features over more modern ones (Aldred and Fairclough 2003). This method is rooted in the concept that the whole landscape, and indeed any landscape, has a historic character, and that the historic landscape is ever-present and ever-changing (Rippon 2004; Fairclough and Herring 2016).

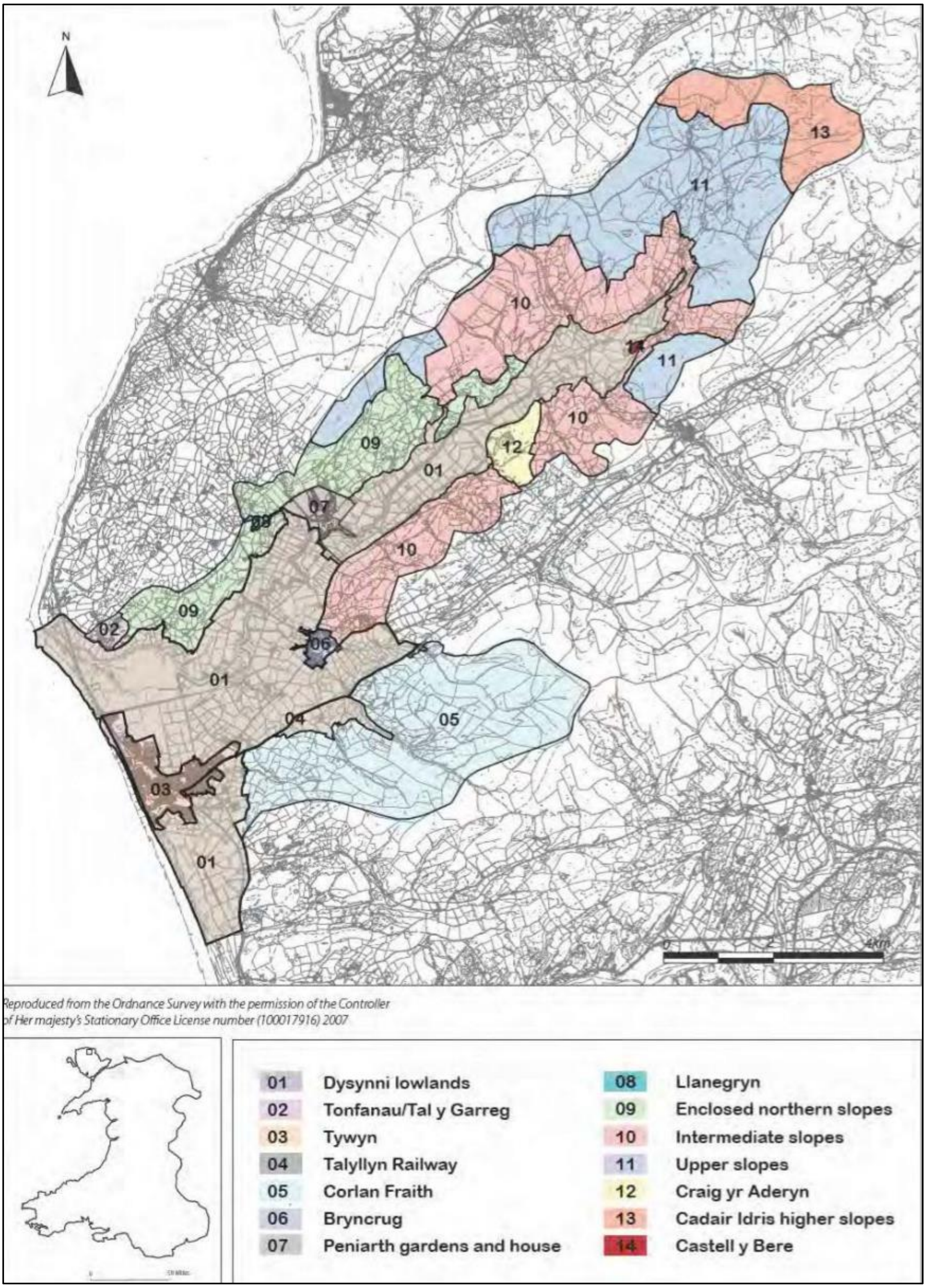


Figure 6.2. *Welsh Historic Landscape Characterisation project by Gwynedd Archaeological Trust (Gwyn and Davidson 2009). Reproduced from the Ordnance Survey with the permission of the Controller of Her majesty's Stationary Office License number (100017916) 2007*

6.3 Methods and applications of Historic Landscape Characterisation in England and beyond

The following section provides a brief review of HLC and the methods commonly used in the creation of HLCs. First, LCA-types and the different ways they are established or defined is discussed, followed by the data sources commonly used in HLC methods. Finally, the various purposes of HLC projects are discussed.

6.3.1 Historic Landscape Character types

HLC uses a continuous mosaic of polygons, rather than representing features using point data, as this represents the spatial element of land uses and remains more effectively. Each polygon is colour-coded to its corresponding LCA, in order to create an understandable model of general LCA distribution. Different projects use slightly different LCA-types. For example, in his HLC for Cornwall, Herring (1998) uses 17 different character types, including a differentiation between enclosures from different historic periods, historic and modern settlement, woodland types, and relict and modern industry (see Figure 6.3). In contrast, Clarke *et al.* (2004) list only 11 LCA types, with only one type of enclosed land, woodland and settlement (see also Rippon 2004, Herring 2009). Often,

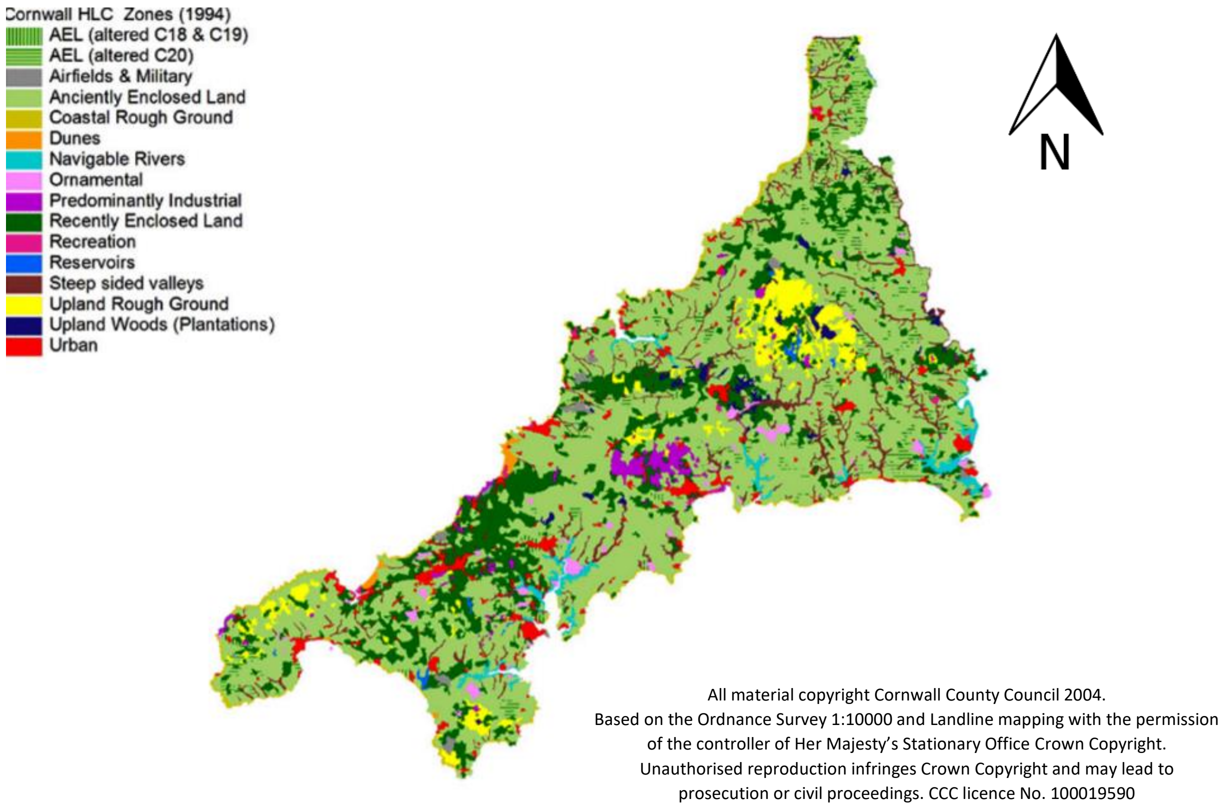


***Figure 6.3**. Historic Landscape Characterisation of Cornwall, carried out by Herring (1998). Source: Historic Environment Record, Cornwall Council, Copyright Cornwall County Council 2004 (scale bar not provided on original map).*

these broad character types are sub-divided into character sub-types; the Scottish Historic Landscape Assessment approach contains over 100 sub-type characterisations (Herring 2009), while Fairclough *et al.* (2002) use 85 sub-types within 14 broad LCA-types in the HLC project for Hampshire. The objective of the classification system is to define a sufficiently large range of LCA-types in order to maintain important characteristics and differences in the landscape, while having few enough to make the output understandable and the method repeatable in another area (Fairclough *et al.* 2002).

The classification of different LCA types can be based on prescriptive, descriptive or multi-mode methodologies. Prescriptive approaches to HLC fit areas of the landscape into pre-defined LCA types. This is the most common approach used in HLC projects (see Cornwall HLC and Hampshire HLC; Cornwall County Council 1996; Herring 1998; Fairclough *et al.* 2002; Aldred and Fairclough 2003). This approach can be the least time-consuming, and is useful for comparing historic character between landscapes if the HLC projects use the same LCA classifications. However, it is considered by some to be less objective or transparent than descriptive methods. Descriptive approaches to HLC assign attributes to each small parcel of land, for instance the field-system type, current land-use, historic land-use, date of predominant features. Areas which share a similar combination of features are then grouped into LCA types (Rippon 2004). This approach is more time-consuming than prescriptive approaches; the Lancashire HLC contained 4,800 individual polygons to which attributes had to be assigned, while the Shropshire HLC contained over 30,000 (Ede *et al.* 2002; Fairclough and Wigley 2005). As a result, descriptive approaches are the least commonly used compared to prescriptive and multi-mode approaches (Aldred and Fairclough 2003). Multi-mode approaches to HLC are the most commonly used within recent HLC projects (e.g. Beckley 2007; Edwards *et al*. 2007; Quigley 2009; Van Eetvelde and Antrop 2009; Turner and Crow 2010; Defra 2014). This approach combines both prescriptive and descriptive methods, so the LCAs are defined based on information in modern and historical maps before areas of the landscape are classified into the LCA-types. This allows the LCA-types to be defined specifically for the types of land-use common within the study area but is not as time-consuming as descriptive methods. For these reasons, the HLC in this thesis is based on a multi-mode method.

Regardless of the method used, the categorisation of areas of land into different character types is inherently subjective (Fairclough and Herring 2016). As HLC is usually carried out by a non-local expert, the way that they perceive and characterise the landscape may be different from the way that it would be done by another stakeholder (Fairclough *et al.* 2006; Fairclough and Herring 2016; Olwig *et al.* 2016). While attempting to keep the results of HLC value-neutral, value judgements can be made during the characterisation process (Fairclough *et al.* 2006; Fairclough and Herring 2016).

The approach used in HLC projects depends on the purpose of the HLC, the spatial scale of the project, and the area in question, as different regions have significantly different historical features within their landscape (Lambrick *et al.* 2013). Therefore, the decision of which features to represent, and how they are displayed, remains subjective.

There is also an issue of a lack of flexibility in the categorisation process; Olwig *et al.* (2016) argue that HLC often fails to "look outside the box" of the character that has been predefined (p.174). HLC projects may fail to capture the unique character of certain landscapes, if the LCA types that they are using are too general and designed to be applicable to many different landscapes. This is particularly an issue if the person undertaking the HLC is not a local person, as they may not be able to capture or understand the character of certain areas as perceived by the local population (Olwig *et al.* 2016). Part of the reason that archive research was undertaken prior to the HLC in this thesis was to gain a greater understanding of the uniqueness of the Dysynni landscape, and the way that historic land-use may have altered the structure and use of the landscape today.

Although a map is the easiest and most accessible way in which to display information about a landscape, Herring (2009) argues that a 2D representation may obscure the complexity of the historic landscape, as it fails to capture movement or action within the landscape. Most HLC projects are based predominantly on field boundary morphology, and fail to take into account other indicators of landscape character, such as place names or architecture type (Rippon 2013). However, a more detailed HLC, including many more different character types and ways of determining character, may obscure general trends in land-use change, and dramatically increase the time required to undertake it (Aldred and Fairclough 2003).

6.3.2 Data sources

In order to establish the landscape change that has occurred during the recent past, characterisations are often carried out on historical as well as current maps. This facilitates the identification of areas of the current landscape that maintain their historic character, and the nature and rapidity of changes. Historic maps such as the first edition Ordnance Survey maps, cadastral maps and tithe maps can be digitised and georeferenced using GIS. Historical maps often include different land-cover and vegetation types compared to modern maps, and the terminology used changes over time. When using both historic and modern maps it is important to standardise the landscape features and vocabulary, in order to create a unified legend (Bender *et al.* 2005; Van Eetvelde and Antrop 2009). Standardisation can be hindered by the fact that many historic maps do not include a legend, so identifying the land type based on cartographic symbols may reduce the reliability of the HLC (Lang *et al.* 2009). Some historic maps may only include information that is relevant to their purpose, such as property and agricultural land in parish maps, and so other details such as heathland may not be recorded (McClure and Griffiths 2002). Furthermore, sometimes symbols on historical maps are used for cartographic effect rather than representing actual geographic features, while lines may indicate either field boundaries, paths, small roads or small streams (Domaas and Grau Møller 2009).

Another issue that may arise is the lack of cartographic coverage before the 18th century in many areas, and the reduced accuracy of maps that are older than the 18th-19th century. Less accurate maps can be georectified using GIS, by identifying common features between the old and modern maps. This may be difficult if there are not many shared identifiable points between the maps (Domaas and Grau Møller 2009). Significant warping of the historic map can occur during georectification, which can cause gaps in coverage (*ibid.*). Therefore, areas of medieval or earlier character within the current landscape are usually identified using the location of known archaeological and historical features, some documentary sources and the recognition of extant prehistoric or medieval field systems. Some projects (e.g. Fairclough *et al.* 2002) elect not to map characteristics that are not included in the historical evidence, thus excluding subsoil archaeological remains. Others utilise aerial and satellite photographs as well as documentary evidence to identify areas of different landscape character (e.g. McClure and Griffiths 2002; Bender *et al.* 2005). Documentary evidence can be useful for indicating the historical processes, such as war, policy changes or agricultural intensification, that led to the changes that are visible in the landscape (Aldred and Fairclough 2003).

While an understanding of the past landscape processes is important for recognising historical elements within the current landscape, Clarke *et al.* (2004) warn that the focus of HLC should remain on the present day landscape. Rather than mapping the original extent of medieval and prehistoric field systems, HLC projects should show the areas of the current landscape in which the medieval character is still evident. This reflects the way that HLC is primarily used, which is by land managers for planning change in the landscape.

6.3.3 Purpose

Most HLC projects have been carried out by local authorities or heritage agencies due to the commissioning of HLCs by Historic England. A key use of HLC is in landscape management and planning, as it has the capacity to accommodate several different viewpoints and facilitate communication and understanding between different stakeholders (Rippon 2004; Turner 2006; Rippon 2013). HLC is also useful for facilitating the understanding of past landscape change and processes, and the surviving state of the landscape, in order to inform landscape planning and predict future scenarios (Haase *et al.* 2007; Bender 2009b; Herring 2009; Lang *et al.* 2009). Therefore, HLC can allow more informed decisions to be made regarding development and indicate areas of historic significance that may be under threat (Herring 1998). Fairclough (2003b) argues that HLC can be the basis for reconciling two issues within historic landscape management: "how to reconcile minimising loss with the needs of the present, and how to ensure that the balance we strike does not reduce too greatly our successors options for understanding and enjoying their inheritance" (Fairclough 2003b, p.24). This is essentially a reiteration of the Brundtland Commission's definition of sustainable development (Brundtland 1987), indicating that HLC may be used as a tool for incorporating the historic landscape into sustainable development, with a focus on economic, social and environmental sustainability.

HLC can be used within archaeological and landscape research, for instance to increase understanding of the distribution of archaeological sites recorded in the Sites and Monuments Record (SMR), either in terms of the reasons behind their preservation, or their original distribution (Fairclough *et al.* 2002; 2003b). Bender *et al.* (2005) use HLC as a tool to predict future landscape change in montane regions of southern Germany, based on historical landscape change. The results from HLC can also be used for identifying areas of higher archaeological potential, which may then be targeted by research and used in DBAs (Herring 1998; Clarke *et al.* 2004).

Another use for HLC projects can be outreach and community engagement. Herring (1998) argues that, because HLC is interpretative and non-hierarchical, communities can be involved in the creation of HLC, and benefit from an increased understanding of historical processes in their landscape (see also McClure and Griffiths 2002). Furthermore, HLC projects should be available to all stakeholders, rather than only the heritage management sector, as the historic landscape is a common resource (Clarke *et al.* 2004). The South Yorkshire Historic Environment Characterisation project, undertaken by South Yorkshire Archaeology Service and English Heritage, created HLC maps for South Yorkshire, covering nine time periods since AD 1400, which is available to the public (Marchant *et al.* 2008). The information from this project was made into an interactive map of the changing landscape, available on the South Yorkshire Timescapes website (SY Timescapes 2008).

Finally, assessing the impact of development, land-use change or conservation policies on the landscape can be facilitated by HLC. Cornwall Council applied a sensitivity model to the 1994 HLC of Cornwall, to determine the sensitivity of the historic landscape to the installation of solar power farms and wind turbines (Cornwall Council 2013). Each LCA-type was given a sensitivity score for the potential impact of each development. A vulnerability map was created from the sum of the scores for each area, and this was used to determine the suitable location for the renewable energy developments (*ibid*.). The application of a vulnerability index (VI) to the HLC in this thesis was inspired by this HLC-based sensitivity model by Cornwall Council (2013).

6.4 Methodology

The LCA types chosen for this project were inspired by those used in the Cornwall HLC (Herring 2008), but have been adjusted to the specific characteristics of the Dysynni valley as determined from studying historic and modern Ordnance Survey maps, the HER and NMRW database, geophysical surveys, aerial photographs, the archive records. The decision was made to allow the LCA polygons to overlap in the HLC, as in many areas the landscape displays features of more than one period or more than one character type. Allowing overlap between LCAs meant that the HLC represents the multiplicity of land-use over time, and does not exclude one type of character in favour of any other in any area.

This section provides an overview of the LCA types used in the Dysynni HLC, including the characteristics of each. QGIS was used to render the LCA polygons using the 2016 1:25,000 Scale Ordnance Survey map as a basemap. Table Ap2.1 in Appendix 2 provides a description and cartographic and visual examples of each LCA type.

Rough Pasture

The Rough Pasture LCA type is characterised by scrub, bracken, heath or rough grassland, and is located in areas of high elevation and/or high relief as indicated by the contour lines in the Ordnance Survey basemap. It includes areas of scree, rocky outcrops and loose rock (Ordnance Survey 2017). The majority of the rough pasture in the study area is unenclosed or has very large enclosures (c.20-100ha). In terms of the LCFs, post-medieval agricultural remains such as sheep folds, clearance cairns and farmsteads characterise rough pasture areas. There are often overlaps between the rough pasture LCA and the ancient and historic industrial LCA types. Most areas of rough pasture are now used for extensive sheep farming, so the extant archaeological remains do not face significant threats from human development or land-use.

Woodland – Ancient

The Ancient Woodland LCA was defined using the Ancient Woodland Inventory available to download as a shapefile from the Welsh Government website (NRW 2011). This inventory is based on the study of historic maps. Areas of woodland that appear to originate from before AD 1600 based on their name, location, nature of surrounding enclosure, and the presence of indicator species, have been classified as ancient woodland (*ibid*.). Areas of ancient woodland are generally small (c.<10-20ha), located in the lower slopes of the Dysynni valley, and are classified in the inventory into Plantation on Ancient Woodland Sites, Ancient Semi-Natural Woodland, Restored Ancient Woodland Site, or Ancient Woodland Site of Unknown Category.

Woodland – Modern

Areas of Modern Woodland LCA were identified as areas of woodland on the Ordnance Survey basemap that were not included in the Ancient Woodland inventory. While ancient woodland consisted mainly of deciduous species, the areas of modern woodland are predominantly coniferous plantations. These plantations are often larger than the ancient woodlands (c.65-400ha), and are located at higher elevations. Many conifer plantations in the UK were planted during the 20th century to increase timber production following the Second World War, so may be viewed as being part of an industrial or military landscape (Herring 2008). Modern woodland plantations can play a significant role in the visible character of a landscape, but this is sometimes considered to be negative as they are perceived as unnatural and ecologically damaging by many people (e.g. Barsoum and Henderson 2016).

Field systems – Regular

Regular field systems are those that have straight, often parallel boundaries and right angles, and are indicative of a large-scale planned group of fields. These are characteristic of agricultural land established in the post-medieval and modern period. In the Dysynni valley, most of the regular field systems are located on the flat valley floor, often with drainage ditches running along the field boundaries. These field systems were only created following the Peniarth and Ynysmaengwyn land improvement scheme. Due to the relatively recent reclamation of the land on which the regular field systems are placed, very few known LCFs are located in this LCA type, other than the field boundaries and ditches. However, as discussed in Chapter 5, several cropmarks were identified in aerial photographs in regular field systems, including a potentially Roman double-ditched enclosure, circular enclosures and linear features which may be ancient trackways or field boundaries. This suggests that the Dysynni valley floor may have been occupied prior to the development of wetland conditions, so there is a high potential that further archaeological remains and features may be preserved in this LCA.

Field systems – Irregular

Irregular field systems are here defined as field systems with small fields, irregular angles, some curved boundaries, and no clear layout, indicative of the gradual establishment of individual fields over time, rather than a planned field system. This type of field boundary morphology is characteristic of areas in which agriculture was established in prehistoric to medieval periods. In the study area, irregular field systems are mainly located on shallow slopes and immediately adjacent to settlements such as Tywyn, Bryncrug, Abergynolwyn and Llanfihangel-y-Pennant, but not the flat valley floor. Most of the LCFs located in irregular field systems are chapels, churches and farmhouses, as these would have been the main areas of settlement. Although farming practices are now more intensive, the same field boundaries are maintained, so irregular field systems are an important visual element of the Dysynni landscape's historic character.

Drained land – Regular

As explained in Chapter 4, large-scale land improvement and drainage projects were undertaken by the Peniarth and Ynysymaengwyn estates in the Dysynni valley in the late 18th-century. Further drainage may have taken place in the Dysynni valley during the early 20th century; archived sources indicate that the Air Ministry and local land owners wanted further drainage to take place north of Tywyn and further up the valley (see section 5.2.2; Merioneth Rivers Catchment Board, 1948; River Dysynni Catchment Board 1942-50).

The land improvement is still evident in the drainage channels that cut across the floodplain of the Dysynni. In some areas, the drainage channels have a typically modern morphology, incorporating right-angles and parallel lines. This indicates areas in which drainage was undertaken as a centralised project, for instance by the estates or local catchment boards. The regular drained land LCA is located predominantly in the lower section of the Dysynni valley floor, shoreward of Craig yr Aderyn, and just north and south of Tywyn. As it was only relatively recently reclaimed from marshland, there are very few LCFs located within the Regular Drained Land LCA, and none which specifically characterise it other than the drainage ditches themselves.

Drained Land – Irregular

The Irregular Drained Land LCA is widespread in the study area. It is characterised by areas of land with irregular drainage ditches, often serving as (or following) field boundaries of irregular field systems. Unlike the regular drainage ditches, these do not have straight, parallel sides or regular angles. It is possible that these were created on a smaller scale, for instance by individual farmers on their own land, rather than as part of the extensive land improvement. Areas of irregular drained land are more dispersed across the study area than the Regular Drained Land LCA, and are smaller. This suggests that these areas were drained individually and potentially at different times, rather than being part of the large-scale land improvement projects. Like the Regular Drained Land, this LCA is not characterised by any particular LCFs. However, both the regular and irregular drained land are characteristic of the study area, as they cover a large area of the Dysynni valley, and are remnants of historic land use and governance.

Ancient

The Ancient LCA-type is defined by the presence of LCFs dating to the medieval period or earlier, such as Iron Age hillforts, early medieval barrows, Bronze Age cairns, or prehistoric and Roman cropmarks. There is a wealth of Bronze Age and Iron Age features at higher elevations in the Dysynni valley, so there are significant areas of overlap between the Ancient and Rough Pasture LCAs. As previously mentioned, extensive cropmarks were identified in the valley bottom, near Bryncrug and Croes Faen, indicative of features such as circular enclosures, square barrows, and a possible Roman double-ditched enclosure. Although the Ancient LCA is less visible within the landscape compared to other LCAs, it is important to include it in order to capture the long history of human habitation in the Dysynni valley and surrounding hills. Moreover, the character of the Dysynni uplands in particular is heavily influenced by the combination of prehistoric LCFs (Ancient LCA) and post-medieval LCFs (Rough Pasture LCA)

Settlement – Historic

The areas of Historic Settlement LCA in the Dysynni valley were defined as the large and small settlements included on the 1853-1904 1:2,500 County Series First Edition map. This included clusters of farms and farm buildings, but not single farmsteads. It is thought that Tywyn was established as a settlement or monastic community in the early medieval period, as Viking raids of Tywyn during the 960s and 970s AD were recorded in Brut y Tywysogion, a monastic chronicle documenting the 7th-14th centuries (Longley and Richards 1974). Habitation of the area increased through the medieval and post-medieval period, evidenced by the construction of Castell Cynfal, Castell y Bere, and the Llanegryn Parish Church in the 13th century, and the growth of the mining and quarrying industries during the industrial period. Other settlements, such as Abergynolwyn, were established during the Industrial Revolution due to their proximity to the mining and quarrying industries. The Historic Settlement LCA is generally located in the same place as current settlements, but is less extensive, suggesting that there has been significant growth in the settlements of the study area during the 20th and 21st centuries. The common LCFs that characterise this LCA are mainly churches, chapels, and post-medieval terraces and individual houses.

Settlement – Modern

The Modern Settlement LCA type is defined as areas of settlement that are present on the modern Ordnance Survey basemap that were not present on the 1853-1904 1:2,500 County Series 1st Edition map. Most of the areas of modern settlement are located around areas of historic settlement, which have expanded during the 20th and 21st century. Tywyn, Bryncrug, Aberdyfi, and Llanegryn in particular expanded in the modern period, due to a combination of military activity during the Second World War, local extractive industries, and a small tourist industry. Few LCFs are located in the modern settlement LCA other than the modern urban buildings, as they are newly built rather than a remnant of historic human activity.

Recreation and Tourism

The Recreation and Tourism LCA is characterised by LCFs that are for tourists and leisure activities, such as camp sites, caravan and mobile home parks, golf courses, and theme parks. In the Dysynni valley, caravan and mobile home parks form the majority of the Recreation and Tourism LCA; around 20 have been identified in the area. There is also one camp site and one golf course. There are overlaps between the Ornamental and Recreation and Tourism LCAs, as the gardens and lands of old estates such as Ynysymaengwyn and Peniarth have been converted into caravan and mobile home parks. There are also caravan and mobile home parks located both inland and by the coast, and at different elevations, so the location of this LCA is not confined to particular areas. The tourism industry in the Dysynni valley grew significantly in the 19th century due to improved transport links, such as the railway. This was instrumental in the development of Tywyn and Aberdyfi as seaside tourist destinations. This is now important to the character of these towns and the Dysynni valley.

Industry – Historic

Although other HLC projects combine all industrial activity into one LCA type (e.g. Herring 2008), this project separates the industrial type into three different LCAs, due to their different visual character and origins. The Historic Industry LCA is defined by the LCFs that are the remnants of extractive industries from the post-medieval period and earlier, predominantly features associated with quarrying and mining (e.g. levels, shafts, spoil heaps, open quarries, and the Tallylyn railway). In the Dysynni valley, the Historic Industry LCA is predominantly located in upland and valley areas, often with high relief. This makes the features susceptible to erosion from heavy rainfall and run-off (Herring 2008). There is significant overlap between the Rough Pasture and Historic Industry LCAs, as they are both characteristic of upland areas, and many areas that were exploited by extractive industries during the 18th- early 20th centuries are now used for extensive grazing.

Industry – Maritime

The Maritime Industry LCA is defined by areas with LCFs that are remnants of maritime industrial activity, such as fishing, shipbuilding and seafaring. As a result, this LCA is confined to coastal and riverine areas in the study area, and often overlaps with the Wetland and Beach and Military LCAs. Aberdyfi was a fishing and ship building port during the post-medieval period, and the structural remains of this (e.g. harbours, shipyards, jetties and shipwrecks) influence the character of the town and coastline (SNPA 2014a). Other areas of Maritime Industry LCA in the study area are characterised by LCFs like medieval and post-medieval fish traps, which may have been used for either subsistence or commercial purposes. Some archaeologists propose that, as Broadwater was once more navigable, there may once have been more shipping activity in the Dysynni estuary than at present (GAT 2015). However, other than a small boat house identified on the Ordnance Survey First edition 25-inch map, no archaeological features related to maritime industry have been identified in Broadwater. There is a high potential for further remains of maritime industrial activity to be preserved in Broadwater or in peat beds near Penllyn. This could increase the understanding of historic and prehistoric trade, sea-faring and industry in the study area.

Industry – Modern

Modern industrial activity in the study area is no longer based on extractive industries, but rather is confined to a sewage works near Broadwater and an industrial estate on the outskirts of Tywyn. The modern industry LCA covers a relatively small area, and is not associated with any known archaeological features.

Ornamental

The Ornamental LCA includes areas of park, garden or estate that have been deliberately designed, for instance the lands, gardens or deer park of a country estate. The main areas of Ornamental LCA in the Dysynni are the Ynysymaengwyn and Peniarth estates, both established in the 15th century, and the early 20th-century Rhowniar country house and garden. By 1800, the Peniarth estate owned 3,838 acres in the valley, although the area of the estate land is presently only around 150 acres (James 2006). The Ynysymaengwyn estate, once a powerful estate, was given to the local council in the mid-20th century and was used for firefighting practice and army training before being demolished. Presently, caravan and mobile home parks are located on the Ynysymaengwyn and Peniarth estate land, so these LCA types overlap. The Rhowniar country house and garden has maintained its visible character as it is used as a rentable holiday home, so this too is now part of the tourism industry in the Dysynni valley. The LCFs that characterise the Ornamental LCA are those associated with the previous estate, such as outbuildings, boat houses, cottages, and large estate houses.

Military

The Military LCA type refers to areas that maintain a character influenced by military activity, predominantly from the Second World War. There was significant military activity in the study area during the Second World War, the remnants of which are most evident along the coastline. The LCFs that characterise the Military LCA include practice trenches, rifle ranges, an RAF airfield, pillboxes, camps, and several air crash sites. There is significant overlap between the Military LCA and the Wetland and Beach and Maritime Industry LCAs, due to the line of pillboxes stretching along the beach from Tywyn (north) to Aberdyfi (south). Several air crash sites are recorded in coastal areas, however in most cases the records are documentary, and no known remains of the air crash site have been identified. Other air crash sites are located at higher altitude, of which there is greater preservation of remains. Second World War military remains represent a monumental time in this country's recent history, and retain immense cultural value for many people (Atkin 2003).

Wetland and Beach

This LCA includes the land and intertidal zone by the coastline and water courses that is comprised of sand, shingle, marsh, reeds or saltings. In the study area, the coastline to the south of the mouth of the Dysynni is fronted by a sand beach, while the coastline to the north is characterised by a predominantly shingle beach. The majority of Broadwater, once an estuary, is also characterised as the Wetland and Beach LCA type, as it has now silted up to form a saltwater lagoon, with sand exposed between low and high tide. A large area of the Dysynni valley was wetland prior to extensive drainage by local estates in the 18th-20th centuries, but the wetland is now confined to the coastline and small areas next to the River Dysynni. A submerged forest and peat bed are revealed beneath the sand in the foreshore of the mouth of the Afon Dyffryn-Gwyn at periods of extreme low tide and after storm conditions (RCAHMW 2014). It is thought that this peat bed may extend inland beneath the Penllyn marshes, south of Tywyn (*ibid*.). The preserved tree trunks and the preservation environment within the peat mean that this environment is valuable for research into the palaeoenvironment of the Dysynni valley, as well as for reconstructing past sea-level change. A similar submerged forest and peat bed 10km further south has revealed finds such as a Mesolithic antler tool, two flint tools, and a partial auroch skeleton, as well as a Neolithic heath (RCAHMW 2012b). It is likely that these two submerged forests and peat beds are associated, so there is a potential for similar finds to exist within the Tywyn submerged forest.

There are several areas of overlap between the Wetland and Beach and Maritime Industry LCAs, as many of the remnants of maritime industry (e.g. fish traps, wrecks, quays, and peat cuttings) are located along the shoreline. Several areas of Military LCA type are located on the beach, for instance the Second World War pillboxes extending southwards along the beach from Tywyn to Aberdyfi.

6.5 Results and discussion

The results of the Dysynni valley HLC are displayed cartographically in Figure 6.4, and figures of the location of each individual LCA can be found in Appendix 2. Around 58% of the study area is characterised as Rough Pasture, in particular in the upland areas. The steep slopes, thinner soils and inaccessibility of many of these areas means that they are unsuitable for anything other than extensive sheep grazing, although coniferous plantations (Modern Woodland) have been established in some upland areas. This is reflected in the high number of medieval and post-medieval LCFs in upland areas related to pastoral agriculture, such as troughs, sheep folds and pens. Most of the Ancient LCA is located in upland areas, however some areas near Bryncrug, Croes Faen and Castell y Bere are characterised by the cropmarks which indicate that the lowlands were in use prior to the medieval period. This may partly be because there is greater preservation of archaeological features in uplands, where land use is less intensive and there has been no urban development. Historic evidence indicates that there has been habitation at Tywyn in some form since the first millennium AD, but the evidence of this is less visible in the current fabric of the landscape.

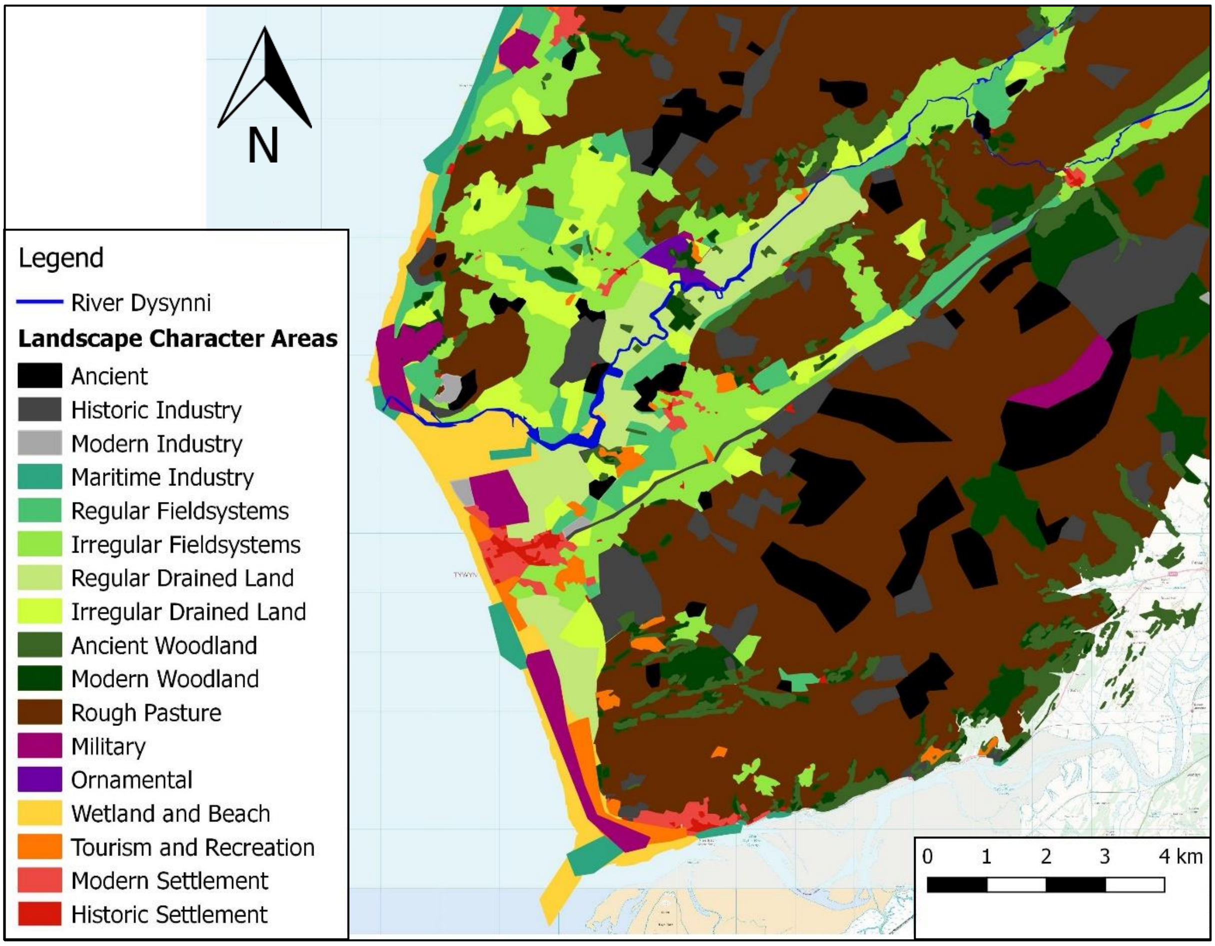


***Figure 6.4**. Completed Historic Landscape Characterisation for the Dysynni valley. Crown copyright and database right 2019 Ordnance Survey 100025252*

The Irregular Fieldsystems LCA is also mainly located in upland areas, although not on steep slopes or the highest elevations, and it is found in some lowland areas, for instance east of Bryncrug, above the 10m contour line. The morphology of these fieldsystems are indicative of enclosures that were developed in a piecemeal way, through a gradual process of land apportionment and sub-division, rather than as part of single events of planned enclosure. In contrast, the Regular Fieldsystems LCA is formed of regular enclosures that were planned over large areas, often on maps, and constructed in a single event. This suggests that irregular fieldsystems are likely to pre-date the more uniform Regular Fieldsystems LCA in the valley bottom. In some places, watercourses form or follow the irregular fieldsystem boundaries, indicating either that the fields were shaped thus to take advantage of the natural boundary of existing streams, or that small drainage efforts were undertaken by landowners or farmers on their individual fields.

Historic Industry is the final LCA predominantly found in upland and sloped areas in the Dysynni valley. This is characterised by extant quarry and mine workings dating mainly to the post-medieval period, and includes the Talyllyn railway line that extends from Tywyn to Abergynolwyn. Although currently sparsely inhabited and used, the wealth of archaeological evidence in the uplands indicates that much of its current form is a product of medieval and post-medieval land-use, with some elements dating to the prehistoric period.

In the lowland areas, the dominant LCAs are Regular Fieldsystems and Regular Drained Land, much of which overlaps as in many areas, field boundaries run alongside drainage ditches. The areas characterised as Regular Drained Land are also fieldsystems, and are mainly used for pastoral agriculture (although some are too waterlogged to use, see Wales Farmer 2017). The extensive, systematic drainage ditches that characterise Regular Drained Land can be identified as the product of the 18th and 19th century drainage programmes by the Peniarth and Ynysmaengwyn estates (see Chapter 4), as the uniformity indicates that they were part of one or two comprehensive projects, rather than piecemeal like the fieldsystems in the upland areas. Furthermore, the location of all regular (and therefore probably more modern) fieldsystems in the lowland areas indicates that this land is unlikely to have been cultivated prior to the establishment of the drainage system. This is corroborated by the historical records of the presence of marshland in the valley bottom before the land improvement schemes were undertaken.

Urban areas in the Dysynni valley are generally small, with the Historic Settlement LCA located in the centre, and Modern Settlement LCA situated on the fringes of current towns. Both Tywyn and Bryncrug are situated in the lowlands, but on ground 5-10m higher than the surrounding lowlands, protecting the majority of the properties from the flooding that frequently affects the floodplain.

The coastline of the Dysynni valley is predominantly characterised by three LCAs: Military, Maritime Industry and Wetland and Beach. Areas of the Military LCA were identified through the remnants of mainly Second World War activity, including a line of concrete pillboxes stretching over 3.5km between Penllyn and Aberdyfi. Although in various states of repair, with some displaying few signs of weathering while others are collapsed and laying as slabs upon the beach, the visibility of each pillbox from its neighbour and their proximity to a rifle range means that this area is significantly influenced by the military history of the landscape. Also important to the military character is the remains of the Morfa barracks, north of Tywyn, and that of an RAF base and airfield at Tonfanau. As this land is just used for extensive grazing, there are still earthworks associated with the RAF camp visible on aerial photographs, even though the buildings are no longer extant.

As suggested by its name, Maritime Industry LCAs are all found along the coastline, other than a small section on the south bank of the River Dysynni, before it reaches Broadwater, due to the presence of a small fishing weir and boathouse. At Aberdyfi, the Maritime Industry LCA manifests as structures such as the modern harbour, jetty, and wharf, while on the beach it is characterised by older and more ephemeral structures, predominantly the remains of fish traps and peat cuttings from the medieval and post-medieval period. This indicates that the industrial activity in the coastal area evolved from smaller-scale ventures to the maritime trade of goods with other regions as the extractive industries in the landscape developed.

The Ancient Woodland LCA is distributed in many small patches across the landscape, although most are on steep intermediate slopes rather than in the high uplands or in the lowlands. This suggests that these areas of ancient woodland remain because they are situated on land unsuitable for urban development, agriculture or forestry plantations.

Areas characterised by the Recreation and Tourism LCA are mainly caravan and mobile home parks, with some camp sites. The largest single area of this type is the Aberdyfi golf club, situated in the sand dunes west of Aberdyfi and also characterised as Wetland and Beach LCA. The majority of these parks developed during the 20th-21st century, and some in the grounds of historic estates, such as Peniarth and Ynysymaengwyn. This is indicative of a shift in the local economy from wealthy estates owning the majority of the land (and undertaking landscape-wide works), to the diversification of estates and adaptation to new industries, such as tourism. The land around these old estate houses still holds evidence of being a designed, ornamental landscape, such as dovecotes, gateposts, and outbuildings. These areas have also been characterised as Ornamental LCA.

On the whole, the upland areas of the Dysynni valley seem to be characterised by older, more structural remains of land-use and traditional economies. In contrast, the lowland areas are mainly characterised by regular, uniform field systems produced by large-scale, modern land improvement projects. However, geophysical surveys and the study of aerial photographs revealed that the land-use history of the Dysynni lowlands is much longer than immediately apparent from the historical records.

6.6 Conclusion

This chapter presented a HLC for the Dysynni valley, based on a range of sources such as historic and modern maps, as well as the results of the landscape analysis in Chapter 5. This created a holistic, spatially continuous representation of the historic landscape and the way that past and present human activity is evident in the features of the landscape. This research aims to transfer the focus of vulnerability studies in archaeology from individual sites (such as the HER and NMRW records), to the historic landscape as a whole. HLC provides a landscape-scale structure which represents the historicity of the landscape, and at which a vulnerability assessment can be targeted. This moves the focal level from individual sites to LCAs (see Hierarchy Theory, section 3.2.2), with the LCFs now informing the characterisation process.

Using the results of the multi-method landscape analysis in Chapter 5 for the landscape characterisation meant that the resulting HLC includes and represents a wide range of historical and archaeological elements that would not have been evident in modern and early Ordnance Survey maps alone. Representing the continuity of the landscape's cultural heritage, and the time-depth of different areas within the landscape through the HLC allows any further assessment to include the historic landscape as a whole, rather than just focusing on elements within it. Therefore, this HLC was created to be used as the focus of the vulnerability assessment in Chapter 6.

HLC is a methodology designed to be applicable to any landscape, and can be used on a range of spatial levels; the Cornwall County HLC covered over 3,500km^2, whereas the Dysynni valley HLC covers around 150km^2. While the same LCA-types can be used across different projects, to facilitate the comparison of different landscapes, it is also possible to create novel LCA-types for a landscape in order to more accurately represent the unique land-use patterns that have occurred there, based on the landscape analysis. This means that HLC methods can be tailored to best suit the landscape in question.

Some limitations of this approach to creating a landscape characterisation include potential inaccuracies in historic maps or the way that historic maps are georeferenced (Bender *et al.* 2005; (Domaas and Grau Møller 2009). However, taking a multi-method approach to landscape analysis (see Chapter 5) can help identify any inaccuracies in one of the methods, and make the results more reliable. Another limitation is that some suggest that HLC can over-simplify the complex, multi-faceted nature of the historic landscape (e.g. Williams 2006); in attempting to make the historic landscape understandable, the intricacies of it can be obscured (Herring 2009). By customising the LCA-types used to the landscape in question, some of the uniqueness of the landscape can still be represented. It could be argued that the current focus within vulnerability assessment and management on discrete sites does more to over-simplify and obscure the intricacies of the historic landscape than broadening the focus to LCAs. The purpose of HLC in this thesis is to move the focal level of vulnerability assessments and management from individual sites to the wider historic landscape. In doing so, it forces vulnerability assessments and historic landscape management to acknowledge the liminal spaces between 'sites', and recognise the historicity of all landscape features.

Chapter 7

Landscape-scale Vulnerability Framework

7.1 Introduction

This chapter addresses Research Aim 2: *develop a landscape-level archaeology vulnerability assessment methodology.* This is divided into three research objectives: 2a: *Determine the potential climatic changes in the study area in the 21st century based on the results of a variety of climate models*; 2b: *Develop a vulnerability index for measuring and quantifying the vulnerability of historic landscapes, informed by the strengths and limitations of other archaeology vulnerability assessments;* and 2c: *Apply the vulnerability assessment established in 2b to the Historic Landscape Characterisation output for the Dysynni valley (objective 1c), to identify any weaknesses in the methodology developed.* Chapter 7 details the development of a methodology for assessing the vulnerability of the historic landscape to climate change, which fits into the Landscape Vulnerability Framework.

In Chapter 6, a HLC was created for the Dysynni valley, as a way of classifying the historic landscape into definable areas (LCAs). The vulnerability assessment developed here, a vulnerability index (VI), was applied to the LCAs of the Dysynni valley, to demonstrate how the focus of vulnerability in archaeology can be moved from individual features, or groups of discrete sites, to the historic landscape as a continuous phenomenon.

After an overview of the concept of vulnerability, which underpins the way in which it is used and conceptualised in this thesis, a review of the VI methods used in archaeology evaluates the most common approaches, and their strengths and limitations. An overview of the climate change projections for the Dysynni valley is then presented, in order to identify the aspects of climate change that may pose the greatest threat to the historic landscape of the study area. A VI methodology is developed, informed by the review of methods and climate change projections. The methodology is then applied to the Dysynni valley, and this is followed by the results and an evaluation of the results and the methodology.

7.1.1 Vulnerability

There is no single definition of vulnerability, due to the widespread use of the term across many different disciplines in reference to a wide range of systems and phenomena (Barnett *et al.* 2008; Daire *et al.* 2012). The assessment of vulnerability is also subjective; an event is only perceived as a threat if the outcomes result in something that is considered to be damaging. For instance, erosion on an uninhabited island is thought of as a natural coastal process, whereas erosion of a populated coastline is considered a threat to which people and infrastructure may be vulnerable (McLaughlin *et al.* 2002; Barnett *et al.* 2008).

In general, however, vulnerability is considered to be the likelihood that a system or phenomenon will experience harm as a result of a hazard, whether a short-term event or long-term stress (Turner *et al.* 2003; Accardo *et al.* 2014). In socially-oriented research, vulnerability is seen as dynamic and a state of being, whereas studies focussing on biophysical vulnerability often consider it to be the outcome of the hazard impacts minus the resilience of the system (Adger 1999; Vincent 2004; Daly 2013; Nguyen *et al.* 2016). Many authors across disciplines see vulnerability as the function of three factors: exposure, sensitivity (or susceptibility) and adaptive capacity (or coping capacity or resilience) (e.g. Allison *et al.* 2009; Balica *et al.* 2009; Yusuf and Fransisco 2009; Balica and Wright 2010; Glick *et al.* 2011; Balica *et al.* 2012; Nguyen *et al.* 2016). Exposure is the likelihood that a system will be exposed to a threat as a result of its location. A coastal town has higher exposure, and therefore higher vulnerability, to storm surges compared to an inland town. Sensitivity (or susceptibility) is defined as the degree to which the exposed elements of a system are affected by the event or phenomena, which influences the probability of damage occurring to, or within, the system. For example, organic archaeological remains have higher sensitivity to desiccation and decay as a result of increasing temperatures, compared to stone remains. Adaptive capacity, also referred to as coping capacity or resilience, is the capacity of a system to respond to change, maintain its functions, and cope with the consequences. The adaptive capacity of a system can be influenced by institutional planning, technology such as warning systems, and defence infrastructure. A high level of vulnerability is the result of high exposure, high susceptibility and low adaptive capacity, while an increase in adaptive capacity or a decrease in exposure or susceptibility will reduce the overall vulnerability of a system.

7.2 Vulnerability Index Methods

VIs are created and used to assess the risk and potential damage to a particular site or system from an event or threat. In particular, the potential impacts of climate change have resulted in the creation of indices addressing the vulnerability of systems to the emerging environmental issues discussed in Chapter 2 , especially in coastal areas (e.g. Thieler and Hammar-Klose 2000; McLaughlin *et al.* 2002; Boruff *et al.* 2005; Boruff and Cutter 2007; Diez *et al.* 2007; Hegde and Reju 2007; Torresan *et al.* 2008; McLaughlin and Cooper 2010). This review summarises VIs that have been developed for archaeology and cultural heritage, focussing particularly on coastal areas. The aim is to inform the development of a VI specifically tailored towards historic landscapes and HLCs.

Following an explanation of what VIs are, and examples of their use in archaeology, this section reviews the most common approaches to vulnerability assessment within archaeological research. It identifies the different variables used as proxies in VI calculations, the range of threats considered by VIs, and the objects selected for VI assessments. In this context, the 'object' of the VI refers to the sites, monuments or areas whose vulnerability is being assessed. There is subsequently a review of the equations that have been used to calculate the vulnerability 'score'. Finally, there is a discussion of the limitations of using VIs both generally and for archaeology in particular.

The following review was limited to the use of VIs in archaeology – a total of 19 studies were identified. Although the search was not limited spatially, the majority of studies focus on coastal areas and principally on natural hazards, such as flooding and erosion. Those addressing solely anthropogenic threats such as urban expansion were not included in the study.

7.2.1 Vulnerability indices

VIs are a common method of vulnerability assessment. They are used to simplify complex and uncertain systems in order to estimate their vulnerability based on certain chosen indicators or variables (Barnett *et al.* 2008; Balica *et al.* 2012). A quantification of vulnerability using these indicators can allow an easier comparison between different entities, such as cities, coastlines, or archaeological sites. This simplification can also increase policy-makers' and decision-makers' understanding of both the system in question, and the impacts of different potential policy approaches (Balica and Wright 2009; Reeder *et al.* 2012; Nguyen *et al.* 2016). Furthermore, the results of vulnerability assessments identify the areas that are most at risk and the reasons for the higher vulnerability, which can help policy-makers, resource managers, and aid organisations target their resources more efficiently (Boruff and Cutter 2007; Glick *et al.* 2011; Daly 2013). For this research, an indicator approach was chosen as the vulnerability assessment method for several reasons. Indices allow different types of data (e.g. qualitative and quantitative) to be combined into a single score, while remaining transparent regarding the scores for each indicator (Sullivan and Meign 2005; Perch-Nielsen 2010). This allows for easy comparison between areas or objects that are being assessed. Furthermore, a range of information can be included within an index, such as different characteristics of the threat, and the susceptibility, exposure and adaptive capacity of the object (Perch-Nielsen 2010; Papathoma-Köhle *et al.* 2017).

Vulnerability matrices are another vulnerability assessment approach in which the interaction between different elements of the threat and different elements of the object are quantified. These also allow a range of indicators and data types to be included. The structure of vulnerability matrices clearly displays the relationship between the processes and consequences in question (Papathoma-

Köhle *et al.* 2017; see Berry *et al.* 2019). However, matrices do not produce a single score that can be compared across the objects of the study, so they are less useful for ranking overall vulnerability and prioritising management compared to indices (Papathoma-Köhle *et al.* 2017). Finally, indices are the most popular vulnerability assessment method used in both archaeology and climate change studies. This provides a much larger source of material to consult for developing a VI for this Landscape Vulnerability Framework.

The indicators chosen can be selected using deductive, inductive or normative approaches (Nguyen *et al.* 2016). Deductive approaches are theory-driven, and are based on scientific knowledge about variables that are relevant for indicating vulnerability. Data-driven, inductive approaches use information on statistical relationships between indicators and observed outcomes of hazard events. Normative approaches are those based on expert opinion on the best variables to use for calculating vulnerability. The majority of VIs use a combination of the three approaches, taking into account the impact of previous hazards as well as theoretical and expert knowledge (*ibid*.). Glick *et al.* (2011) argue that there is no single correct approach to VIs, as the necessary approach depends on the focus of the vulnerability assessment, and what the VI will be used for. This, and the difficulties faced when attempting to simplify such complex systems, means that there have been hundreds of attempts to create VIs (Barnett *et al.* 2008). For example, different VIs have been created for assessing the vulnerability of several coastlines at a range of spatial levels, for instance in Northern Ireland, USA, the Caribbean, Buenos Aires, and Mangalore (McLaughlin *et al.* 2002; Boruff *et al.* 2005; Boruff and Cutter 2007; Diez *et al.* 2007; Hegde and Reju 2007; Yusuf and Francisco 2009; McLaughlin and Cooper 2010). It is worth noting that these studies do not incorporate predictions of climate change, but instead only assess the threat posed by present conditions such as wave height and storm-surge frequency. Only a minority of the VI studies identified consider future scenarios under climate change (e.g. Torresan *et al.* 2008). Yusuf and Francisco (2009) argue that, as there is uncertainty surrounding future climatic conditions, the results of a VI based on projected climate would be less reliable than one using only present conditions. This does not account for the fact that VIs based on present conditions will become less accurate in the near future as climate change alters precipitation, temperature and coastal processes.

7.2.2 Vulnerability indices in archaeology

Several studies have used VIs to research the vulnerability of archaeological and historical sites in changing coastal environments. They can take into account not only the general vulnerability of the study area, but also the characteristics of the cultural heritage resource itself which may increase or decrease the sensitivity of the site. The following section reviews the ways in which VIs have been developed and utilised for coastal cultural heritage.

VIs have been developed for archaeological and historical sites in many locations worldwide, including the Santa Barbara Channel (California), France, Skellig Michael (Ireland), Newfoundland, Northern Ireland, and Chesapeake Bay (USA). The spatial extent and resolution of these studies varies depending on the length of the coastline in question and the resources available to the study. Many VI research projects were desk-based, which allowed a wider geographical area to be included in the study and reduced the time required to undertake the assessment (e.g. Reeder-Myers *et al.* 2010; Westley *et al.* 2011; Daire *et al.* 2012; Reeder *et al.* 2012; Chadwick-Moore 2014). In contrast, very few involved detailed examination of individual sites and the characteristics that would influence vulnerability (e.g. Daly 2013). This may be because one of the purposes of VIs is to speed up the process of identifying vulnerability, so undertaking site visits would be counterproductive to this aim.

The threats addressed also vary between studies, with some incorporating both natural and anthropogenic threats (e.g. Daire *et al.* 2012; Reeder *et al.* 2012; Van Rensselaer 2014), while others only measure the vulnerability of sites to natural hazards like erosion (e.g. Nageswara Rao *et al.* 2008; Westley *et al.* 2011; Reeder *et al.* 2012; Reeder-Myers 2015). Certain studies aimed to calculate the *relative* vulnerability of sites within the study area, and therefore left out variables that threatened all sites equally, such as mean wave height or tidal range (e.g. Reeder *et al.* 2012). This facilitated the comparison of vulnerability between sites within the study area, but reduced the possibility of comparing the results of this study with the vulnerability of another location, as differences in mean wave height and tidal range would not be included. In contrast, the ShoreUPDATE survey in Scotland aimed to assess the relative vulnerability of sites at a national level rather than in individual areas, so that sites could be prioritised for management for the whole of Scotland (Hambly 2017).

Many studies create risk maps rather than a full index, for example by using GIS to overlay maps of erosion and flood risk with a map of the cultural heritage sites to identify the locations with high or medium risk (e.g. Robinson *et al.* 2010; Westley *et al.* 2011; Westley and McNeary 2014). This review focuses on the methods that develop or use a full VI, as it is a more thorough and reliable approach.

Variables included

Most VI projects have been desk-based, allowing a wider geographical area to be included in the study and reducing the time required to undertake the assessments. Only a few projects involved the detailed, field-based examination of the vulnerability of individual sites (e.g. Daly 2013). This may be because one purpose of VIs is to act as a replicable and efficient management tool. As a result, most VIs only considered characteristics that could be assessed remotely and across large areas, for instance topographic slope angles, rates of relative sea-level rise, and tidal ranges of the nearest coastlines (e.g. Pendleton *et al.* 2005; Westley *et al.* 2011; Reeder *et al.* 2012; Reeder-Myers *et al.* 2015; Chadwick-Moore 2014; Van Rensselaer 2014; Westley and McNeary 2014; Rockman *et al.* 2016). Only a few VIs considered the characteristics of the archaeological sites themselves, including the materials from which sites are constructed and current levels of preservation (e.g. Daire *et al.* 2012; Daly 2013; Robinson *et al.* 2010). Daly (2013), in a study limited to two World Heritage sites, considered a wide variety of characteristics that could influence the vulnerability of each site, including the structural damage from visitors, the vegetation cover, and numbers of animal burrows.

The spatial extent and number of sites included in a study influences the resolution of the assessment. However, studies solely considering the threats determined by sites' locations only address the exposure element of vulnerability, and neglect the sensitivity and resilience of the site to threats. For instance, a vulnerability model for Bering Land Bridge National Preserve created by the US National Park Service, was based only on a coastal erosion model and local climate change projections, and included no information on site resilience or susceptibility (Devenport and Hays 2015; Rockman *et al.* 2016). An archaeological site may be buried and well preserved, or constructed of durable materials, and therefore have greater resilience to any threat than a site in the same location that is exposed and susceptible to damage (Daire *et al.* 2012).

Although the studies considered vulnerability across a range of scales, none acknowledged that spatial scale and the resolution of the data can influence the variables included in the VIs. This is an important consideration, partly because some datasets are only available for specific areas or resolutions (Torresan *et al.* 2008). McLaughlin and Cooper (2010) argue that some variables are scale-sensitive, while others are important regardless of the spatial extent or resolution of the study. They suggest that geology is a scale-sensitive variable, as at a regional level there may be different types of bedrock, but at a local level the geological variation is likely to be negligible. McLaughlin and Cooper's (2010) approach is valid when calculating relative vulnerability, which is limited to the comparison of vulnerability between sites within a study area (see Pendleton *et al.* 2005; Westley *et al.* 2011; Reeder *et al.* 2012). However, relative VIs reduce the potential for inter-regional comparison. Therefore, geological variation is still an important consideration if the aim is to generate results that can be compared to results from a different study area.

Threats

The threats considered within VIs vary between studies, with some incorporating both natural and anthropogenic processes (e.g. Daire *et al.* 2012; Reeder *et al.* 2012; Van Rensselaer 2014), while others only measure the vulnerability of sites to natural hazards (e.g.; Westley *et al.* 2011; Reeder-Myers 2015). Despite the importance of climate change as an emerging threat, few studies explicitly included the threat of climate change or its effects. Van Rensselaer (2014) mentions climate change and includes specific sea-level rise projections in his calculation of vulnerability. Consideration of changes to temperature, precipitation patterns and wind were included in Daly's (2013) vulnerability assessment of Skellig Michael and Brú na Bóinne (see also Grossi *et al.* 2007; Westley *et al.* 2011; Chadwick-Moore 2014). In contrast, while acknowledging that climate change may increase the vulnerability of archaeological and heritage sites, several studies only based the VI on historic or observed rates of erosion or sea-level rise, rather than projected future change (e.g. Daire *et al.* 2012; Reeder *et al.* 2012; Westley and McNeary 2014; Reeder-Myers *et al.* 2015). Several studies did not even acknowledge the impact that climate change is likely to have on the threats posed to archaeological heritage (e.g. Accardo *et al.* 2003; Fitzpatrick *et al.* 2013; Minos-Minopolous 2015).

Objects

The majority of the studies focus specifically on archaeological 'sites'. Reeder *et al.* (2012, p.189) define archaeological sites in their study as encompassing features from "large villages and workshops to fragmented shell middens and lithic scatters", while Daire *et al.* (2012, p.175) state that their research looks at sites comprising "all remains of built structures of anthropogenic origin or materials transformed by human activities." Three studies (Robinson *et al.* 2010; Chadwick-Moore 2014; Westley and McNeary 2014) only define sites as the records included in archaeological databases. All other studies provided no definition for archaeological 'site', despite this being the focal level of their VIs (e.g. Fitzpatrick *et al.* 2006; Westley *et al.* 2011; Chadwick-Moore 2014; Van Rensslelaer 2014; Reeder-Myers 2015). Therefore, there is evidently no single agreed meaning for 'site' as the object of archaeology vulnerability assessments. There have been important debates within archaeology over what constitutes a 'site' and how it may be delineated from the surrounding landscape. Often, the term 'site' is used to refer to a concentration of evidence of human activity, such as monuments, shipwrecks, or large clusters of artefacts, but it is not used for single find-spots (Dunnell 1992). Dunnell (1992, p.29) argues that 'sites' are "not really things or qualities, but rather concentrations or quantities." Using this argument, the archaeological record could be seen not as a collection of individual sites, but as a more or less concentrated distribution of evidence of human activity across the Earth's surface (Dunnell and Dancey 1983). This raises questions about how 'sites', as concentrations of evidence of activity, can be assessed in isolation from the surrounding landscape in which human activity also took place (Cooney 2003). The results of these studies can only indicate which 'sites' or archaeological features are at more or less risk of damage from a certain threat. They cannot provide information on how the historic character of the landscape may be affected by impacts of climate change. Furthermore, only known, recorded sites can be included in vulnerability assessments. This excludes features in areas that have not yet been systematically surveyed or where archaeological material is masked by overlying sediments.

Equations

VIs are calculated with equations that incorporate the scores given to each of the indicators. A commonality between studies using VIs is that they give each of the variables a score on the same scale, for instance between 1 and 5 or 0 and 1 (e.g. Thieler and Hammar-Klose 2000; Torresan *et al.* 2008; Balica *et al.* 2009; Daire *et al.* 2012; Chadwick-Moore 2014; Daly 2013; Reeder-Myers 2015; Nguyen *et al.* 2002). Using the same scale allows quantitative and qualitative indicators such as the distance to coastline and geomorphology to be compared more easily and combined into a single vulnerability score (McLaughlin and Cooper 2010; Reeder *et al.* 2012). It is also important to note that the relationship between a variable and vulnerability may not be linear; Reeder *et al.* (2012) note that vulnerability decreases exponentially as distance from the coastline increases. This is exemplified by the fact that there is a greater difference in the vulnerability of sites 1m and 100m from the shore than sites 1000m and 1100m from the shore. Therefore, the value represented by each score given to an indicator may not increase linearly.

There are two main approaches used to calculate the overall VI score: unweighted indicators and weighted indicators.

Unweighted Indicators

The equation most commonly employed in unweighted VIs is:

$$VI = \sqrt{\frac{a \times b \times c \times d \times e}{n}}$$

n being the number of indicators included, in this case five (*a*-*e*) (see Thieler and Hammar-Klose 2000; Pendleton *et al.* 2005; Alexandrakis *et al.* 2010; Van Rensselaer 2014). This calculates the square root of the geometric mean, which is used when comparing different items or systems when each item has multiple properties that are measured on different numerical scales, as it normalises the values on different scales. This type of equation can provide a useful way to compare the vulnerability of archaeological sites where the level of protection is measured between 0 and 5 but the exposure to flooding is measured between 1 and 10, for example. If the arithmetic mean was used, the exposure to flooding variable would be given relatively greater weighting than the level of protection variable (Transaction Processing Performance Council 2019)

Chadwick-Moore (2014) uses a simpler approach: they use three indicators and rank each between 0 and 3. The sum of these was the overall vulnerability score (between 0 and 9). Using the score given to each indicator without weighting some as more important than others has the benefit of being straightforward, so different variables could be included or removed easily (Reeder *et al.* 2012). However, there is a risk that the results of this approach could be skewed by a variable that is of lower relative importance, while the influence of others may be underrepresented (McLaughlin *et al.* 2002). Vulnerability scores calculated using an unweighted index by Diez *et al.* (2007) for two coastal areas near Buenos Aires differ dramatically despite the areas having very similar geomorphology and sea-level rise. The authors suggest that the index used was too sensitive to changes in individual indicators, in this case mean wave height, which may have been avoided through weighting.

Weighted Indicators

Some studies aim to more accurately represent the relative importance of some indicators over others by weighting them differently when calculating the VI score. Nageswara Rao *et al.* (2008) use the following equation:

$$VI = 4g + 4s + 2c + t + w$$

(*g* = geomorphology, *s* = coastal slope, *c* = historic shoreline change, *t* =spring tidal range, and *w* = significant wave height)

The weightings indicate that the researchers consider geomorphology and slope to be the most important, followed by the historic rate of shoreline change, with tidal range and wave height as the least important indicators of vulnerability (see also Diez *et al.* 2007; Ortiz *et al.* 2014).

Weighting different variables allows those with a greater influence to be taken into account, to prevent their impact from being under-represented (Reeder *et al.* 2012). Although Daire *et al.* (2012) use unweighted indicators in their research, they suggest that a good approach may be to weight certain variables differently based on the specific study area. For example, in areas with higher rates of coastal retreat, the 'distance to coast' variable should be weighted more highly than in areas with little erosion. Many studies avoid using weighting methods due to a lack of knowledge about which indicators should be weighted above others, and by how much. While it is thought that weighted variables can make the VI more accurate, the judgements about which indicators to weight above others are subjective and may be based on incomplete data, and therefore do not necessarily increase the reliability of the VI score (Daly 2013; Nguyen *et al.* 2016).

While the studies already discussed in this section use only one equation to calculate the VI score, others use more than one. Reeder-Myers (2015) developed the following equation to calculate the vulnerability of the shoreline (1), and a second equation (2) that calculates the vulnerability of the archaeological site using the result of (1) as well as other indicators.

(1): $Shoreline\ Vulnerability = \frac{4(u+v+w)+3(x)+2(y+z)}{6}$

(*u* = geomorphology, *v* = historic sea-level rise, *w* = coastal slope, *x* = historic erosion rates, *y* = wave height, *z* = tidal range)

(2): $Site\ Vulnerability = \frac{2(a+b)+3(c)+2(d)}{3}$

(*a* = distance to the shoreline, *b* = elevation, *c* = shoreline vulnerability (Equation 1), *d* = land-use)

A similar approach was taken by Reeder *et al.* (2012). The benefit of using two equations is that it simplifies the equation needed to calculate the vulnerability of each archaeological site, as the vulnerability of the shoreline can be worked out for a larger area.

Balica *et al.* (2012) also use more than one equation to calculate the overall VI. They calculate separate hydrogeological, social, economic and politico-administrative VIs based on separate indicators, and use the sum of these as the total VI score (see also Minos-Minopolous 2015). This approach could use either unweighted indicators (see Balica *et al.* 2012) or weighted indicators (see Minos-Monipolous 2015), but benefits from the fact that comparisons can be made between the types of vulnerability experienced in different areas, rather than only an overall score. This can reveal differences in the driving forces of vulnerability at different locations, and facilitate an understanding of the most suitable management approaches (see also McLaughlin *et al.* 2002; Grossi *et al.* 2007).

Some authors investigate the data further by generating a vulnerability ‘percentage’, rather than just using the raw vulnerability score produced by their VI equation. For example, McLaughlin *et al.* (2002) and McLaughlin and Cooper (2010) normalised the results of their VIs using the following equation:

$$Vulnerability\ (\%) = \frac{VI\ score - minimum\ possible\ score}{maximum\ possible\ score - minimum\ possible\ score} \times 100$$

Using this equation, in the study by McLaughlin and Cooper (2010), seven variables were ranked between 1 and 5, so the possible scores for the VI range from 7 to 35. If a site scored 15 on its VI, the vulnerability percentage would be:

$$\frac{15-7}{35-7} \times 100 = \frac{8}{28} \times 100 = 28.6\%$$

Normalisation of the results makes it easier to merge the results of indices, for instance in studies that combine several indices into an overall score. Within the studies reviewed this is an uncommon approach, with most using the raw value obtained from the VI as the vulnerability score.

Limitations

There are some limitations to the use of VIs for archaeology. Firstly, desk-based VIs are often used to increase the speed at which the vulnerability of sites can be assessed. Westley *et al.* (2011) argue that this may neglect crucial aspects of certain sites that render them more or less vulnerable than the chosen variables suggest. Therefore, they suggest that site-specific assessment should also take place as part of the VI.

Another limitation is that some VIs use variables that have the potential to change in the near future, such as the proximity to development or the visitor numbers (e.g. Minos-Minopoulos 2015). Although this acknowledges the dynamic nature of vulnerability, it means that the results for a particular area are only accurate in the short-term. The approach taken in this thesis incorporates threats that are changing, for instance sea-level rise and flood risk, which are projected to increase in the future. The vulnerability of areas in this thesis is based on the projected sea-level rise and flood risk for 2100, rather than the present conditions. This takes a longer time-frame into account, which is useful for informing proactive, rather than reactive, adaptation. It is acknowledged, however, that projections for future climate and weather conditions may change in the future if new knowledge or modelling techniques are developed.

A wide variety of methods and variables are used across VIs in archaeology and other disciplines. The inclusion of different indicators of vulnerability in different studies makes it difficult to compare the vulnerability of sites between studies. This means that the vulnerability of the subject matter is only calculated in relative terms within the scope of each study. This is difficult to resolve, as different conditions and forcing factors exist in each study area, so making a VI that was applicable to all areas would either be too detailed to be of any practical use or too general to generate meaningful results.

VIs can be a useful tool for informing stakeholders about the vulnerability of different areas or sites, as the results they produce are simple and clear, facilitating comparisons between phenomena. However, the quantitative appearance of the VI score can hide important qualitative judgements introduced by the researchers. Firstly, the way that vulnerability itself is defined involves value judgements, as it is based on cultural perceptions of what constitutes ‘damage’, and how much damage is acceptable (McLaughlin *et al.* 2002; Barnett *et al.* 2008). Decisions regarding what indicators should be included or omitted, and how each should be weighted (or not) are also implicitly subjective, even when made by experts (Vincent 2004; Nguyen *et al.* 2016). This is obscured by the transformation of these value judgements and decisions into quantitative data, which may lead to indices being treated as neutral 'fact' rather than indicators based on human values. Subjectivity is not necessarily negative, but it is important to understand the transformation of data from qualitative to quantitative through the creation of indices, and to take a critical approach to the data produced. It is also important to note that this subjectivity is not necessarily an insurmountable limitation of VIs; as long as it is understood that a VI is "a numerical expression of multiple subjective judgements" rather than an empirical measure (Barnett *et al.* 2008, p. 113).

Finally, the focal level of all studies reviewed was the 'site', whether or not that was defined within the study. This causes several issues, which are discussed in 7.2.5, such as a lack of coverage in areas that have not been systematically surveyed, a lack of clarity about what constitutes the 'sites' included, and a lack of recognition of the historicity of the landscape as a whole. The scale of archaeological research and investigation influences the scale of archaeological management. However, there is currently a mismatch between the scale of the impacts of climate change, and the scale at which archaeological management is undertaken. For example, coastal erosion around the UK is increasing as a result of climate change. Archaeological research and management of erosion risk is most commonly directed at individual sites. Even when research covers a stretch of coastline, the focal level is still on the individual archaeological sites along that coastline, rather than the historic coastal landscape (e.g. Daire *et al.* 2012; Reeder *et al.* 2012; Chadwick-Moore 2014; Van Rensselaer 2014; Westley and McNeary 2014). There are several limitations with managing discrete archaeological sites in the face of climate change. This approach makes it difficult to appreciate sites in their contexts and in their relationships with other sites and the surrounding landscape. It implicitly assumes that archaeological data are confined to discontinuous spaces within a landscape and obscures the historical-cultural importance of the landscape as a whole (Turner 2006; Bender 2009a). The whole landscape can include the intangible values held by people, such as connections with local heritage, the maintenance of traditional land-use practices, and senses of place.

To address this limitation, the VI that was created for this project used the LCAs as the focal level, rather than looking exclusively at sites or features within the landscape. This is a novel approach to vulnerability assessment within archaeology, and addresses the issue of the historic landscape being excluded from other VIs. The results of the landscape-scale VI create a continuous map of vulnerability for the study area, rather than only measuring the vulnerability of discrete points within the historic landscape.

7.2.3 Summary

As shown by this review, there are many ways in which VIs have been developed and used with regard to coastal archaeology, among other subjects. The approaches taken, and the results they produce, are influenced by many factors including the spatial extent and resolution of the study, the available datasets, and the threats under examination (Nguyen *et al.* 2016). It is important to acknowledge that these choices can influence the use of the VI. Both Barnett *et al.* (2008) and Torresan *et al.* (2008) argue that VIs should be addressing issues at a high-resolution and smaller spatial scale, as the more general results of broad-brush studies are not meaningful for informing management decisions. However, vulnerability is influenced by processes and systems that operate at a wide range of spatial and temporal levels, so it may be prudent to consider more than one observational scale within vulnerability assessments (Turner *et al.* 2003). The information gathered during this literature review was used to inform the development of a VI that focuses on the historic landscape (see 7.4)

7.3 Climate Change Projections for the Dysynni Valley

This section provides an overview of the various climate change projections that have been made for the study area. The main sources of data used are the UKCP18 projections (Met Office 2018) and the IPCC AR5 projections (Church *et al.* 2013; Collins *et al.* 2013; Kirtman *et al.* 2013), as they are the most highly regarded climate modelling projects, although other sources are also included. Projections vary between sources because different studies use different climate model ensembles with varying geographical resolution. The climatic changes that are included in this review are limited to temperature change, sea-level change, and precipitation change, as these three factors will drive the majority of the projected meteorological changes, such as increased storminess, drought, and flooding. The results of this review were used to determine the climate projection values that were used in this thesis for the development and application of a VI to the Dysynni valley.

As climate model projections produce a range of results, this thesis mainly focuses on the ‘central estimate’, which is the value at the 50th percentile, or the value which has a 50% chance of being exceeded, and a 50% chance of not being met (UK Climate Projections 2014b).

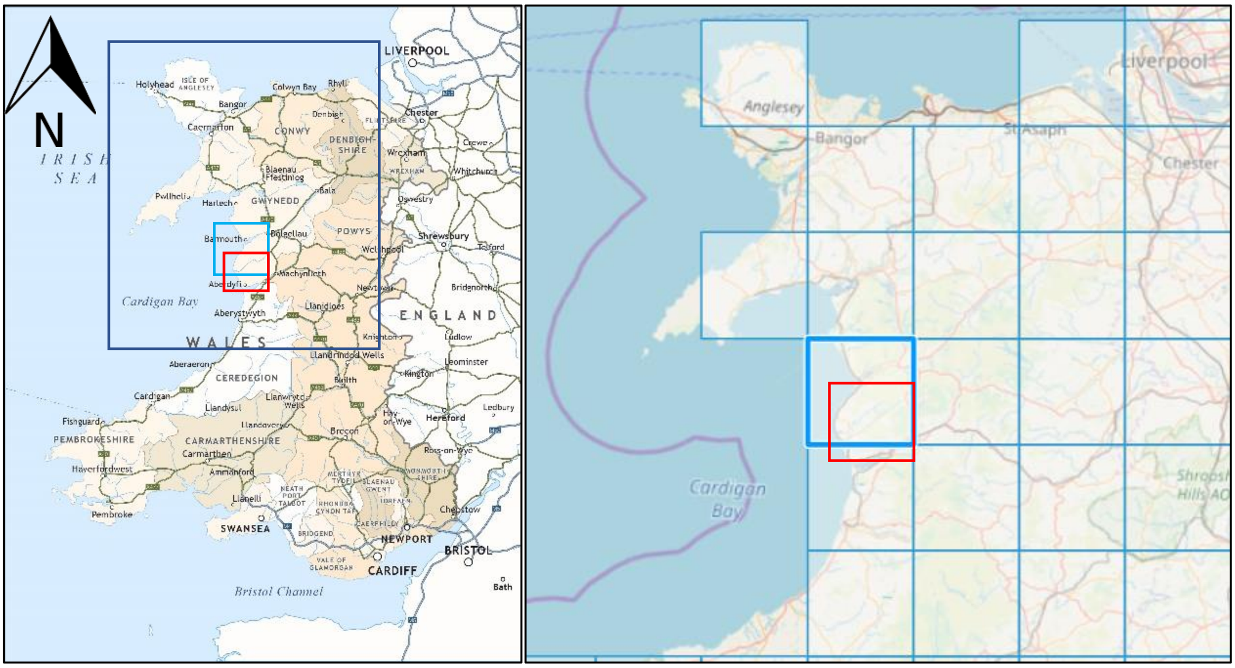


Figure 7.1. *The blue square indicates the location of grid reference 262500, 312500, the area included in the UKCP18 temperature change projections. The area covers the majority of the Dysynni valley study area (red square). Copyright Maproom 2019 (left) Copyright Met Office 2019 (right).*

7.3.1 Variable 1: Temperature Change

Temperature change projections indicate that the impacts of climate change are likely to vary seasonally. Although temperature is projected to increase annually, the rate of increase is higher in the summer than in winter (see Table 7.1). This could result in an increase in the magnitude and frequency of heatwaves (Jones *et al.* 2010). UKCP18 seasonal air temperature anomaly projections for RCP6.0 and RCP8.5 for grid reference 262500, 312500 (Figure 7.1) are synthesised in Figure 7.2 (Met Office 2018). These indicate that, for the Dysynni valley area, the mean winter temperature is projected to increase between 2 - 4°C by the end of the 21st century, and the mean summer temperature is projected to increase around 4 - 6 °C, depending on the emission pathway. It is noteworthy that even under a moderate emissions scenario, temperature is projected to exceed the 1.5°C target defined by the United Nations Framework Convention on Climate Change (UNFCCC) in the Paris COP21 Agreement (UNFCCC 2016) (see Figures 7.2 and 7.3).

Figure 7.2. *UKCP18 temperature anomaly projections for summer (A) and winter (B) for 2000-2100 using a baseline of 1981-2000, for the grid reference outlined in Figure 7.1. Each graph includes RCP6.0 and RCP8.5 scenarios, and the upper (95th percentile) and lower (5th percentile) bounds of likely projections, as well as the central estimate (50th percentile). Data downloaded from the UKCP18 user interface.*

Table 7.1: *Temperature Change Projections for the 21st Century*

Category	Scenario	Temperature change (central estimate °C)	Time frame	Baseline	Region	Source
Mean winter air temperature anomaly	RCP6.0 (moderate)	+2.7	2080-99	1961-1990	West coast of Wales	UKCP18 Met Office 2018
	RCP8.5 (high)	+3.8				
Mean summer air temperature anomaly	RCP6.0	+4.9	2080-99	1981-2000	West coast of Wales	UKCP18 Met Office 2018
	RCP8.5	+6.2				
Mean annual air temperature anomaly	RCP8.5	+3.4 - 6.2	2081-2100	1986-2005	Global land mass	IPCC AR5 WG1: Collins *et al*. 2013
	RCP6.0	+1.8-4.1				
	SRES A1B, but with a radiative forcing target of 2.9Wm^{-2} in 2100. RCP2.6, a low-emission scenario)	+2-3	2070-2099	1961-1990	UK	ENSEMBLES Royer *et al*.2009

7.3.2 Variable 2: Sea-Level Rise

Table 7.2 summarises the wide range of sea-level rise projections that have been generated by different models. Such a variety of projections makes using this information in decision-making difficult, for instance when designing coastal defences. The H++ scenario in Table 7.2 refers to an extreme but physically plausible potential scenario developed for the UKCP09 and UKCP18 projections, in which ice-sheets melt more quickly than initially expected (Jenkins *et al.* 2009; Humphrey *et al.* 2017). The aim of this scenario was to provide information on potential extreme cases for those involved in contingency planning (*ibid*.). However, rates of melting in Greenland and Antarctica have increased recently, leading to an acceleration of global sea-level rise (Weeman and Lynch 2018). Across the more 'usual' climate scenarios, the projected relative sea-level rise ranges from +0.48m to +0.905m, and the likely range of sea-level rise for the study area according to the UKCP18 RCP8.5 projections is between +0.625m and +0.785m (see Figure 7.3). The Environment

Agency (2017) states that coastal flood risk assessments should allow for a sea-level rise of 0.99 - 1.14m by 2115, depending on location.

Table 7.2: *Projected Change in Relative Sea Level*

Projected change (Central estimate m)	Scenario	Time frame	Baseline	Region	Source
+0.93-1.9 (likely limit)	H++	2100	1961-1990	UK	UKCP09 (Lowe *et al*. 2009)
+0.83	RCP8.5	2115	1981-2000	Dyfi Estuary	UKCP18 (Met Office 2018)
+0.905	SRES A1F1 (high)	2095	1990	South UK	Defra (Lowe *et al*. 2009)
+0.547	RCP4.5 (low-moderate)	2115	1981-2000	Dyfi Estuary	UKCP18 (Met Office 2018)
+0.4-0.82	RCP8.5	2100	1971-2010	Global	IPCC AR5 (Church *et al*. 2013)
+0.99	Climate change allowances for flood defences	2115	1990	North West UK	(Environment Agency 2017)
+1.14				South West UK	

As well as an increase in relative sea level, UKCP18 projections indicate that extreme high-water levels will increase faster than the rate of sea-level rise (See Figure 7.4). In Abersoch (on the Llŷn peninsula) in 2017, a 1-in-1000 year extreme high water level was +4.13m aOD, but the UKCP18 projects a 1-in-1000 year extreme high water level of +5.266m aOD for Barmouth (four miles north of the study area) in 2100, an increase of +1.136m (see Figure 7.4) (NRW 2015b; Met Office 2018). This is significantly greater than the projected rate of sea-level rise. As a result, coastal defences designed to protect against water levels of a certain return period will no longer protect against events of that magnitude, even if defences are enhanced in line with the rate of sea-level rise. Assuming a 2°C temperature rise, the Committee on Climate Change project that on the mid-west coast of England and Wales, vertical sea walls with a standard of protection (SoP) of 1-in-200 year event will have a SoP of 1-in-17 years by the 2080s (See Table 7.3; Sayers *et al.* 2015). Therefore, coastal defences in many areas are likely to become obsolete in the coming century.

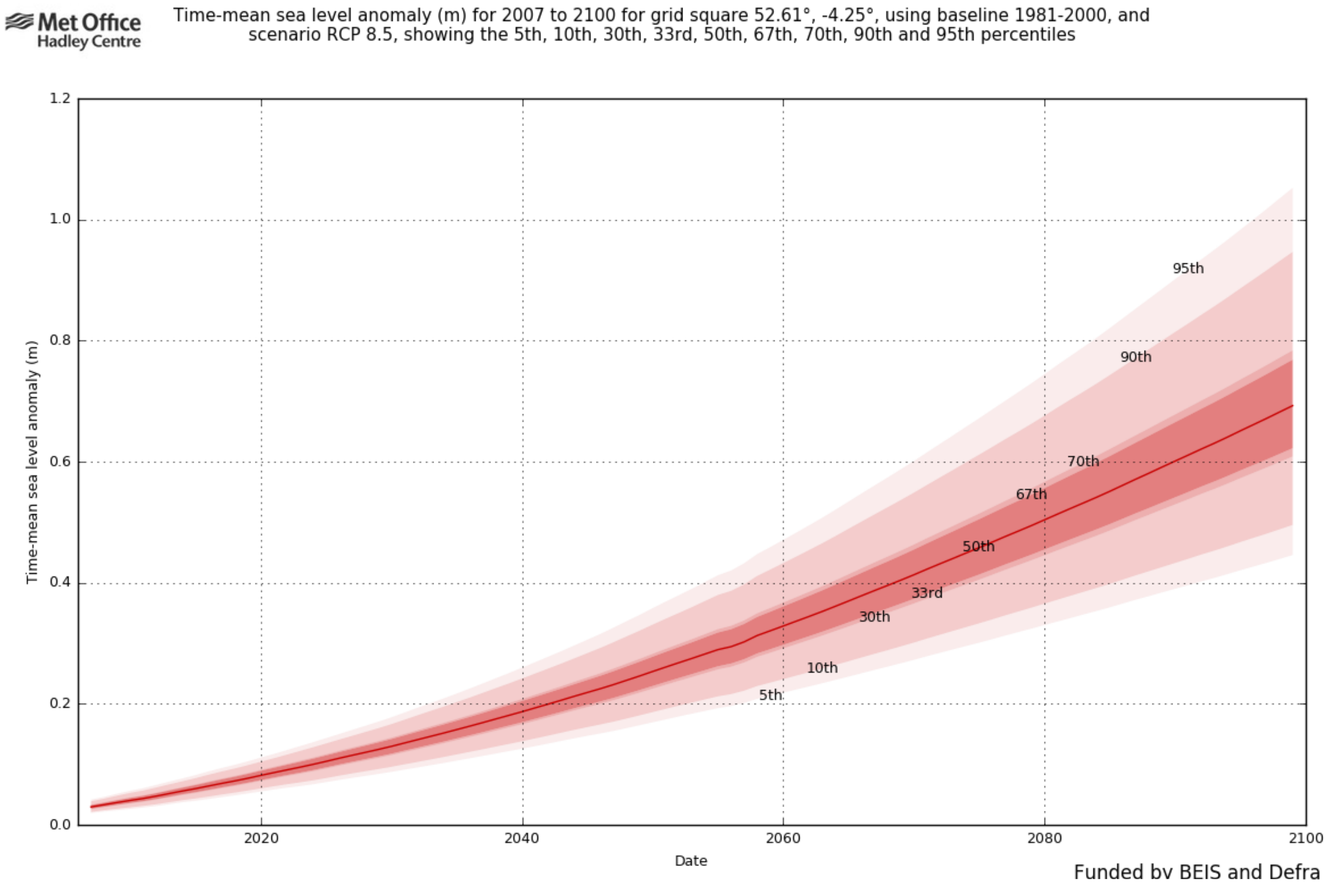


Figure 7.3. *UKCP18 sea-level anomaly projection for RCP8.5 for the Dysynni coastline for 2007-2100 based on a 1981-2000 baseline. Graph downloaded from the UKCP18 user interface.*

Table 7.3: *Changes in the standard of protection of coastal defences by 2080s assuming a 2°C temperature rise (adapted from The Committee on Climate Change: Sayers et al. 2015)*

Location	**East coast**	**South-east**	**South-west**	**Mid-west**	**North-west**
Present day SoP	Future SoP				
Coastal defence type: **Vertical Wall**					
10	3	4	3	3	3
50	13	4	23	3	16
100	20	8	61	5	32
200	53	20	153	17	48
Coastal defence type: **Embankment**					
10	4	4	3	3	3
50	13	4	23	9	16
100	33	6	61	17	32
200	93	10	123	26	96
Coastal defence type: **Shingle Beach**					
10	4	4	3	3	3
50	13	4	23	9	16
100	40	6	61	26	32
200	106	10	123	34	80

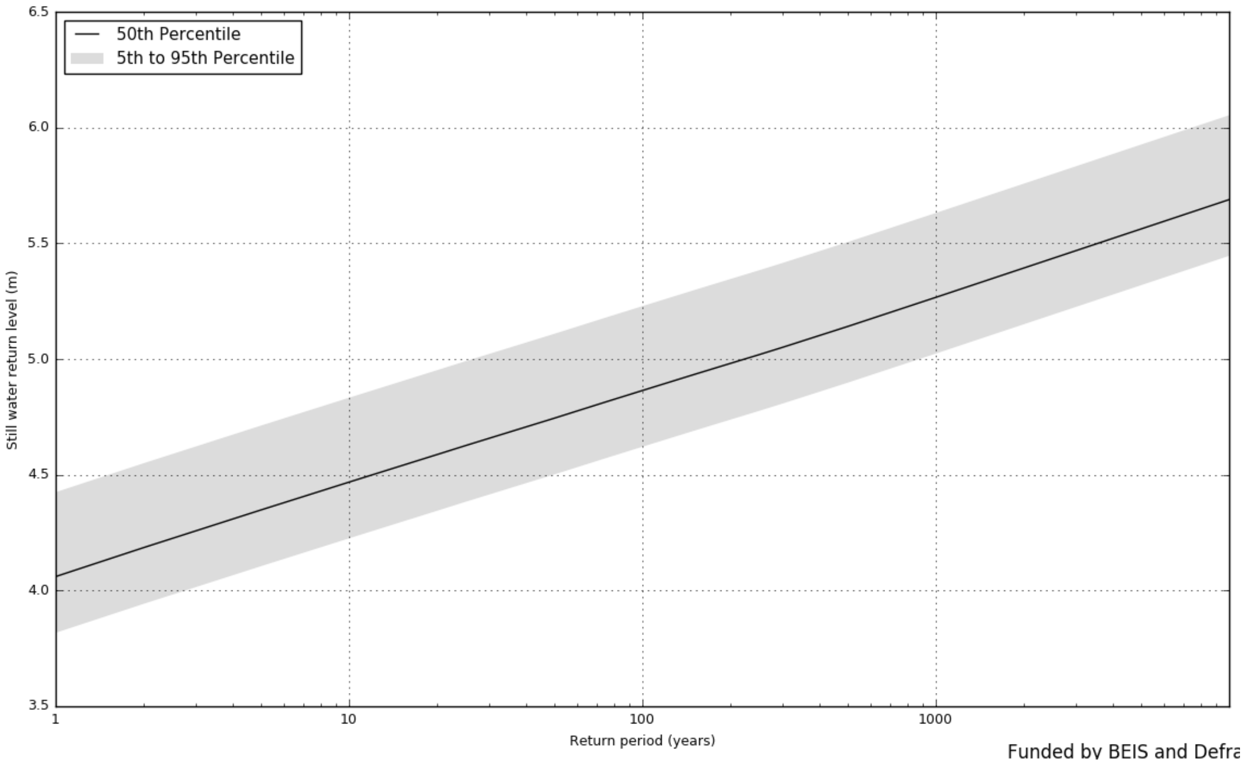


Figure 7.4. *UKCP18 projections for extreme still water return levels at Barmouth in 2100 under the RCP8.5 scenario. Graph downloaded from the UKCP18 user interface.*

7.3.3 Variable 3. Precipitation Change

The precipitation change projections in Table 7.4 show that, across different climate models, mean precipitation is expected to increase in winter and decrease in summer. The range of projections is wide, but the UKCP18 central estimate for RCP8.5 projects a 30-40% decrease in summer rainfall, and a 20-30% increase in winter rainfall in the study area (see Figure 7.5). It is thought that the precipitation patterns will also involve more intense events, increasing the risk of flash flooding (Kirtman *et al.* 2013). The Committee on Climate Change predict that the return period of run-off events would almost half by 2100 if intense rainfall increased by 20% (Sayers *et al.* 2015). This means that run-off events would be almost twice as likely in 2100 compared to 1990. The IPCC projects that, under a medium emission scenario, global mean run-off would increase by 6 - 8% by 2035, but that the increase will be greater in mid-high latitudes, as the tropics and subtropics record a decline (Kirtman *et al.* 2013). Therefore, it is likely that run-off will increase in the study area at a greater rate than the global projected mean, particularly during the winter.

The projected reduction in rainfall during the summer, combined with the aforementioned temperature rise, is likely to result in an increase in the frequency and intensity of droughts in the UK (Watts *et al.* 2015). This may cause desiccation and destabilisation of soils, further increasing the susceptibility of the soils to pluvial erosion (Abdalla and Smith 2016).

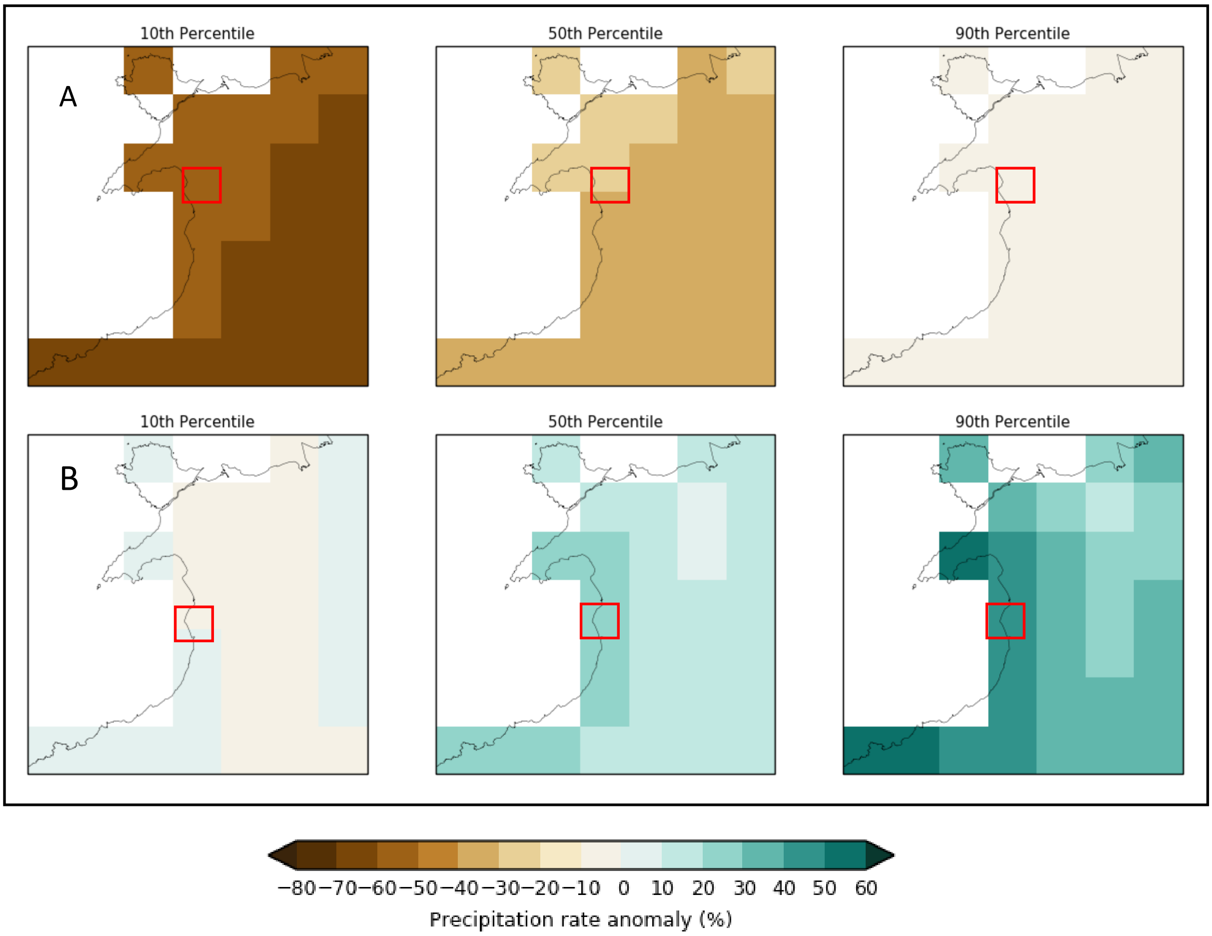


Figure 7.5. *UKCP18 projection for RCP8.5 for seasonal average precipitation rate anomaly (%) for Summer (A) and Winter (B) in 2070-2099 in west Wales, using baseline 1961-1990. Study area is demarcated in red.*

Table 7.4: *Precipitation change projections*

Category	Scenario	Change (Central estimate)	Time frame	Baseline	Region	Source
Mean winter precipitation	RCP8.5 (High)	+20-40%	2061-2080	1981-2000	West coast of Wales	UKCP18 (Murphy *et al*. 2018)
	RCP8.5	+0-10%	2081-2100	1981-2005	UK	IPCC AR5: (Collins *et al*. 2013)
	Medium, i.e. A1B	+33%	2080s	1961-1990	West coast of UK	UKCP09 Watts *et al*. 2015
	RCP4.5	+11% ±3%	2100	1986-2005	Northern Europe	IPCC AR5 Christensen *et al*. 2013
Mean summer precipitation	Medium i.e. SRES A1B	-40%	2080s	1960-1990	South UK	UKCP09 Watts *et al*. 2015
	RCP8.5	-30 - -50%	2061-2080	1981-2000	West coast of Wales	UKCP18 Murphy *et al*. 2018
	RCP8.5	-10 - -20%	2081-2100	1981-2005	UK	IPCC AR5: Collins *et al*. 2013
Mean run-off	560ppm atmospheric CO_2	+6-8%	2035	1750	Global	IPCC AR5: Kirtman *et al*. 2013
1 in 20 yr flood peak	Medium i.e. SRES A1B	+28%	2080s	1960-1990	West Wales	Kay *et al*. 2014

7.3.4 Projections used in this thesis

As evidenced by Tables 7.1-7.4, there are a wide range of climate change projections due to uncertainties surrounding both future anthropogenic activity, and the subsequent reaction of the climate system. Therefore, for the purpose of this thesis, it is more important to be informed by the trends indicated across all models and scenarios for which there is a high certainty. This section details the climate change projection values that were used in the VI developed in 7.4

Temperature Change

All models indicate that temperature is projected to rise during the 21st century, with a greater increase in summer than in winter. Rather than base the vulnerability assessment on specific temperature values, the vulnerability assessment in this thesis focuses on the vulnerability of features to a general rise in temperature and increase in heatwave frequency. The change in summer temperature will have a more marked effect on desiccation and drought conditions, while warmer winters and fewer frost days may have significant impacts on species phenology, range and distribution, and ultimately on the structure of ecosystems (Jones *et al.* 2010; Watts *et al.* 2015).

Sea-level Change

The sea-level rise projection of +0.83m by 2115 (See Table 7.2) was used in this thesis to identify areas at risk of flooding and inundation. There are a wide range of sea-level rise projections for the study area and at larger spatial scales, but this projection is the highest-resolution for the study area, and the most recent projection available. The RCP8.5 scenario is used rather than the more modest RCP4.5 projection, as the precautionary principle is recommended for coastal management and climate change adaptation (European Parliament and Council 2002; McKenna *et al.* 2008).

Precipitation Change

As with temperature change, the models reviewed have significant variations in the amount of precipitation change, but they all follow the same trends. There is projected to be a decrease in summer precipitation and an increase in winter precipitation for all models and scenarios. The vulnerability assessment in this thesis focuses on these trends, rather than on a single specific projection. The increase in winter precipitation is likely to result in an increase in waterlogging and rising groundwater levels. It is also projected to increase run-off and therefore gully erosion (Zhang *et al.* 2012). In contrast, the projected decrease in mean summer precipitation may result in longer and more frequent drought periods (Watts *et al.* 2015). Combined with an intensification of high magnitude rainfall events, this will increase the risk of soil erosion (Herle *et al.* 2009). Heavy precipitation events also have the potential to cause flash flooding and cause rivers to break their banks.

7.3.5 Summary

This section provided a brief overview of the various climate change projections for the study area, and used them to determine the climate projection values that were used in this thesis. Climate modelling cannot produce single value projections, or provide complete certainty for the projections generated. However, basing the vulnerability assessment on a range of sources increases the reliability of the results. The climate projection values identified above were used in the vulnerability assessment for archaeological features and historic landscapes in the coming chapters.

7.4 Development of the Vulnerability Index Methodology

This section details the development of a landscape-scale VI for assessing the vulnerability of the historic landscape. This VI was developed to address the limitations of site-focussed VIs as discussed in 7.2.7, and generate a methodology that can be applied to other landscapes through the use of HLC. Firstly, the landscape-scale VI methodology is described and justified, with a detailed description of the variables and threats considered. A logistical and technological test was carried out to test the methodology and establish the usability and suitability of the techniques and technologies chosen. The methods, results and implications of this test are discussed in 7.4.2.

7.4.1 Development of the vulnerability index

The landscape-scale VI is divided into two sections, each with a different equation. Firstly, the vulnerability of LCFs is calculated using a set of variables that assess their sensitivity, resilience and exposure to climate change impacts (Stage 1). The second VI equation (Stage 2) works at the level of the LCA, and calculates the vulnerability of the LCAs using the vulnerability of the LCFs (as calculated in the first equation), as well as a range of variables that relate to the exposure of the LCA to climate change impacts. This two-stage VI is influenced by that developed by Reeder *et al.* (2012) and Reeder-Myers (2015), as it can calculate the vulnerability of both small and large areas and considers the way that the vulnerability of one can influence that of another. Stage 1 addresses LCFs as the lower level of the Hierarchy Theory, while Stage 2 makes the LCAs the focal level of this VI. Figure 7.6 provides a visual representation of how this VI fits into the Hierarchy Theory framework. This acknowledges the influence that LCF vulnerability has on the overall LCA vulnerability, as the lower level of the Hierarchy Theory can act as mechanisms and initiating conditions for the focal level, as well as just characterising components (Wu 2013).

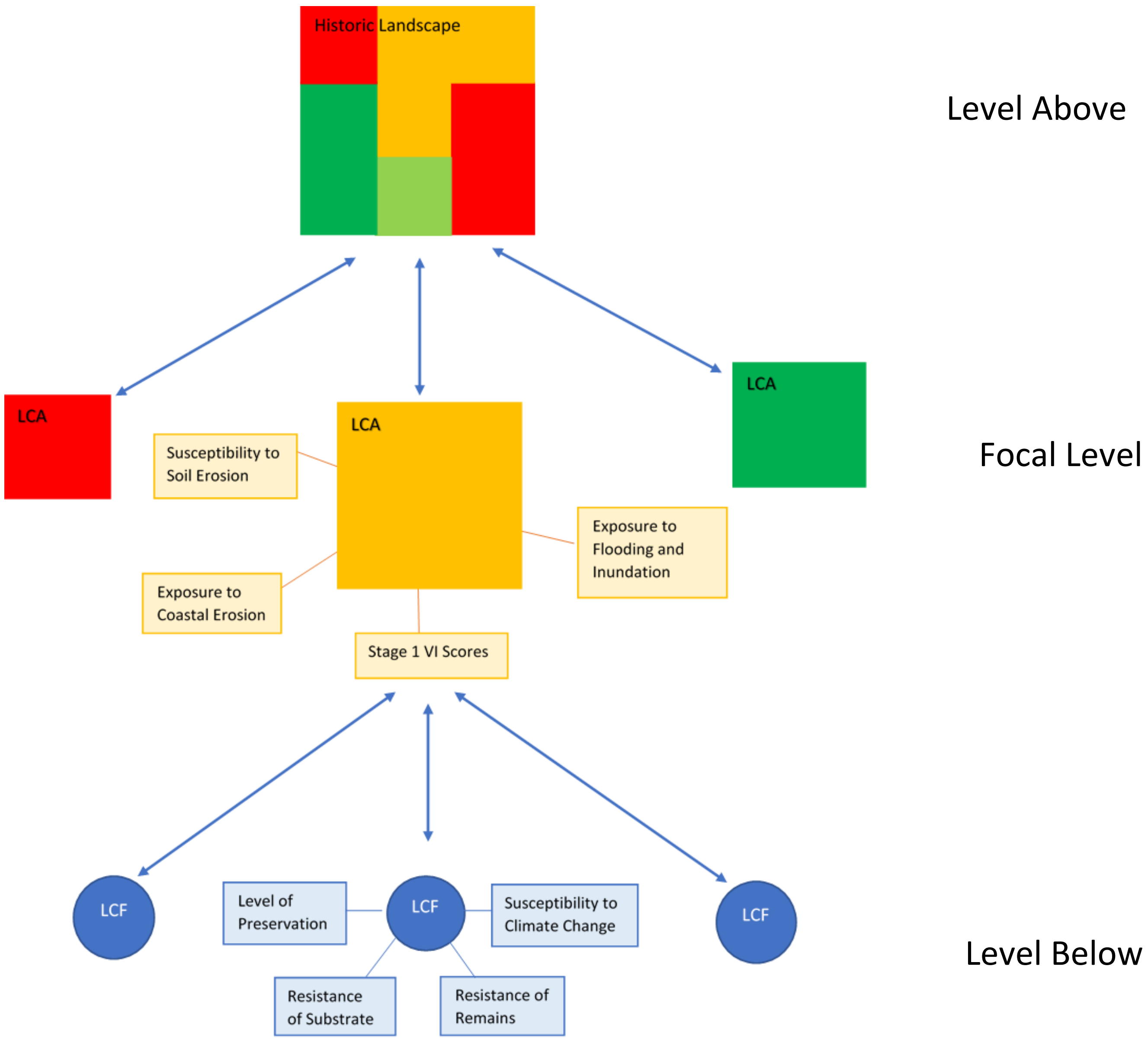


Figure 7.6. *Visual representation of how the VI developed in Chapter 7 fits into the Hierarchy Theory framework*

Vulnerability of Landscape Character Features

It is acknowledged that there are a multitude of variables that would measure the vulnerability of LCFs to climate change impacts. McLaughlin and Cooper (2010) argue that it is not necessary to consider every variable for which data exists, as some of them are highly correlated, and so would likely be measuring the same phenomena. For instance, the susceptibility of the LCF to predicted precipitation change is likely to be closely related to the susceptibility of the feature to storminess, as the impact of storms includes heavy precipitation. In addition, Lane *et al.* (1999) state that variables used in VIs should be “measurable, accessible, transferable, easy to be applied in practice, and not redundant". Therefore, the variables used in this study were chosen on the basis of their accessibility and their transferability between regions. Five variables were identified for the VI for the LCFs: current level of preservation, resistance of the remains, resistance of the local substrate, the susceptibility of the feature to projected precipitation change, and the susceptibility to projected temperature change in the 21st century. These variables and the scoring system for Stage 1 are detailed in Table 7.5.

Variables

Current Level of Preservation

The current level of preservation of a feature measures how much damage it has already succumbed to. This includes whether the site is buried or exposed, and how much of the site remains extant. The level of preservation indicates which sites have been damaged due to past or current environmental conditions or management practices, and which may therefore be more vulnerable to further damage than those which have remained well preserved.

Resistance of the Remains

The resistance and mechanical strength of the constituent material of the LCFs is an important consideration. LCFs made of organic remains, earthworks, or living features are likely to be more susceptible to weathering or erosion compared to brick or stone constructions. Features that are currently used and managed, such as historic buildings and field boundaries, have greater resilience to environmental threats than unmanaged remains, as they may be protected and repaired. Finally, archaeological features that are buried are less exposed to any impacts of climate change compared to those that are above ground.

Resistance of the Local Substrate

Resistance of the local substrate can influence the vulnerability of archaeological remains as features located on less resistant deposits, such as unconsolidated sediments or sand, are at greater risk of being undermined or disturbed than those positioned on resistant bedrock. Disruption of the context of features will have a negative impact on the survival of archaeological information, even if the features themselves have not been eroded. An important objective with this thesis is to identify the absolute vulnerability of LCAs to climate change, rather than their relative vulnerability. As previously discussed, several studies exclude variables such as geology from the VIs as it is unlikely for the geology to vary significantly over the study areas, and therefore it does not influence the relative vulnerability of the sites studied. This is only suitable if the aim is to compare sites within a single, geologically homogeneous study area. This approach does not allow the VIs to be compared across different study areas. Nor is it appropriate for areas with significant geological variation, for example where differences in superficial deposits can influence vulnerability to erosion.

Susceptibility to Projected Temperature Change

As the focus of this VI is on the threat of climate change in particular, it was important to include variables that specifically address climate change impacts. As climate models predict that sub-zero temperatures will become less common during winter months in the future, the main threat of temperature change will be caused by rising summer temperatures (Murphy *et al.* 2009; Jones *et al.* 2010; Kirtman *et al.* 2013). LCFs that are most sensitive to rising temperatures include organic remains, particularly those preserved in waterlogged conditions, which may dry out in the future. Living features are sensitive to both the damaging effects of higher temperatures and heatwaves, as well as secondary impacts such as invasive species and wider ecosystem effects. Brick and stone-built structures are the most resilient to temperature changes, so are less likely to be affected by this aspect of climate change.

Susceptibility to Projected Precipitation Change

As discussed in 7.3, precipitation in the study area is projected to increase in the winter and decrease in the summer, with the rain that does fall occurring in more intense events. This is likely to exacerbate the impacts of increased winter precipitation, such as soil erosion and gully erosion. LCFs located on steep slopes and in gullies may therefore become more exposed to erosion. The projected decrease in precipitation during summer months is likely to result in more frequent and severe droughts, to which LCFs such as ancient woodland, parks and gardens, and organic remains, are particularly sensitive. To generate this score, the feature type was combined with the flow accumulation at its location. Flow accumulation is a tool in GIS which indicates where water flowing down a slope will accumulate based on the topography, for instance in gullies and valley bottoms. Areas with greater flow accumulation are therefore areas that are more likely to experience torrents and gully erosion during high rainfall events (Mitasova *et al.* 1996; Zlocha and Hofierka 2014).

Stage 1 Equation

Each LCF was given a score between 1 and 5 for each variable, as this was a common scoring method used in the studies reviewed (e.g. Thieler and Hammar-Klose 2000; Reeder-Myers 2015; Nguyen *et al.* 2016).

The vulnerability score for each LCF (VLCF) is calculated using the following equation:

$$VLCF = \frac{a + b + c + d + e}{5}$$

Where *a* = level of preservation, *b* = resistance of the remains, *c* = resistance of the local substrate, *d* = susceptibility to projected temperature change, *e* = susceptibility to projected precipitation change. The equation used here calculates the arithmetic mean rather than the geometric mean, which is a common approach in other VIs (see 7.2.2). The arithmetic mean was chosen because all variables were scored on the same scale (1-5), and the VLCF score also had to score between 1 and 5. This is because the VLCF scores were used in a second equation for Stage 2 in which the variables are also scored between 1 and 5.

Table 7.5. *Vulnerability Index Stage 1 variables and scoring system*

Variable	Classes	Score
Level of preservation	no visible damage/buried	1
	Some small damage or visible weathering to structure. Buried archaeological feature slightly exposed	2
	Structures show structural damage and weakness Buried features are exposed and show signs of weathering,	3
	Significant weathering damage, little evidence remains of the features	4
	Extremely damaged, ephemeral remains	5
Resistance of the remains	Solid built feature, actively used, managed or protected.	1
	Made of resistant materials such as rock/stone, but is less fixed i.e. a drystone structure	2
	Made of less resistant materials, such as organic remains or earthwork, but remains buried or has a small amount of protection	3
	Feature or site characterised by a collection of artefacts rather than a structure, so lacking foundations. Also made of less resistant materials	4
	Features made of a less resistant or very fragile material, previously buried but are now exposed.	5

Resistance of local substrate	Feature is positioned on solid bedrock, in an area of low relief (<5°) with no visible weathering or erosion nearby	1
	Feature is positioned on solid bedrock in an area of medium relief (5-15°). Little or no visible weathering or erosion in the area.	2
	Feature is positioned on bedrock in an area of high relief (>15°), or on unconsolidated sediments in a low relief area. Some visible erosion and weathering in the vicinity	3
	Feature is positioned on or in unconsolidated sediments in a medium relief area, or sand in a low relief area. Visible weathering or erosion nearby	4
	Feature is positioned on or in unconsolidated sediments in an area of high relief (>15°) or sand in an area of medium or high relief. Significant visible erosion and weathering near the remains	5
Susceptibility to projected temperature change	Solid built feature, made of rock or other resistant material	1
	Buried features not thought to include organic remains	2
	Organic or wet-preserved remains, but located in areas unlikely to be prone to desiccation, such as the intertidal zone	3
	Living features such as parks and gardens	4
	Organic or wet-preserved remains, in areas susceptible to desiccation or peat fires i.e. uplands	5
Susceptibility to projected precipitation change	Solid built feature, actively used, managed or protected, or made of resistant materials, Located in very low flow accumulation area (<20). Or In intertidal zone	1
	Made of resistant materials such as rock/stone**,** In a low flow accumulation area (20-50). Not affected by drought	2
	Made of resistant materials**,** but located in areas with moderate flow accumulation (51-100) or on the banks of water courses. Alternatively, made of less resistant materials such as earthworks or organics and	3

	located on unconsolidated sediments in areas with very low flow accumulation (<50).	
	Made of less resistant materials such as earthworks or organics and located in unconsolidated sediments in areas with moderate flow accumulation (50-100) or on the banks of water courses/rivers or made of resistant materials in areas with high flow accumulation (>100)	4
	Made of less resistant materials and located in valley or gully areas with high flow accumulation (>100) Organic, living or wet preserved remains susceptible to desiccation	5

Stage 2: Vulnerability of Landscape Character Areas

The main aim of this chapter is to develop an approach that assesses the vulnerability of the historic landscape to climate change, rather than focussing on individual sites. The second stage of the VI calculates a vulnerability score for the LCAs in the study area. The variables for Stage 2 used are the Stage 1 VI scores for LCFs that characterise the LCA (VLCF), the proportion of the LCA threatened by coastal, fluvial and pluvial flooding or inundation, the proximity of the LCA to an eroding stretch of shoreline, and the susceptibility of the soil in the LCA to erosion. These variables and the scoring system are detailed in Table 7.6.

Variables

Stage 1 VI score

The first variable is the average vulnerability score of the LCFs that characterise each LCA (VLCF). This is because the vulnerability of LCAs does not depend only on their exposure and sensitivity to climate change impacts, but also on the way that characteristic features of each area will be impacted. LCAs are characterised by the presence and structure of features such as field boundaries, settlements and buildings, vegetation, and historic and archaeological features. While the focal level of this vulnerability assessment is LCAs, it still must acknowledge the influence that individual LCFs have on the landscape.

Proportion of the LCA at Risk of Fluvial and Tidal Flooding and Sea-Level Rise

Sea-level rise and seasonal increases in precipitation both escalate the risk of flooding, particularly in lowland or coastal areas. In very low-lying areas, a shift in the intertidal zone may result in some places becoming periodically flooded and transforming into wetland such as saltmarsh. The subsequent change in vegetation, land-use and visual character of the area would significantly impact the historic landscape. Furthermore, periodic wetting and drying cycles can be particularly detrimental to any archaeological remains affected (González and Scherer 2006; Pokines *et al.* 2018; see Chapter 2).

Table 7.6: *Vulnerability Index Stage 2 variables and scoring system*

Variable	Classes	Score
Mean vulnerability score of the features characteristic of this LCA	1<=x<1.5	1
	1.5<=x<2	2
	2<=x<3	3
	3<=x<4	4
	4<=x<=5	5
Proportion of the LCA at risk from fluvial and tidal flooding, and sea-level rise	<5% the LCA area at risk of sea-level rise, or at risk of flooding from rivers and seas by 2100 (RoFRS)	1
	<20% threatened by any RoFRS high storm surge or flooding from rivers, but none threatened by sea-level rise.	2
	20%-50% threatened by high or medium RoFRS and <20% threatened by sea-level rise alone.	3
	>50% threatened by high or medium RoFRS storm surges (below 5.715m OD) and river flooding, and/or 20-50% of the LCA threatened by sea-level rise 2100 (within 2.965m OD)	4
	>50% at risk of inundation by 2100 (within 2.89m OD) and/or >70% at high RoFRS	5
Proximity to unprotected eroding shoreline	0% located within 100m of unprotected shoreline or in front of defences	1
	LCA has <10% of area within 100m of unprotected shoreline or in front of defences, or shoreline with managed retreat policy	2
	10-50% of LCA area is within 100m away from unprotected shorelines or shoreline with managed retreat policy	3
	10-50% of LCA area is located 0-50m away from unprotected shorelines or shoreline with managed retreat policy OR most sites (>50%) are located within 100m of unprotected shoreline or in front of defences or shoreline with managed retreat policy	4
	>50% of the LCA located within 50m of unprotected shoreline, shoreline with managed retreat policy or in front of defences	5

Table 7.6 cont.

Variable (cont.)	Classes (cont.)	Score (cont.)
Susceptibility of soil type to erosion: the classification chosen should be based on the most common soil characteristics for each LCA	Very little risk, as soils are freely draining, relatively cohesive, and low relief.	1
	One of the following criteria: In an area at risk of floodwater scouring or runoff Sandy/unstable soils at risk of wind erosion during dry periods Risk of sheet erosion during high-precipitation events Shallow soils and bare rock in places Risk of soil erosion due to grazing and trampling Slow or impeded drainage Steep slopes	2
	Two of the above criteria	3
	Three of the above criteria	4
	Four or more of the above criteria	5

Proximity to Eroding Shoreline

Shoreline erosion is projected to increase as a result of sea-level rise and increased storminess, both impacts of climate change (see Chapter 2). Along soft, unprotected coasts in particular, shoreline erosion has the potential to completely destroy and remove large areas of land, as seen on the east coast of England (see Dunwich case-study, section 1.3). This completely changes the character of the historic landscape, as well as destroying any archaeological information. The rate of shoreline erosion can be identified by comparing the shoreline position in historic and modern Ordnance Survey maps, and historic and modern aerial photographs.

Susceptibility to Soil Erosion

Although the resistance of the substrate was included in Stage 1 for each of the LCFs, the susceptibility of the whole LCA has also been included here. This is because soil erosion can dramatically change the character of large areas of land, even if no specific features are impacted, as it alters the visual character and the ability of vegetation to grow (Arnaez *et al.* 2011).

Stage 2 Equation

The equation used to calculate the vulnerability of LCA-types (VLCA) is:

$$VLCA = \frac{VLCF + f + g + h}{4}$$

Where *VLCF* = the vulnerability score for the LCFs that characterise each LCA, *f* = proportion at risk of flooding or inundation, *g* = proximity to eroding shoreline, and *h* = susceptibility to soil erosion

Summary

This section describes the development of a VI that addresses the vulnerability of the historic landscape to climate change. The focal level of this VI is LCAs, rather than archaeological sites. However, it still incorporates features within the landscape (LCFs), including archaeological sites, in the first stage of the index. This recognises the important role that archaeological and historical features play in the cultural heritage of an area, while expanding the focus to include living and current features, and the spaces between sites. Section 7.4.2 details a logistical and technological test which was undertaken to trial the techniques and technology chosen for the developed methodology and establish any changes that may be required.

7.4.2 Logistical and technological test

The fieldwork session available for the VI assessment was time-limited, so a logistical and technological test was designed to determine the time taken to assess features, and to identify any limitations or issues with the techniques and technologies chosen. Adverse weather conditions in late February 2018 caused the planned logistical and technological test in the Dysynni valley to be cancelled due to impassable roads, so the Stage 1 VI data collection methods were tested on HER sites in the vicinity of the author's residence. This was sub-optimal in terms of testing the VI methods on the wide range of sites found in the study area, including hillforts and coastal features. However, a range of site types were visited (i.e. churches, earthworks, military structures), which allowed the technology and general methodological approach to be tested in order to identify any potential changes that could be made and any technical issues that may occur.

Methods

Twelve records from the local HER database (Peterborough City Council, n.d.) that covered a range of site types, including earthworks, buildings and monuments, were chosen for the logistical and technological test. The full list of visited features is available in Table Ap3.1 in Appendix 3. A form including each of the features to be visited and each variable in the VI was created in Microsoft Excel, and subsequently downloaded into an iPad.

As well as an iPad, a Garmin GPS device was used for this fieldwork to link to the iPad and provide location data in GIS. Although the location of each feature was provided in the HER record, this was often inaccurate, so the latitude and longitude of the feature was recorded using the Garmin GPS device, which is accurate to 3m (Garmin 2018). This is an acceptable amount of potential error considering the size of many of the features, and the resolution of the Ordnance Survey maps used in GIS. The elevation of the features was obtained later using LiDAR data in GIS (see section 5.2.2)

Photographs were taken at each site in order to document the preservation and appearance of the feature, and as a memory-aid for future study. A separate table was added to the Excel file, in which the photograph number, site number, orientation, and description of each photograph was logged. Although time consuming, this is useful for remembering which photographs are of which site, to avoid confusion later on in the assessment process.

Prior to the fieldwork, point data relating to the features identified for assessment were downloaded onto an iPad in order to view them in iGIS. This allows the user to identify their location in relation to the features. When using the free version of iGIS, only vector files i.e. point, line and polygon shapefiles) can be downloaded and used. Although a satellite basemap is provided in the application when it is online, the application cannot load a basemap for any new areas while offline, for instance when one is in the field. The resolution of the loaded basemap can also reduce when offline. Therefore, an Ordnance Survey vector map was downloaded for the test study area from the Ordnance Survey website. This covers the whole National Grid Reference (NGR) square and includes a range of features such as buildings, roads, surface water, woodland, junctions, electric car charging points, and railways. This was too much information to load into iGIS, and caused the application to crash. The vector files had to be clipped to the relevant area using QGIS, and only those useful for navigation (roads, surface water, railways and woodlands) were downloaded into iGIS.

Due to snow cover, Features 1 and 2 were not visible or accessible on the day of the fieldwork. Feature 7 could not be found in the location provided or nearby, and Feature 9 was not able to be distinguished from the other similar features in the vicinity. Different features took different amounts of time to assess. For instance, the Saxon Villas (Feature 10) were easily identifiable and could be assessed in 5-10 minutes. The ridge and furrow at Fletton Playing Fields (Feature 11) took longer to be located and identified, and the vulnerability assessment took longer, in total around 20 minutes. Furthermore, around 10-15 minutes was spent looking for sites that were not found (Features 7 and 9). Overall, in 3 hours, 8 sites were assessed and 4 more were unsuccessfully sought out. This includes the time taken travelling to sites, either by car (Features 1-6) or on foot (Features 7-12). This means that it took on average around 25 minutes to assess each site when travel is accounted for.

To assess the Susceptibility to Projected Precipitation Change, the r.flow algorithm was used in QGIS, which uses a DEM to construct flowlines downhill from each cell in order to identify areas where flowlines accumulate (Heywood *et al.* 2011). The point sampling tool was then used to extract the flow accumulation data for each of the HER records.

Superficial and bedrock geology information was downloaded from Digimap, where it is freely available with license. This information indicates which sites are located on unconsolidated sediments, and which are positioned on harder substrate. This was used to address the variable *Resistance of Local Substrate*.

Results

The Stage 1 scores for each of the features visited during the logistical and technological test are provided in Table 7.7. A breakdown of the scores given for each variable at each feature are provided in Appendix 3 Table Ap3.2. The initial results of the logistical and technological test suggest that the categories are skewed towards giving low-vulnerability results. However, the VI has been developed with the Dysynni valley in mind, which has many steep slopes and areas at risk of gully erosion during high-precipitation events. In contrast, the area that the logistical and technological test was carried out in has consistently low relief, so little risk of erosion. Furthermore, the main study area is predominantly rural, and many more sites are earthworks or less consolidated structures. The features visited during the test were mainly located in urban areas or villages, and more were buildings or more robust structures, which explains the generally low level of vulnerability.

Table 7.7*: Vulnerability scores for the test features*

ID	PRN/NPRN	Name	Vulnerability Score
3	2814	Whittlesey Butter Cross	1.6
4	2928	St Mary's Church	1.4
5	3917	Whitecross Stone	1.6
6	50457	Pillbox	1.2
8	1411	St Margarets Church	1
10	50585	Saxon Villas	1.4
11	53704	Fletton Playing Fields Ridge and Furrow	2
12	53820	The Nene Viaduct (Great Northern Bridge 184)	1.6

For this logistical and technological test, only Stage 1 of the VI was undertaken, because this is the only part of the VI that requires fieldwork. Stage 2 is based on the HLC undertaken for the study area, and incorporates Stage 1 with other variables to identify which LCAs are most vulnerable to climate change. As Stage 2 does not rely on fieldwork, but rather on data analysis in GIS, it can be altered and re-run if required during the main assessment.

Implications of the logistical and technological test

The logistical and technological test indicated that the locations given in the HER for features are often slightly inaccurate, which could affect the results of some of the vulnerability variables. The *Vulnerability to Projected Precipitation Change* variable is partly based on the flow accumulation in the cell that the feature is positioned within. An inaccuracy of even a few metres will have a significant impact on this result. It is acknowledged that in reality, many features cover a wider area than a single flow accumulation raster cell ($5m^2$), so using the value found at a single point location is not an accurate portrayal of the exposure of the whole feature to runoff. It is still important to be as accurate as possible, rather than having a point value that is not located within the bounds of the feature's actual location. The accuracy of the GPS equipment used should also be considered. For this test, a Garmin GLO GPS device was linked via Bluetooth to the iPad. This has an accuracy of 3 metres (Garmin 2018), which is an acceptable amount of potential error considering the size of many of the features, and the resolution of the flow accumulation raster.

For the logistical and technological test, the name and record number of the features identified for visiting were input into the VI form prior to the fieldwork. This was done in the order that the features were found in the online HER database (Peterborough City Council, n.d.), rather than the order in which the features were to be visited. This led to some confusion when entering data into the form. For the main fieldwork, the features were listed in the VI form in the order in which they were visited.

In order to facilitate the identification of features, and avoid being unable to assess features that cannot be found, a copy of the descriptions of the features from the HER and NMRW was taken into the field during the main fieldwork. A short list of 'back up' features was compiled, which could be assessed if several of the features that were planned to be visited could not be found or were inaccessible. Based on the time taken to undertake the logistical and technological test, 15 minutes was given for assessing each site, which allowed for some to take longer and others to take less time. The additional walking and driving time was also considered in order to plan for the right number of sites each day. An average of 14 features was planned for each day. Fewer were planned for days in which accessing the sites took more time, i.e. upland features, while more were covered on days which focussed on features that are located close together in urban areas, i.e. historic buildings.

In order to avoid any issues with losing the basemap in iGIS during the fieldwork, the Ordnance Survey vector map was downloaded for the study area. Only the relevant area of the map, and relevant features for navigation (i.e. roads, surface water and woodland) were downloaded into iGIS, as the application has a relatively low capacity to deal with large amounts of data compared to full GIS programmes. QGIS was used to clip the vector files to the correct area prior to downloading them onto the iPad.

The logistical and technological test identified changes that were required to the methodology in order to undertake the data collection as efficiently as possible. Although it could not be undertaken in the Dysynni valley, the methods and technology used were the same, so the general approach to data collection for the vulnerability assessment could still be tested.

7.4.3 Summary

This section details the development of a landscape-scale vulnerability assessment for applying to HLC projects. The main reason behind developing a new VI that focusses specifically on landscapes and LCAs is to address the current limitations in archaeological vulnerability assessments, as explained in 7.2.7. By dividing the assessment into two equations, the VI acknowledges the value of historic and archaeological features of an area, while also considering the importance of the historic landscape as a spatially continuous phenomenon.

7.5 Vulnerability Index Methodology

This section details the application of the VI methodology developed in 7.4 to the Dysynni valley study area, informed by the climate change projections described in 7.3. First, Stage 1 of the VI is applied to a sample of LCFs from the Dysynni valley. Subsequently, Stage 2 of the VI is applied to each LCA in the study area.

7.5.1 Vulnerability index stage 1

Landscape Character Feature Sampling

Prior to undertaking the VI, it was necessary to select a range of LCFs to which Stage 1 of the VI could be applied. It is also important to explicitly define the population that the sample was drawn from. In this case, the population is the NMRW and HER database records located in the study area, additional LCFs identified in Level 1 surveys undertaken by University of Sheffield MA students, and cropmarks identified in aerial photographs. The HER and NMRW databases had 1931 records in the study area. Once those listed as 'documentary evidence only' were removed, 1526 records were left. There were also 57 cropmarks and buried features, and 56 LCFs from the Level 1 surveys, 1639 LCFs in total.

This study used a stratified, systematic sampling approach. The population was stratified by the LCA in which they are located, and whether they are characteristic of that LCA. For instance, the medieval Domen Ddreiniog motte was not included in the 'Regular Fieldsystems' LCA VI, even though it is technically located within this LCA, as it does not characterise post-medieval and modern fieldsystems. Rather, Domen Ddreiniog was included in the 'Ancient' LCA. It is for this reason that the LCAs were allowed to overlap in this HLC, as some areas of land are characterised by features from more than one time period or activity. The LCFs sampled from each LCA are detailed in Table Ap3.3 in Appendix 3.

Data collection

Five days were available during fieldwork for me to visit LCFs and apply Stage 1 of the VI to them. Based on the findings from the logistical and technological test (see 7.4.2), this would allow 70 LCFs to be assessed. This would mean only 4% of the recorded LCFs in the study area would be included in the VI (in fact, only 64 features were actually visited during fieldwork, as some could not be found, or were inaccessible due to vegetation). A greater population sample would provide a more robust assessment of the vulnerability of LCFs in the study area. Therefore, the site visits during fieldwork were used as a ground-truthing exercise, to establish the reliability and accuracy of the information included within the HER and NMRW databases and L1 survey results. If the information available on LCFs proved reliable and accurate, it would suggest that other LCFs could be assessed in the VI without being visited. The ground-truthing exercise revealed that 91% (n=64) of the records have sufficient information to undertake the VI without visiting the LCFs. Furthermore, variables *c* (resistance of the local substrate) and *e* (susceptibility to projected precipitation change) are related mainly to the *exposure* of the features, and are assessed through GIS analysis rather than site visits. Following the fieldwork, a further 80 LCFs were included in Stage 1 of the VI through a DBA, so the total sample was 144, around 8.8% of the LCF population (see Table Ap3.4 in Appendix 3). The LCFs suitable for inclusion in the second sample were identified based on the amount of additional description about them in their respective databases. It was considered acceptable to apply Stage 1 of the VI to these additional LCFs based on the high level of accuracy of information in the HER and NMRW records, as established during the initial ground-truthing fieldwork

Another reason for applying Stage 1 to a virtual collection of LCFs was to establish whether this framework would be suitable for applying to a landscape that may be too large or inaccessible for archaeologists to visit many features, or for projects with time or budget restraints but an existing resource of survey information for the features in the area. This study found that Stage 1 of the VI could easily and satisfactorily be applied to LCFs virtually, as long as records had sufficient and relatively up-to-date information on each feature, for instance on the level of preservation, material type and current usage.

Reliability and robustness of the data collection

The field-based ground-truthing exercise and subsequent desk-based completion of Stage 1 of the VI were undertaken to increase the number of potential LCFs included in the VI for the Dysynni valley, to make the results more robust. A second aim of trialling both field-based and desk-based methods was to test the suitability for using this vulnerability framework both in the field and remotely, in order to make it usable for a range of different landscapes with different levels of existing heritage/archaeological data. For the most part, it was determined that the information provided in the HER and NMRW databases, and the descriptions provided from the L1 surveys carried out by MA students, were sufficient for satisfying the Stage 1 VI variables.

Including more LCFs through desk-based methods allowed the results of the VI to be more reliable and robust. In total, 144 LCFs were assessed, 8.8% of the recorded features in the study area. If only the visited LCFs were included in the assessment, only 3.9% of the recorded features in the Dysynni valley would have been included, which is less reliable for assessing the vulnerability of the whole historic landscape. The reliability of the scores produced by the field-based and desk-based exercise is analysed further in 7.6.3.

Assessment of each variable

This section provides an overview of the methods and data used to calculate the scores for each variable in Stage 1 for the study area (see Table 7.5).

Level of Preservation

During the site visits, the level of preservation was assessed by identifying any weathering or structural damage and, if the feature was previously buried, whether any of it had become exposed. Alternatively, during the desk-based analysis of additional LCFs, this variable was based on information held in the database records regarding whether structures were buried, standing, or ruined, and information on any erosion or weathering noted.

Resistance of the Remains

The resistance of the remains variable was based on the constituent material of the feature. This is included in the description of features from the HER, NMRW and L1 survey records, and proved to be accurate during the ground-truthing. Features made of resistant materials such as brick or rock were given a low vulnerability rating for this variable, while those including organic remains or living features were rated more highly.

Resistance of the Local Substrate

The resistance of the local substrate was based on information on relief in the feature location, whether the feature was positioned on bedrock or superficial deposits, and whether there was evidence of erosion near the feature. Prior to the fieldwork, British Geological Survey 1:50 000 scale digital geology maps were downloaded and consulted (BGS Geology 2016). The maps contain information on the bedrock and superficial deposits (see Figures 4.3 and 4.4). The Point Sampling tool was used in QGIS to extract the geological information at the exact location of each feature.

The slope relief at the location of each LCF was calculated before the fieldwork took place. A 1:10 000 scale Digital Terrain Model (DTM) was downloaded from Digimap. Using the DTM and the Terrain Analysis tool, a model of slope relief was created as a raster file in QGIS. The Point Sampling tool was again used to extract the slope relief (in degrees) for each LCF.

The evidence of erosion near a feature was investigated during site visits, or alternatively determined from the feature descriptions in the database records. It is acknowledged that the use of the Point Sampling tool to extract information is slightly problematic, as some features covered a wide area and therefore would have had different levels of slope steepness in different areas. However, the pixels for the DTM covered 25 square metres, which is larger than many of the features included in this assessment. Groups of geological materials cover wide areas (several hectares at least), so it is unlikely that the point data for LCFs would be so inaccurate as to provide incorrect information for this variable.

Features positioned on solid bedrock, in areas of low relief, with no visible erosion nearby were given low vulnerability scores. Features positioned on unconsolidated sediments, in areas with greater relief, and/or with visible erosion nearby, were given higher vulnerability scores.

Susceptibility to Temperature Change

The susceptibility of the feature to temperature change was based on its constituent material, which was identified in the description of the feature in the corresponding databases. The ground-truthing exercises established that the information provided in the feature records was accurate and sufficient for this variable. Features considered to have low susceptibility to temperature change include those constructed of resistant material, such as brick or stone. Features considered more susceptible to temperature change include living features, and those containing organic remains particularly in areas susceptible to desiccation.

Susceptibility to Precipitation Change

The susceptibility of LCFs to projected precipitation change was based predominantly on areas likely to experience gully erosion. Using the DTM of the study area, the flow accumulation was calculated in QGIS using the r.flow algorithm. This algorithm constructs flowlines downhill from each cell in the DTM to identify areas where flowlines accumulate (Heywood *et al.* 2011). The results create a model of where water will flow as it travels across a landscape, based on topography (see Figure 7.7). Areas with greater flow accumulation are therefore more likely to experience torrents and gully erosion during high rainfall events (Mitasova *et al.* 1996; Zlocha and Hofierka 2014). The Point Sampling tool was then used to extract the flow accumulation data for each of LCF. As above, the usefulness of the Point Sampling tool can be questioned as, if the GPS co-ordinates provided for any of the LCFs are inaccurate, the flow accumulation result would be incorrect. The initial results indicate that high flow accumulation scores are generally located in sloped areas, while level areas in both the uplands and lowlands tend to have low flow accumulation scores.

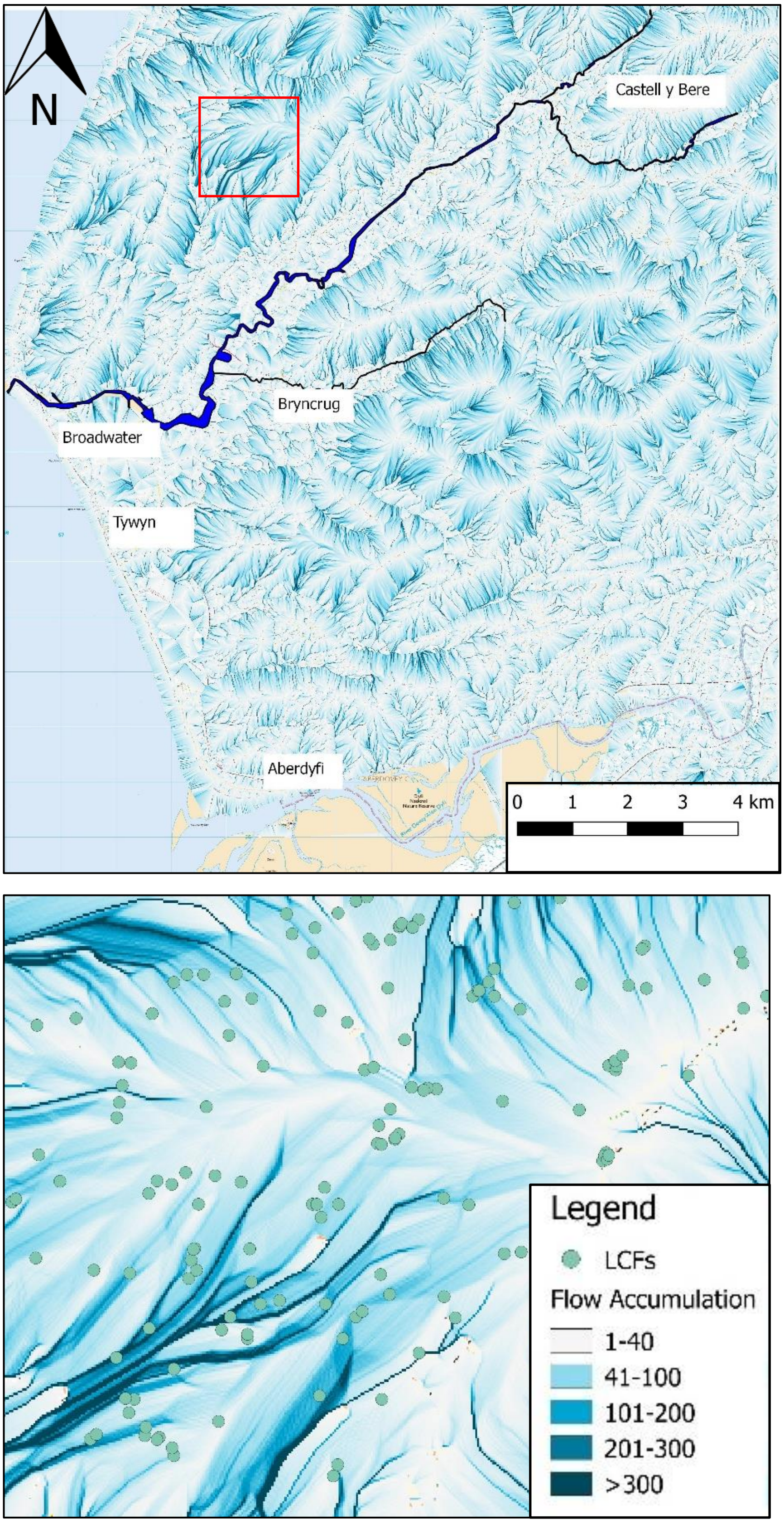


Figure 7.7. *Flow accumulation calculated for the Dysynni valley (ltop) and a magnified section of the study area with LCFs included (below). LCFs located over the darker blue sections are in areas with higher flow accumulation and are at greater risk of erosion. Crown copyright and database right 2019 Ordnance Survey 100025252*

7.5.2 Vulnerability index stage 2

The results of Stage 1, as well as further desk-based research and modelling, were used for Stage 2 of the VI, which assessed the vulnerability of each LCA to the impacts of climate change. Table 7.6 provides an overview of how different variables were classified for Stage 2 based on the data sources used.

Assessment of each variable

Stage 1 VI score

The first variable used in the Stage 2 equation is the average Stage 1 vulnerability score for the LCFs that characterise the LCA in question.

Proportion of the LCA at Risk from Fluvial and Tidal Flooding, and Sea-Level Rise

The spatial extents of the flood risk areas were defined by the Risk of Flooding from Rivers and Sea (RoFRS) shapefile downloaded from NRW (2016a) (see Figure 7.8). The RoFRS shapefile was categorised by the level of risk:

- High Risk: Areas with greater than a 1-in-30 (3.3%) chance of flooding
- Medium Risk: Areas with between a 1-in-30 (3.3%) and 1-in-100 (1%) chance of flooding
- Low Risk: Areas with between a 1-in-100 (1%) and 1-in-1000 (0.1%) chance of flooding
- Very Low: Areas with less than a 1-in-1000 chance of flooding (0.01%).

These projections took into account the existing flood defences, including the height and condition of the defences. The terminology used in flood risk assessments can be misleading. A 1-in-100 year flood does not mean that a flood of this magnitude will only be experienced once in 100 years. Rather, it means that each year there is a 1-in-100 (or 1%) chance of a flood of that magnitude occurring; indeed it could occur each year, or more than once a year. Although new flood risk probabilities have not yet been generated based on projected changes to precipitation patterns or sea-level rise, Hall *et al.* (2005) argue that the likelihood of flood levels that currently have a 1-2% annual probability of occurrence may increase tenfold or more by the end of the 21st century.
The areas of the specific LCA at 'High' (>3.3%), 'High and Medium' (1% - 3.3%), and 'Any' (>0.01%) risk were calculated by using the Clip function in QGIS, to create a new shapefile of the area of overlap between the LCA polygon and the RoFRS polygons. The percentage of the LCA at varying levels of risk could then be calculated by comparing the area of the new shapefile with the area of the LCA.

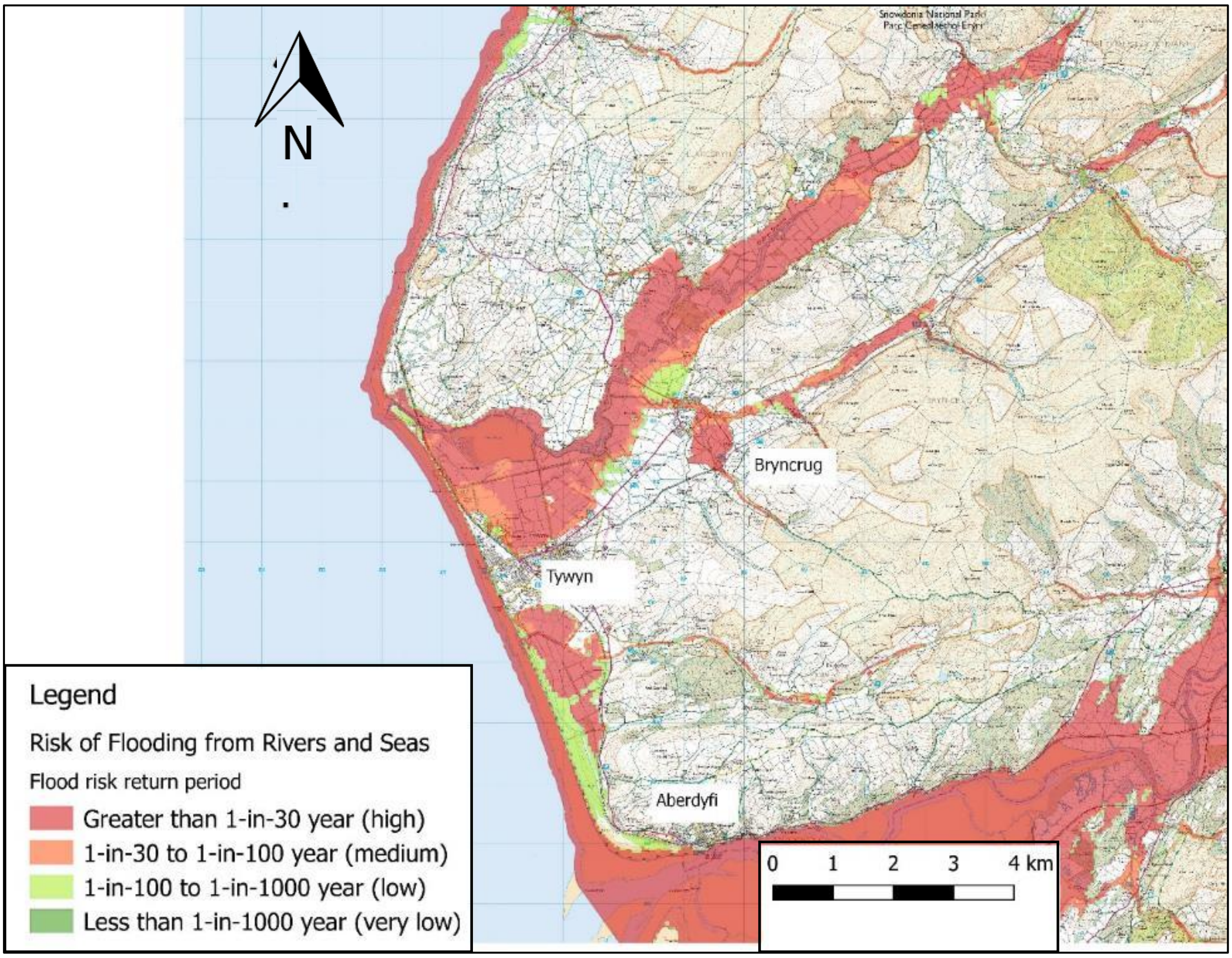


Figure 7.8. *Areas at risk of flooding from rivers and seas from different return periods. Shapefile downloaded from NRW geoportal Lle.gov.wales Copyright CNC/NRW and CEH, Crown copyright and database right 2019 Ordnance Survey 100025252*

The areas at risk of inundation or frequent flooding under a future sea-level rise scenario were also calculated. The level chosen for the new high-tide mark (+2.89m) was a sum of the projected sea-level rise by 2115 in the RCP8.5 scenario (+0.83m: see Table 7.2) and the current level of average high tide above Ordnance Datum (+2.06m), based on tide gauge data for Aberdyfi (visitMyHarbour 2017). The new high tide mark was represented by a raster file in QGIS (0= below 2.89m, 1=above or equal to 2.89m), so the Zonal Statistics tool was used to calculate the mean value for the area covered by each LCA. The mean value (between 0 and 1) was multiplied with the total area of the LCA to identify the amount of land in the LCA that was *not* at risk from sea-level rise. This was then used to calculate the proportion of each LCA that was at risk of inundation at high tide by 2100 under this sea-level rise scenario.

Proximity to Eroding Shoreline

This criterion identified areas at risk from coastal erosion in the long-term. The Spatial Flood Defences with Standardised Attributes shapefile was downloaded from NRW (NRW 2019) to identify areas of the coast that are protected by built defences. This shapefile contains features such as natural banks, cliffs and dunes as well as built defences. The natural features were removed from the shapefile as, although they can provide protection against flooding, they themselves can be susceptible to erosion. This left only the areas along the coast protected by built defences (see Figure 7.9). Although built defences can be affected by erosion, the rate of shoreline retreat in defended areas is markedly less than in undefended areas (Sutton-Grier *et al.* 2015). For the unprotected stretches of shoreline, the Buffer tool was used in QGIS to create two buffer zones, 100m and 50m inland of the current high-water mark on the Ordnance Survey map (see Figure 7.9). The buffer zones were used to calculate the proportion of each LCA that was within the buffer zone or seaward of the high-water mark, and therefore the exposure to coastal erosion over the next century and beyond. The difference in both MHW and MLW between the historic and modern maps was measured every 200m along the Dysynni coastline (see Figure 7.9). The most rapid rate of retreat for the MHW line was 0.44m per year, which would equate to around 36.75m retreat by 2100. For the MLW, the most rapid rate of retreat was 1.08m per year, which would equate to around 90m additional retreat by 2100. These values are based on historic rates of erosion, and so do not account for any acceleration of shoreline retreat due to sea-level rise or increased storminess. The values of 50m and 100m from the MHW line were chosen in order to satisfy the precautionary principle.

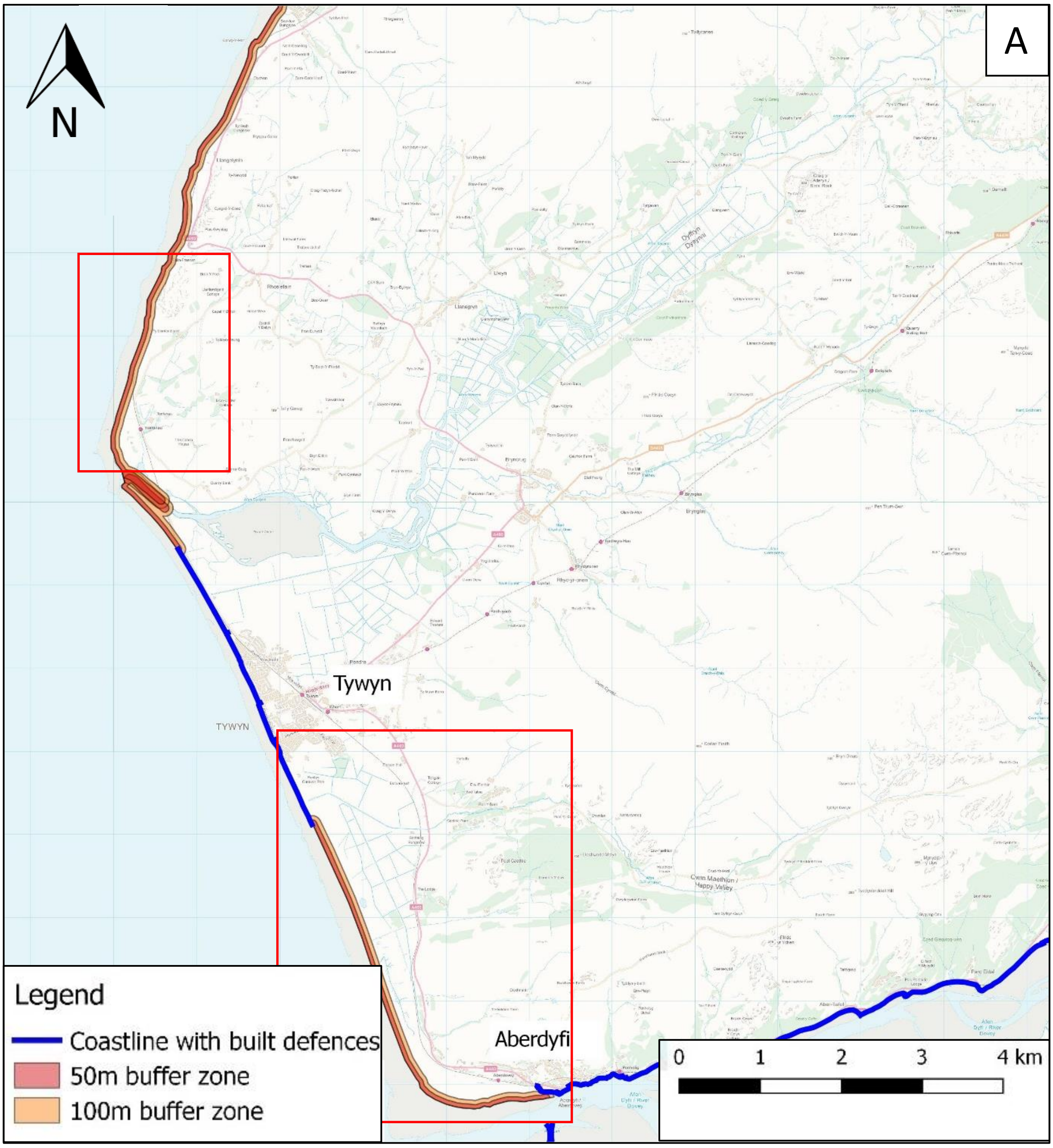
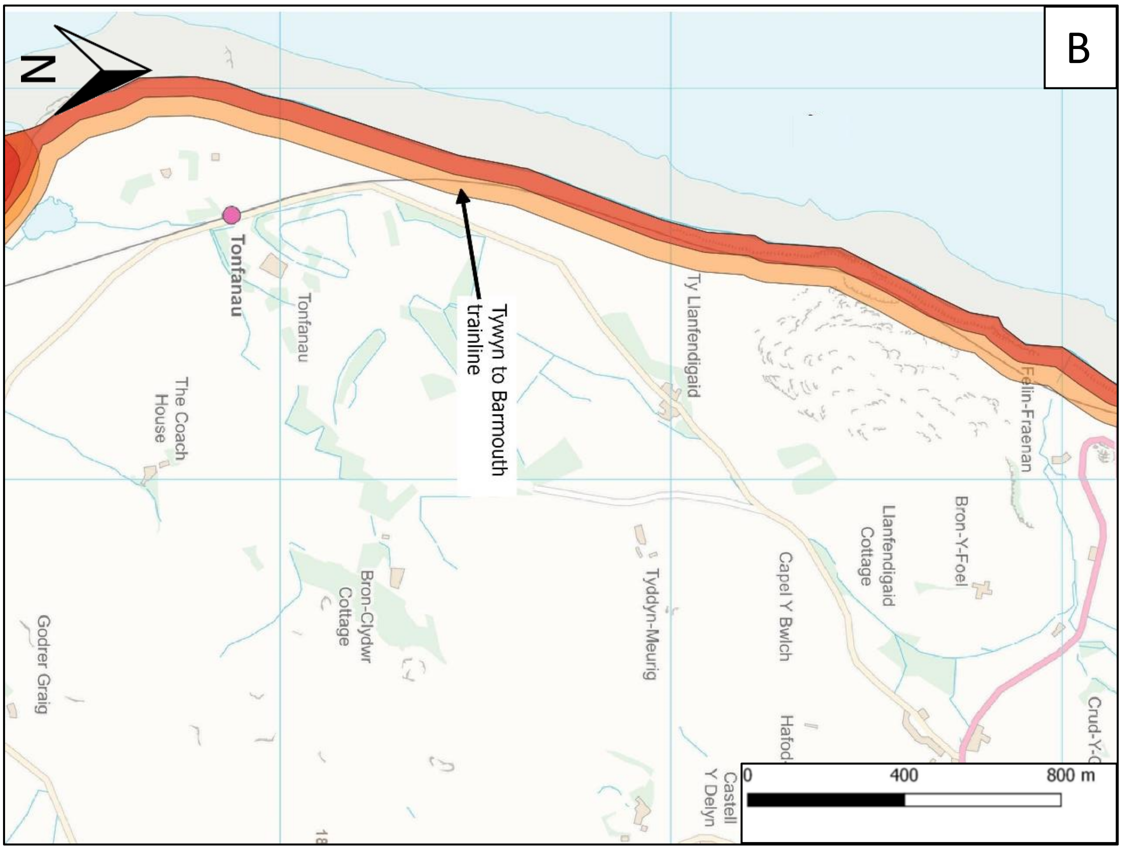


Figure 7.9. *Map indicating the location of built defences in the study area, and the erosion buffer zone along unprotected stretches of shoreline (A). B and C (below) are magnified areas indicated in red in A, demonstrating the assets at risk from erosion, such as the Aberdyfi Golf Club and the trainline. Crown copyright and database right 2019 Ordnance Survey 100025252*



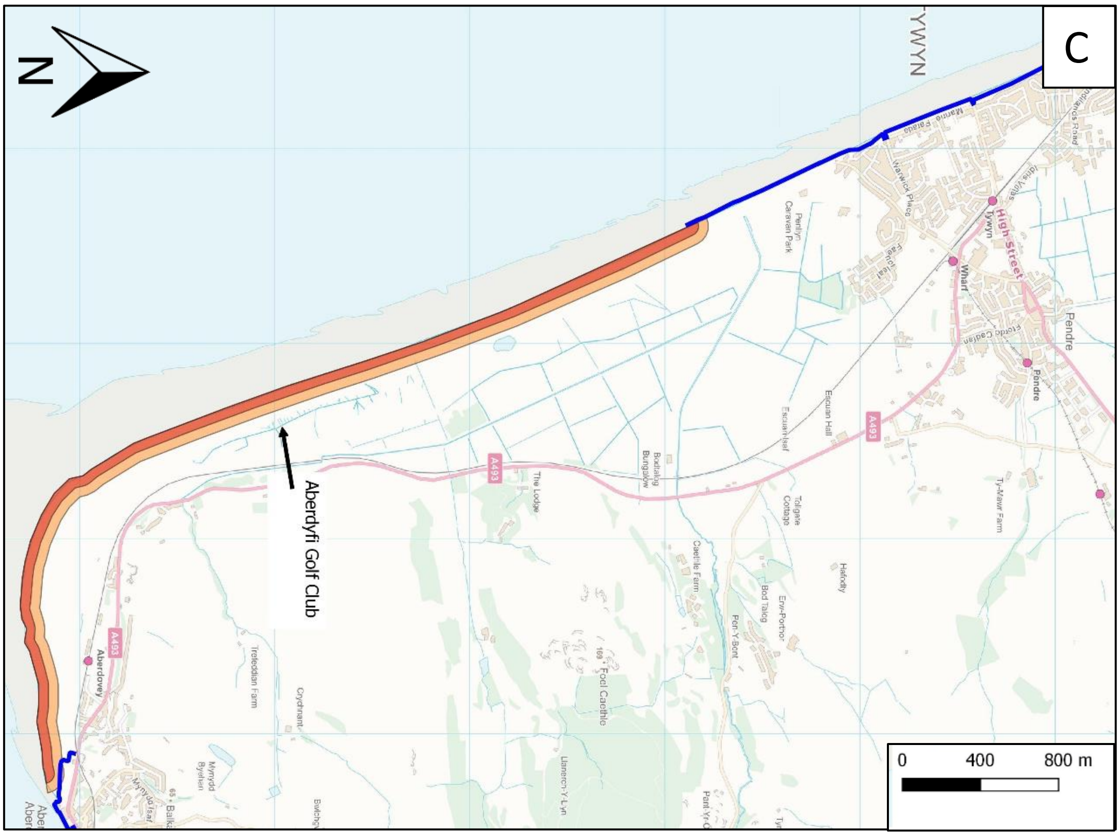


Figure 7.9 cont.

Susceptibility to Soil Erosion

The final criterion studied the susceptibility of each LCA to loss of land surface, and therefore a change in character, due to soil erosion. Soil property data was downloaded for the study area from the British Geological Survey (Cranfield University 2018), which comprised 69 polygons and included attributes such as drainage, fertility, land use, soil water regime, dominant and associated soils and their characteristics.

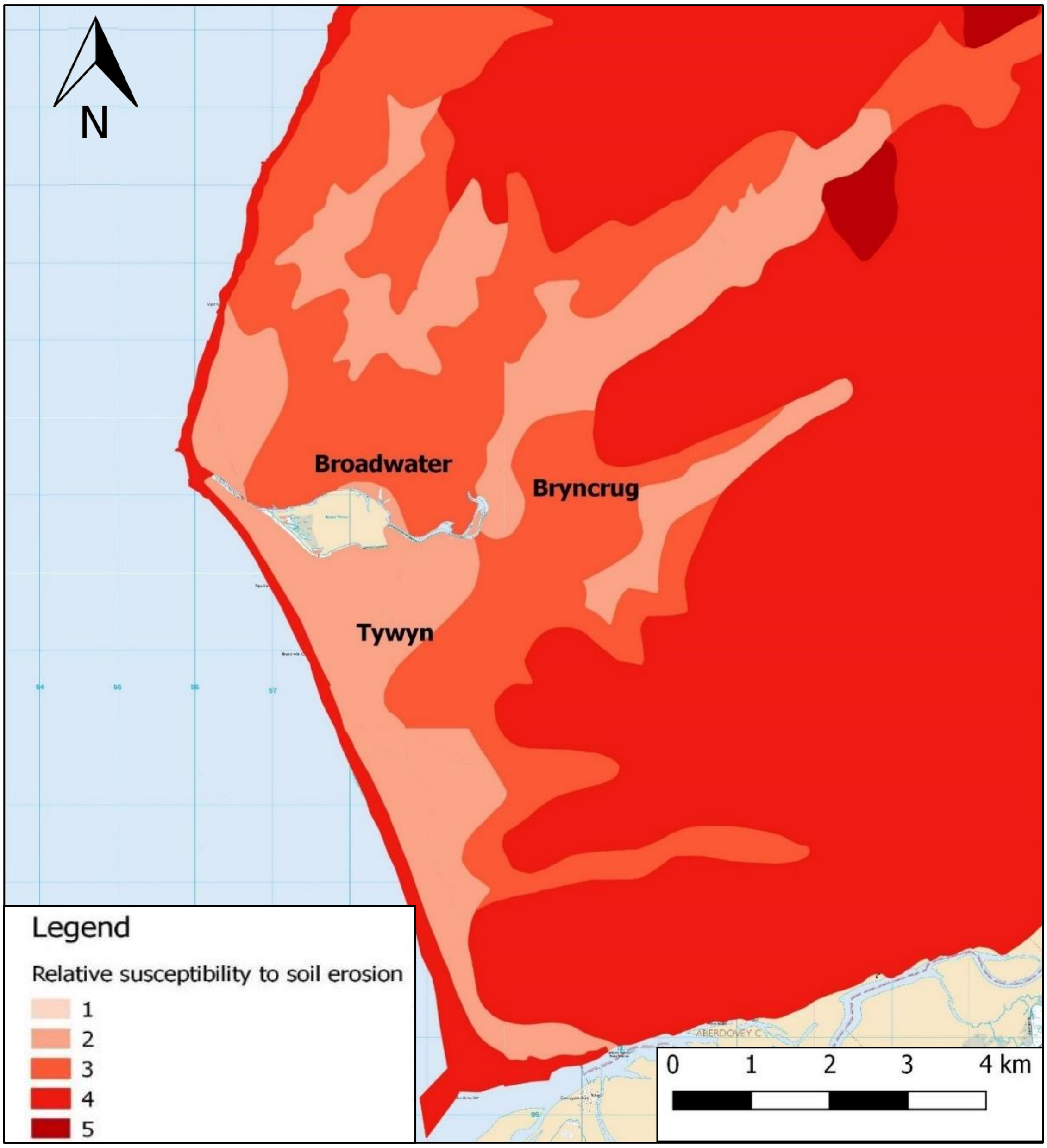


Figure 7.10. *Susceptibility of soil in the Dysynni valley to soil erosion, based on soil characteristic data from the British Geological Survey, from 1 (very low) to 5 (very high). Crown copyright and database right 2019 Ordnance Survey 100025252*

The susceptibility of each polygon to erosion was ranked between one and five based on the following characteristics:

i) In an area at risk of floodwater scouring or runoff

ii) Sandy/unstable soils at risk of wind erosion during dry periods

iii) Risk of sheet erosion during high-precipitation events

iv) Shallow soils and bare rock in places

v) Risk of soil erosion due to grazing and trampling

vi) Slow or impeded drainage

vii) Steep slopes

Polygons with none of the above characteristics were given a susceptibility rating of 1. Those with one of the above characteristics were rated 2, those with two of the characteristics were rated 3, those with three of the characteristics were rated 4, and those with four or more of the above characteristics were rated 5 (see Figure 7.10; Table 7.6). The soil map shapefile was then transformed into a raster file using the Rasterize function, and the susceptibility to soil erosion was kept as the attribute field. The Zonal Statistics tool was then used to extract and calculate the mean susceptibility to soil erosion from the soil map raster for the area in each LCA. The values obtained were used as the values in the Stage 2 VI equation. An alternative method would be to use the susceptibility rating of the most common soil type in the LCA, in order to have only whole numbers in the VI equation. However, this method could either obscure or overstate the susceptibility of the LCAs to soil erosion. For instance, if 50% of the LCA had a soil susceptibility rating of 2, 40% had a rating of 3, and 10% had a rating of 4, using the mode value (2) instead of the mean (2.6) would understate the susceptibility of the LCA to soil erosion.

7.5.3 Results

Stage 1 results

In total, 144 sites were included in the initial vulnerability assessment of archaeological features. This includes both the 64 sites visited during the ground-truthing exercise, and the desk-based analysis of a further 80 sites. The Stage 1 scores for each LCF can be seen in Figure 7.11 and Appendix 3 Table Ap3.5.

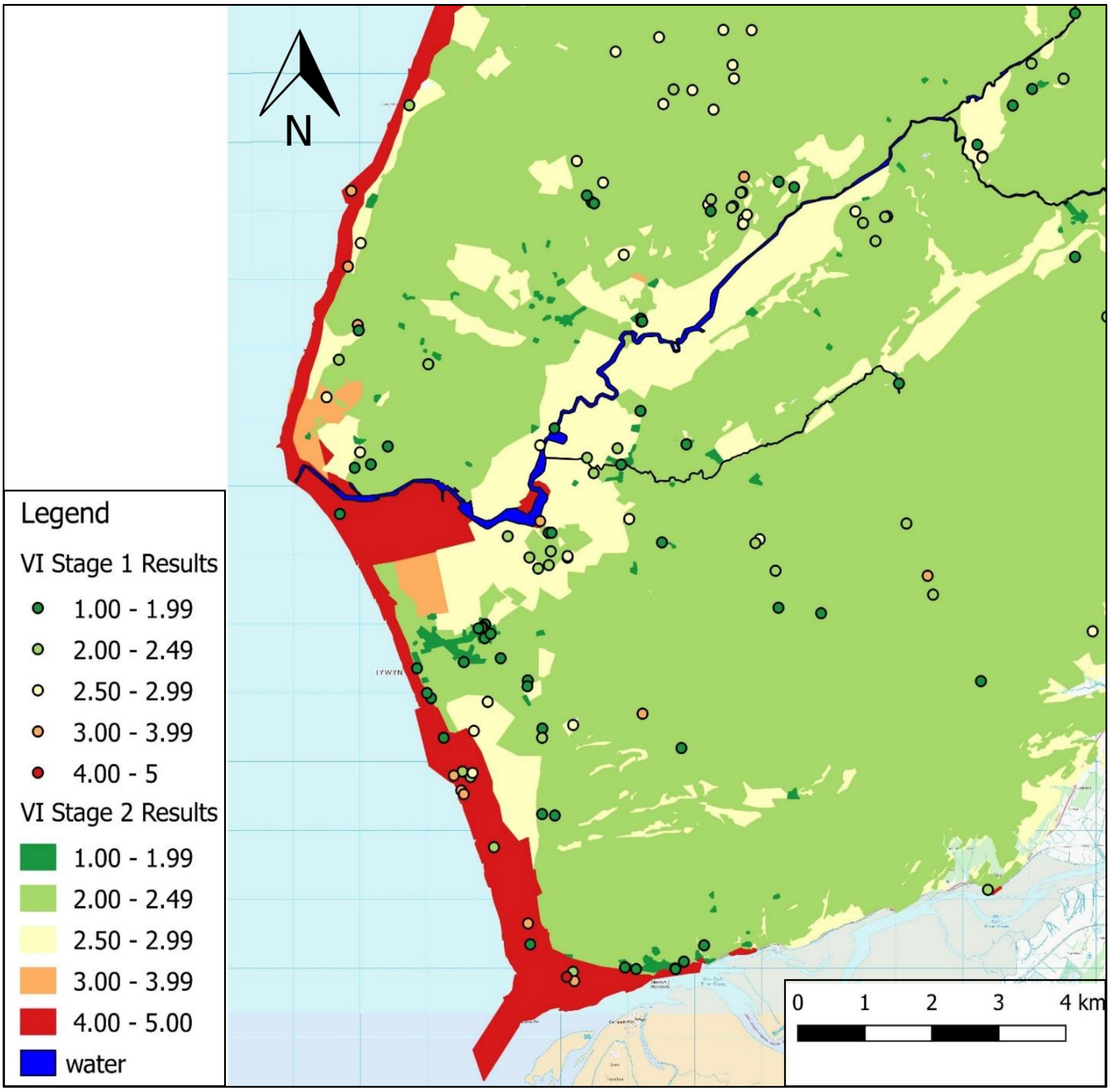


Figure 7.11. *Results of Stage 1 and Stage 2 of the vulnerability index, from 1 (very low vulnerability) to 5 (very high vulnerability). Crown copyright and database right 2019 Ordnance Survey 100025252*

Of the LCFs analysed, 42 (29.2%) had a Stage 1 VI score of $1 \leq x < 2$, considered a very low vulnerability score. Most of these (n=32) were post-medieval or modern built features that were currently in use, such as a new church, farm cottages, and townhouses. This means that they were relatively recently constructed, and are also being actively managed against decay. It is noteworthy that 28 of these features are located in urban areas, which are positioned mainly in flatter areas at lower risk from gully erosion.

Fifty-one features (35.4%) had Stage 1 VI scores of $2 \leq x < 2.5$, or low vulnerability to the potential impacts of climate change. These features are spread across both lowland and upland areas, and include a range of modern and historic, built and earthwork features. Twenty-six features (18%) had Stage 1 VI scores of $2.5 < x < 3$, or moderate vulnerability. Most of these were located in upland areas, and consisted of features such as the remains of post-medieval quarries and sheep-farming.

Only 22 LCFs (15.3%) had Stage 1 VI scores of $3 \leq x < 4$, or high vulnerability. Of these, over half (n=12) were located in steeply sloping areas, indicating that flow accumulation (or the risk of gully erosion) may be an important factor for addressing the threat of climate change to archaeology in mountainous or hilly areas. Furthermore, 11 (50%) of these features are earthworks, compared to none of the low vulnerability features and 27% of the moderate vulnerability features. This suggests that earthwork features are more vulnerable to the potential impacts of climate change compared to stone and brick-built features. This is partly determined by the fact that feature material was, for two of the variables, used to influence the score given, so earthwork features were given a score of at least 3 for two variables. For features to have Stage 1 VI scores greater than 3, the mean score of the variables must be greater than 3. Therefore, having only two variables that give earthworks a score of 3 does not solely account for the high proportion of earthworks with high vulnerability. Another explanation may be that earthworks were also more likely to be found on unconsolidated sediments, and in a less well preserved state, which further increased their vulnerability.

Finally, only three features (2%) had a Stage 1 VI score of ≥ 4. Two of these features were organic remains (a section of submerged forest, and an area of peat cutting – see Figure 7.12), making them particularly susceptible to temperature increase and desiccation. Additionally, two of the features were located on sand or beach deposits in the intertidal zone, making them at high risk of undermining due to the unstable nature of this superficial deposit.

Stage 2 results

Of a possible range of 1-5, the results LCA VI scores range from 1.93 to 4.2 (see Table 7.6 and Figure 7.11). Only one LCA (Historic Settlement) has a Stage 2 VI score of less than 2. In particular, the

Historic Settlement LCA had low scores for both LFC vulnerability and risk of coastal erosion, likely due to the presence of coastal defences along the urban areas in the Dysynni valley.

Figure 7.12. *Two of the most vulnerable features as assessed by Stage 1 of the vulnerability index: an area of peat cuttings (A) and the remains of a submerged forest (B), both on Tywyn beach. The images DS2016_066_005 and DS2016_066_009 are Crown copyright and are reproduced with the permission of Royal Commission on the Ancient and Historical Monuments of Wales (RCAHMW), under delegated authority from The Keeper of Public Records.*

Nine LCAs (53%) had a Stage 2 VI score of 2 ≤ x < 2.5 (Modern Woodland, Ancient, Irregular Fieldsystems, Modern Settlement, Irregular Drained Land, Tourism, Modern Industry, Historic Industry, Rough Pasture). These are mainly located above the floodplain, and predominantly in inland, upland areas, so have 'very low' or 'low' risk of tidal and fluvial flooding and coastal erosion. The Tourism LCA does have a large area located at the coastline (Aberdyfi golf course), however the high dunes fronting the golf course protect the area from 1-in-100 year or more frequent flood events. Furthermore, there are several other areas of the Tourism LCA (generally caravan and camp sites) located further inland.

Table 7.8: *Stage 2 Vulnerability Index scores, in descending order of Stage 2 score*

LCA	Stage 1 score	Risk of Flooding or Inundation	Risk of Coastal Erosion	Risk of Soil Erosion	Stage 2 Score
Maritime Industry	3.2	5	5	3.6	4.2
Wetland	3.083333	5	5	3	4.021
Military	2.2	4	4	3.8	3.5
Regular drained	2.485714	5	1	2.1	2.646
Ancient Woodland	2.575	3	2	3	2.644
Regular field	2.4	3	2	2.8	2.55
Ornamental	2.171429	4	1	3	2.543
Rough pasture	2.473684	1	2	3.8	2.32
Historic Industry	2.388889	1	2	3.8	2.297
Modern Industry	2	3	1	3	2.25
Tourism and Recreation	1.8	2	2	3	2.2
Irregular drained	2.08	3	1	2.5	2.145
Modern Settlement	1.4	2	2	2.9	2.075
Irregular Field	2.311111	2	1	2.9	2.053
Ancient	2.482353	1	1	3.7	2.046
Modern Woodland	2.514286	1	1	3.5	2
Historic Settlement	1.72	2	1	3	1.93

Four LCAs had a Stage 2 VI score of $2.5 \leq x < 3$ (Ornamental, Regular Field Systems, Ancient Woodland, and Regular Drained Land). These LCAs are predominantly located on the flat valley floor, and are therefore at risk of both fluvial and tidal flooding, but they are located away from the coastline and so are not threatened by coastal erosion.

Finally, only three LCAs scored greater than 3 (Military 3.5, Wetland and Beach 4.021, Maritime Industry 4.2). A small area of the Military LCA is located in the uplands, but most of the Military LCA is located on or near the coastline, such as the line of pillboxes along Aberdyfi beach – see Figure 7.13), and is therefore at risk of flooding or coastal erosion. Both Wetland and Beach and Maritime Industry LCAs are located on the coastline or in Broadwater, and so are at high risk from both coastal erosion and flooding. Furthermore, the features that characterise both of these LCAs had high Stage 1 scores due to their ephemeral nature and high levels of degradation.

The VI scores for these three LCAs are the only ones classified as outliers (over 1.5xIQR greater than the third quartile). This indicates that they are significantly more vulnerable than the other LCAs to the impacts of climate change, based on this VI.

Summary

This section discussed the results of the VI applied to the HLC of the Dysynni valley, both Stage 1 (vulnerability of LCFs), and Stage 2 (vulnerability of LCAs). Overall, the results revealed that more than half of the Stage 2 scores were clustered between 2 – 2.32, and that very few had scores lower than 2 or greater than 3. The spread of the Stage 2 scores allowed easy identification of outliers with particularly high vulnerability relative to other LCAs: Military, Wetland and Beach, and Maritime Industry. The coastal and flood risk management approaches discussed in Chapter 8 are analysed in terms of their impact on these three LCAs.

Figure 7.13. *Two examples of pillboxes along Aberdyfi beach at different levels of preservation*

7.6 Discussion

The following section reviews different methods of result classification that are used in academic studies, and how they influence the conclusions or suggestions for management. Subsequently, there is a discussion regarding the implications of the VI results, the robustness of the data used in the VI, and what the results were used for in the following chapters.

7.6.1 Classification and display of results

Having completed the VI methodology development and data collection, the next aim of this thesis was to evaluate approaches for the sustainable management of the most vulnerable elements of the historic landscape. In order to do this, the LCAs that occur in the 'most vulnerable' bracket based on the VI results were identified. The VI produces a numerical score between 1 and 5, but this alone does not provide a threshold score that defines whether or not an LCA should be prioritised for management.

There are several different methods used by other studies to divide and display results, and therefore inform which areas or sites are considered a priority for management. The purpose of this literature review is first to discuss the different ways in which other researchers who use VIs (or other similar indices) classify their results into different levels of vulnerability, and what the implications would be if each method was applied to the results of this study. The second section explores the ways in which different studies use the VI score and classification to define which sites or areas should be prioritised for management or further study. The results of the second section informed the methods that were used to classify the VI results, and crucially which LCAs were included when evaluating potential management approaches. In the final section, several different classification approaches were applied to the results, to determine what impact the different approaches could have on the conclusions of this study.

7.6.1 Classification and display of results in other studies

A. Binary (i.e. Yes/No)

Some researchers who used very simple indices divided their results in a binary fashion, so areas were either 'at risk/vulnerable' or 'not at risk/not vulnerable', rather than creating a scale of more to less vulnerable. Bickler *et al.* (2013) only included two variables in their VI: coastal flooding and coastal erosion. Sites in their study area were either defined as at risk (because they were in the defined flood zone and/or erosion zone) or not at risk (because they were not in the flood and erosion zones) (see also Robinson *et al.* 2010; Westley and McNeary 2014).

When applied to this study (see Figure 7.14A), the threshold for which LCAs were considered vulnerable was set as a score of 3, because it is the middle point of the available scores (1-5). In this case, the LCAs considered 'vulnerable' are Military, Wetland and Beach, and Maritime Industry, and all other LCAs are considered 'not vulnerable' (see Table 7.14). This approach is not suitable for the results of Stage 2 of the VI as more variables were included than in the example studies above, and the range of results is too wide to be confined to two categories.

B. Equal Interval

A common method used is to divide results into groups of equal interval based on the VI score. Widyastuti and Suprayogi (2016) divide their results into low vulnerability (score 10-20), medium (>20-30) and high (>30-40) (See also Barbat *et al.* 2010; Kurniawan *et al.* 2016). Other researchers, such as Guégen *et al.* (2007), use a greater number of classes with a smaller interval. In this case, their results range from 0 to 0.75, and they divide the results into 15 classes each with an interval of 0.05 (see also Yoo *et al.* 2011). This is a very simple method of categorising the VI results as it does not require any analysis of the data. It can also facilitate the comparison of results between different areas, as the scores defining low, medium, and high vulnerability (or whatever divisions are chosen) will be the same regardless of the skew of the scores produced. It is less useful a method of classification in instances where the results are skewed so that most fall into a single vulnerability class. Except in cases where a large number of classes with a small interval are used, this classification method is not useful for indicating the relative vulnerability of the sites or areas in the study.

Three different iterations of the equal interval approach were undertaken for the results of this study (see Figure 7.14B): B1 had three classifications (Low [1-2.33], Moderate [2.34-3.66], High [3.67-5]), B2 had four classifications (Low [1-1.99], Moderate [2-2.99], High [3-3.99], Very High [4-5]), and B3 had five classifications (Very Low [1-1.8], Low [1.81-2.6], Moderate [2.61-3.4], High [3.41-4.2], Very High [4.21-5]). The threshold of LCAs considered Low and Moderate vulnerability varied significantly between the iterations. Wetland and Beach and Maritime Industry were considered High vulnerability in B1 and Very High vulnerability in B2. In B3, Military and Wetland and Beach were classified as High Vulnerability, with only Maritime Industry classified as Very High Vulnerability (see Table 7.19).

Table 7.9: *Comparison of the results when classified in different ways: Binary (A), Equal Interval (B), Equal Count (C), Standard Deviation (D), Jenks Natural Breaks (E)*

LCA	Score	A	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3
Historic Settlement	1.93	Low	Low	Low	Low	Low	Low	Very Low	Moderate	Low	Low	Low	Low	Very Low
Modern Woodland	2.0	Low	Low	Moderate	Low	Low	Low	Very Low	Moderate	Low	Low	Low	Low	Low
Ancient	2.046	Low	Low	Moderate	Low	Low	Low	Very Low	Moderate	Low	Low	Low	Low	Low
Irregular Field System	2.053	Low	Low	Moderate	Low	Low	Low	Very Low	Moderate	Low	Low	Low	Low	Low
Modern Settlement	2.075	Low	Low	Moderate	Low	Low	Low	Low	Moderate	Low	Low	Low	Low	Low
Drained Irregular Land	2.145	Low	Low	Moderate	Low	Low	Moderate	Low	Moderate	Low	Low	Low	Moderate	Low
Tourism and Recreation	2.2	Low	Low	Moderate	Low	Moderate	Moderate	Low	Moderate	Low	Low	Low	Moderate	Moderate
Modern Industry	2.25	Low	Low	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Low	Moderate	Moderate
Historic Industry	2.297	Low	Low	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Low	Moderate	Moderate
Rough Pasture	2.32	Low	Low	Moderate	Low	Moderate	High	Moderate	Moderate	Moderate	Low	Low	Moderate	Moderate
Ornamental	2.543	Low	Moderate	Moderate	Low	Moderate	High	High	Moderate	Moderate	Low	Moderate	High	Moderate
Regular Field System	2.55	Low	Moderate	Moderate	Low	High	High	High	Moderate	Moderate	Low	Moderate	High	Moderate
Ancient Woodland	2.644	Low	Moderate	Moderate	Moderate	High	High	High	Moderate	Moderate	Moderate	Moderate	High	Moderate
Drained Regular Land	2.646	Low	Moderate	Moderate	Moderate	High	Very High	High	Moderate	Moderate	Moderate	Moderate	High	Moderate
Military	3.5	High	Moderate	High	High	High	Very High	Very High	High	High	High	High	High	High
Wetland and Beach	4.021	High	High	Very High	High	High	Very High	Very High	High	High	Very High	High	Very High	Very High
Maritime Industry	4.2	High	High	Very High	Very High	High	Very High	Very High	High	High	Very High	High	Very High	Very High
Legend		Very Low			Low		Moderate			High		Very High		

C. Equal Count

Another simple method of classifying results is by equal count, in which the same number of objects are put into each vulnerability category. This displays the vulnerability of the sites or areas by the score relative to the other objects in the study, rather than the absolute score. Allison *et al.* (2009) use quartiles to divide their results; the first quartile (0-25%) of objects scores are classified as 'very low vulnerability', the second quartile (25-50%) are 'low vulnerability', the third quartile (50-75%) are 'medium vulnerability', and the fourth quartile are 'high vulnerability'. Garthe and Hüppop (2004) use a similar method, but use 20 percentiles rather than 25 percentiles to divide results (see also Özyurt and Ergin 2009). The equal count method was also undertaken with three different iterations when applied to the results in this research (see Figure 7.14C). C1 had three classifications

(Low [1-2.4], Moderate [2.41-2.73], High [2.74-5]), C2 had four classifications (Low [1-2.22], Moderate [2.23-2.5], High [2.51-2.75], Very High [2.76-5), and C3 had five classifications (Very Low [1-2.18], Low [2.19-2.45], Moderate [2.46-2.7], High [2.71-2.8], Very High [2.81-5]). In all three iterations, Drained Regular Land, Ancient Woodland, Regular Field System, Military, Wetland and Beach and Maritime Industry were classified as High or Very High vulnerability, and in C2 and C3, Ornamental land was also considered High vulnerability (see Table 7.11). C2 is the only iteration across all approaches that classifies Rough Pasture as having High Vulnerability.

D. Standard Deviation

Standard deviations are another way that VI results are classified into levels of vulnerability. Rygel *et al.* (2006) classify results into four categories based on the amount that they deviate from the mean: <-0.5 SD; -0.5-0.5 SD; 0.5-1.5 SD; >1.5 SD. McLeod *et al.* (2010) also use standard deviation, but they divide the results into three vulnerability classes: Low vulnerability (<-1 SD), Medium vulnerability (+/- 1 SD), and High vulnerability (>+1 SD) (see also Dismukes and Narra 2015). This approach does not produce classes of equal interval or equal count, but rather indicates how much more or less vulnerable an area is compared to the average.

When applied to the results of this research, three iterations of this approach were undertaken: D1 has three classifications (Low [<-1 SD], Moderate [+/-1 SD], High [>+1 SD]), D2 also had three classifications (Low [<-0.5 SD], Moderate [+/-0.5 SD], High [>+0.5 SD]). D3 had 5 classifications (Very Low [<-1 SD], Low [-1 SD – 0 SD], Moderate [0 SD - +1 SD], High [+1 SD - +2SD], Very High [>+2 SD]). In all three cases, Military, Wetland and Beach, and Maritime Industry LCAs are classified as High vulnerability, with Wetland and Beach and Maritime Industry classified as Very High in D3 (see Figure 7.14D, Table 7.11). In D1, no LCAs were classified as having Low Vulnerability, indicating that the data is positively skewed.

E. Jenks Natural Breaks

Only one of the VI studies reviewed (Ghobadi *et al.* 2018) used the natural breaks technique, also known as the Jenks natural breaks classification method or Jenks optimisation method. This approach is a data clustering method which groups scores into classes in which the scores are as close to the median of the class as possible, and as far as possible from the median of other classes. This maximises the similarity of scores within each class, and maximises the differences between classes. Unlike the other methods tested, this approach goes some way towards addressing the limitation that classifying scores into groups can hide the similarities between scores in different classes.

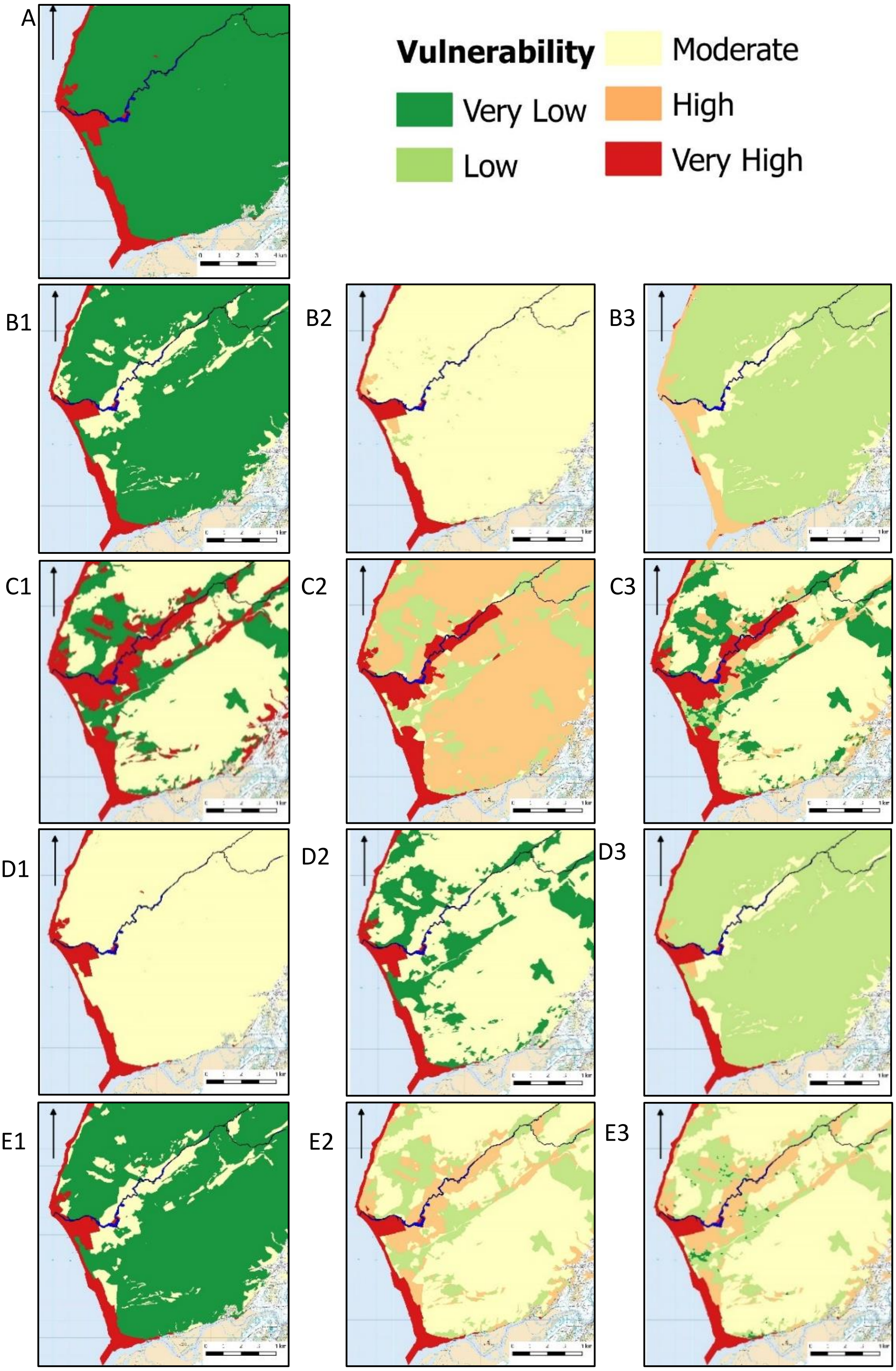


Figure 7.14: *Comparison of the 5 different methods of result classification: Binary (A), Equal Interval (B), Equal Count (C), Standard Deviation (D), Jenks Natural Breaks (E). Methods B-E had 3 different iterations with different number of classes or class divisions. Larger, more detailed maps are provided in Appendix 3 Figure Ap3.1. Crown copyright and database right 2019 Ordnance Survey 100025252*

The Jenks natural breaks method was undertaken three times when applied to the results of this research (see Figure 7.14E): E1 had three classifications (Low [1-2.23], Moderate [2.24-2.77], High [2.78-5]), E2 had four classifications (Low [1-2.23], Moderate [2.24-2.5], High [2.51-3.7], Very High [3.71-5]), and E3 had five classifications (Very Low [1-2], Low [2.01-2.23], Moderate [2.24-2.5], High [2.51-3.7], Very High [3.8-5]). This method showed the most variation in the way the LCAs were classified between iterations compared to the other methods (see Table 7.11). E1 classified Wetland and Beach and Maritime Industry as High, with E2 and E3 classifying them as Very High vulnerability. Military was classified as High vulnerability across all three iterations. E2 also classified Ornamental, Regular Field System, Regular Drained Land, and Ancient Woodland as High Vulnerability.

Low, Moderate and High, but not (seemingly) related to a score

Several studies display their results in vulnerability classes (often low, medium and high, or very low, low, medium, high, very high) without indicating how the classification was decided or undertaken. In some cases the authors provide information on which raw scores are divided into each class, but no obvious justification is given, and the classes have unequal intervals and unequal counts (e.g. Abuodha and Woodroffe 2010; Botero-Acosta *et al.* 2017). In other cases, the vulnerability classes are displayed visually on a map but there is no indication of which VI scores go into each class (e.g. Ibe *et al.* 2001; Andreo *et al.* 2006; Hunt 2011; Reeder *et al.* 2012). This is not a transparent way to display results, as the results could be divided and classified in a way that specifically supports or disproves a certain hypothesis or agenda. Regardless of the classification method used, it is important to explain the method used and explicitly state which VI scores fall into which vulnerability class. Without this, it is difficult to justify why some objects should be given management or conservation priority over others. This method was not applied to the results of this study, as it is not a defined method.

Classification and displaying the results of this study

Of the studies reviewed, the most common approach for classifying and displaying results is to create vulnerability classes without indicating how/why the results were divided thus, or in some cases what scores are classified into each group. This is concerning as the most common method for identifying objects to prioritise for management and conservation is by the vulnerability class that they fall into. If the score range for these classes is decided arbitrarily, or not justified, then the threshold for what should or should not be prioritised is also somewhat arbitrary.

All methods of result classification tested classified Wetland and Beach and Maritime Industry LCAs as High or Very High vulnerability. The Military LCA was also classified as High or Very High vulnerability in all but one iteration. All other LCAs were more frequently classified as Moderate, Low or Very Low vulnerability than High or Very High. The next section of this research, namely evaluating the suitability of potential coastal and archaeological management approaches, focuses predominantly on the Military, Wetland and Beach and Maritime Industry LCAs and the specific threats posed thereto. These three LCAs are consistently classified as being highly or very highly vulnerable regardless of the classification method used. Moreover, the VI scores for these three LCAs are the only ones classified as outliers (over 1.5xIQR greater than the third quartile). This indicates that they are significantly more vulnerable than the other LCAs to the impacts of climate change, based on this VI.

Using results to inform prioritisation and management

This section compares the different ways that other VI studies use their results to suggest prioritisation or management of the objects of their research. Some studies recommend the prioritisation and management of sites that were classified as 'high' vulnerability, or 'high' and 'very high', depending on the classifications chosen in the study (e.g. Garthe and Hüppop 2004; Allison *et al.* 2009; McLeod *et al.* 2010; Hunt 2011; Westley *et al.* 2011; Reeder *et al.* 2012; Ghobadi *et al.* 2018). The objects included in the 'high' and 'very high' vulnerability classes are dependent upon the method used to group the results, as discussed above. In many cases the chosen method of result classification and display has a direct impact on the way that the results may be utilised.

In the case of Bickler *et al.* (2013), their simple VI meant that sites were classified as vulnerable or not vulnerable, so all objects classed as vulnerable may be priorities for management or conservation. This is a straightforward method of prioritisation, but is not applicable in instances where the VI is more complex and produces a range of results. It is also unhelpful if too large a number of objects would be classified as 'vulnerable' for them all to be prioritised, as then another method of ranking would also have to be used.

Westley and McNeary (2014) identify regions that are outliers in terms of their vulnerability, i.e. areas with particularly high scores, as the scores for the other areas cluster closely together with little to separate them. They argue that objects that are markedly more vulnerable should be addressed or prioritised, rather than just an arbitrary percentage of the overall objects. If this approach was used for the results of Stage 2 of the VI, the outlying LCAs would be Military, Wetland and Beach, and Maritime Industry, as all other results are clustered more closely together.

Rather than focusing on the final VI score, Adu *et al.* (2017) argue that prioritisation of areas for further study and management should be based on those that scored highest for individual variables. This would make the type of management required easier to define as there may be a single issue to address, rather than a high vulnerability score caused by a wide range of issues. However, this might not capture the areas that are most in need of management, or those in which the interaction between different variables compounds the overall vulnerability.

Rather than state which objects should be researched or managed based on the VI results, some studies only touch upon the way that their results should be used. Ortiz *et al.* (2014), in identifying areas of environmental risk in a historic city, say that their results should be used to help decide which historic monuments should be prioritised in order to carry out preventative conservation measures. However, they do not specify exactly which monuments, or level of vulnerability, this refers to. Preston *et al.* (2009) used a VI for an Australian landscape to identify areas more or less vulnerable to bush fires. They state that the vulnerability maps created as an output can be used in local government risk assessment and adaptation, but they don't specify which areas should be prioritised or exactly how the information would inform risk assessment and adaptation (see also Abuodha and Woodroffe 2010; Dismukes and Narra 2015; Kurniawan *et al.* 2016; Botero-Acosta *et al.* 2017).

Finally, a large number of studies reviewed did not discuss specifically how the results of their VI would, or should, be used at all beyond answering that study's research question (see Rygel *et al.* 2006; Fekete 2009; Alexandrakis *et al.* 2011). Several of these papers were focussed on developing a VI methodology using a case study rather than researching the vulnerability of a particular system for policy purposes. Therefore, these do not help inform the methods for displaying the VI results in this study, or identifying the LCAs that should be prioritised for management (see Chapter 8).

Summary

This research assesses the vulnerability of 17 LCAs over a large landscape, so narrowing down the number prior to evaluating the most appropriate management approaches is crucial. Public sector archaeological organisations have tight budgets, and many coastal management techniques can be extremely costly. The range of threats, land-uses and environmental conditions in the study area means that identifying a suitable, sustainable management approach that would suit all 17 LCAs would be difficult if not impossible. The VI results of this research (and therefore suggestions for management of LCAs) must be classified based on their level of vulnerability. When applied to the results in this study, there was clear variation in the way that different LCAs were classified in terms of their vulnerability (see Table 7.9, Figure 7.14).

7.6.2 Implications of the vulnerability index results

The three LCAs identified as being the most vulnerable in the study area are also particularly important for the Dysynni landscape. As a coastal area, Wetland and Beach is a key element of the character of the landscape, and links strongly to local identity and sense of place. Seaside tourism is an important industry for both Tywyn and Aberdyfi – 29% of the employment in Tywyn is in the hotel, café and restaurant sector (Beatty *et al.* 2009). However, Tywyn in particular has an ageing population, and had a 15% decline in employment rates between 2003/4 and 2006/7 (*ibid*.). Tywyn beach has lowered and retreated significantly, and the presence of sea walls and groynes reduces the amenity value of the beach for leisure (Mead 2009). Further damage to the Wetland and Beach LCA could have a detrimental impact on Tywyn as a seaside resort, and therefore on the local economy, as well as on the historic landscape.

The Maritime Industry LCA is also important for the local history of the study area. Aberdyfi village was founded around the fishing and ship building port here during the post-medieval period, and the structural remains of this (e.g. harbours, shipyards, jetties and shipwrecks) strongly influence the character of the town and coastline today (SNPA 2014a). Commercial use of the jetty and wharf continued until 1959, and since then it has been a popular marina for recreational seafaring, as well as some small-scale fishing (Lewis 1997). Numerous sources suggest that Broadwater was also used for shipbuilding before it silted up, and that small sailing boats could traverse the River Dysynni to transport peat cuttings in the 18th and 19th centuries (Rolt 1998; Hawes 2014; Tilt 2015; Brominicks 2016), although there is no firm historical evidence for this. Archaeologists also suggest that the River Dysynni was used for maritime and river transport during the Neolithic, and that Broadwater may have been an important landing place during prehistory, indicated by a prehistoric trackway leading northwards from Broadwater towards Dolgellau (Bowen and Gresham 1967; Smith 2004b; GAT 2016). This connection to seafaring and maritime industry is an important element of the heritage of the Dysynni valley, and to the way that local people perceive the landscape.

Finally, the Military element of the historic character of the Dysynni valley, and its associated features, date primarily to the First and Second World Wars. The coastline of Cardigan Bay was a strategic location as the Irish Free State across the Irish Sea was considered to be vulnerable to German invasion during the Second World War. Defensive features such as pill boxes were installed along the coastline, and RAF Towyn (sic) was established and operated between 1941 and 1945. Following the Second World War, the RAF Towyn camp was taken over by the army and was in use until 1965 (Gwyn and Davidson 2009). There are also several aircraft crash sites in the landscape, and a memorial stone for three children killed in 1944 by an unexploded mortar bomb (BBC News 2015). Other memorials to both world wars in the Dysynni valley include Tywyn Memorial Gardens (WWI+II), Tywyn Church Porch memorial (WWI+II), Llanegryn memorial (WWI), Aberdyfi Memorial (WWI+II), and Tywyn Memorial Hospital (WWI). The First and Second World Wars are still an important part of national identity for many British people, and the military remains and high density of memorials in the Dysynni valley (population c.6000 – ONS 2011) suggests that this is a significant element of the character of the historic landscape.

This is not to say that the LCAs that are less vulnerable to climate change also happen to be less important to the historic character of the study area; an important principle of HLC is that it is 'value-free', and does not give some LCAs greater worth than others. However, it is important to recognise that some LCAs and associated features may have a greater connection to local people's sense of cultural heritage, and connection to their history or current way of life.

When displayed visually (see Figure 7.11), the results indicate that the character of the historic landscape most threatened by climate change is the coastline and the estuary of the River Dysynni. This is perhaps unsurprising as two of the four variables used to assess vulnerability were related to coastal and hydrological processes (Risk of Flooding; Risk of Coastal Erosion). The results for the Risk of Soil Erosion variable negatively correlate with the overall results and have higher scores in upland areas. Furthermore, even though Stage 1 of the VI assessed a range of factors unrelated to the coastal location of the study area, there is a moderate positive correlation between the Stage 1 score variable and the Risk of Coastal Erosion variable (0.56) and Risk of Flooding variable (0.4). The Maritime Industry and Wetland and Beach LCAs also scored significantly higher for the Stage 1 scores than any other LCA, indicating that LCFs located near the coast are more vulnerable to the impacts of climate change even before the exposure to erosion and flooding is considered. This may be because these features have been subject to coastal processes, and so have lower levels of preservation than features located in the uplands. Overall, therefore, the historic character of the landscape in the coastal regions of this study area is most vulnerable due to sensitivity and resilience as well as exposure. With vulnerability index methods, the choice of variables used to determine vulnerability inevitably influence the findings. If the only variables chosen related to inland processes, the results would be different. This is why a detailed discussion of climate change impacts was necessary (see Chapter 2), in order to ensure that the variables chosen were the most relevant to known threats.

7.6.3 Reliability and robustness of the study

Part of this study involved a field-based ground-truthing exercise, and then a desk-based completion of Stage 1 of the VI. In order to establish whether carrying out over half of the Stage 1 analysis remotely affected the overall VI results, the Stage 2 results were calculated based only on the LCFs visited, as well as on all LCFs assessed. There was a correlation of +0.989 between the visited LCFs only Stage 2 results and the overall Stage 2 results. Therefore, the LCFs that characterise each LCA gave similar Stage 1 scores regardless of whether they were visited or assessed remotely. This indicates that the VI methodology developed here can be employed both in the field and remotely, and that there is no reason that one approach would give markedly different results to another as long as there is sufficient documented information about each feature. When applying this vulnerability framework to other landscapes, the most suitable method is therefore determined by the availability and coverage of any heritage databases, the accessibility of features in the landscape, and any time and budget restraints.

7.7 Conclusion

This two-stage VI was created as part of the Landscape Vulnerability Framework developed in this thesis. In order to address the limitations associated with the site-focussed VIs commonly used in archaeology, the Hierarchy Theory framework was used to guide the focus of the VI to LCAs developed in Chapter 6, as informed by the vulnerability of LCFs. The results, namely the identification of the most vulnerable elements of the historic landscape to climate change, including their location and the nature of their features and assets, was used to inform the approach taken in Chapter 8.

Creating a VI scoring method with well-defined variables improves the transparency and clarity of the methods, in order to avoid some of the limitations mentioned in 7.2.2. It also allows results from several landscapes to be compared. This contrasts with several VI methodologies that are developed to be specific for the study area, and so are not useful for applying to other regions or comparing between studies. The structure of the Landscape Vulnerability Framework and the VI means that it can be added to or repurposed to assess vulnerability to a different threat. While the focus of this thesis is on coastal historic landscapes, the methodology could be applied to inland historic landscapes, for instance the location of the logistical and technological test, if the Risk of Coastal Erosion variable was removed or exchanged with a different variable, and the Risk of Flooding variable used only pluvial, fluvial and groundwater flooding data.

As the LCA classifications developed were based on the specific character and historic land-use/management in the Dysynni valley, the application of this framework to a different landscape may require slightly different LCA classifications to be used. This precludes direct comparison of the vulnerability of specific LCAs between landscapes. However, it still allows researchers to compare the most vulnerable LCAs across landscapes, the vulnerability of the historic landscapes as entities, and the most significant threats identified.

Using indices for climate change vulnerability assessments can be considered as simplification (perhaps over-simplification) of a complex threat and the multi-facetted nature of the impacts

(Small-Lorenz *et al.* 2013). However, when prioritising areas and assets for management, it is important to offer a clear and transparent justification for the choice (Perch-Nielsen 2010), rather than create an elaborate prioritisation system that requires the investment of significant time and resources to carry out.

The results generated in this chapter were used to inform Chapter 8, in which potential coastal management methods are assessed in terms of their sustainability across social, economic and environmental factors, as well as their suitability for addressing the threat to the vulnerable elements of the historic landscape as identified here.

Chapter 8
Sustainable Management of the Historic Landscape

8.1 Introduction

Coastal management is an important consideration in the UK in the face of climate change; currently, nearly 2 million properties are at risk of coastal flooding in England and Wales, totalling around £200 billion in value (OST 2004a, 2004b). The *Foresight Future Flooding* project predicted that, if there is no change to the current spending and approaches used in coastal flood defence, the annual economic loss to flooding would increase by up to £27 billion per year by the end of the 21st century, depending on the emission scenario (OST 2004a, 2004b).

Some approaches to coastal management, particularly hard defences, have received criticism for the high cost of construction and maintenance, adverse environmental impacts, and for causing policy lock-in. Policy lock-in is where a policy decision creates conditions in which the decision cannot be reversed (Brown *et al.* 2017). For instance, hard defence construction to reduce flood risk can lead to a false sense of security among the residents, and increased business and property development. The value of assets protected by the hard defences therefore increases, so it becomes less socially or economically viable to remove or stop maintaining the defences regardless of the economic cost or ecological impacts (*ibid.*). There is clearly a need to review the appropriate coastal management strategies, and develop those that are more sustainable. In order for a project to be sustainable, it must meet the requirements of sustainability as outlined in section 3.2.4, by considering social, economic, and environmental factors, and providing a solution that is equitable across both present and future generations (Brundtland and Khalid 1987; Stocker *et al.* 2012; Sánchez-Arcilla *et al.* 2016). Sustainable coastal management would "provide the maximum possible social and economic resilience against [threats such as erosion and] flooding, by protecting and working with the environment, in a way which is fair and affordable, both now and in the future" (Werritty 2006, p.19). In order to address the threat to the historic landscape identified in section 2.6 it is important that both heritage assets and the wider character of the historic landscape are considered when identifying the most suitable approach for coastal management.

Chapter 8 addresses Research Aim 3: *establish a way to identify the most appropriate approach(es) for sustainably managing the coastal historic landscape in the face of climate change*. This is divided into three research objectives: 3a: *Identify, through literature research, a sustainability assessment* *approach that could be used in the Landscape Vulnerability Framework;* 3b: *Review the current coastal and flood-risk management approaches in the Dysynni valley, and research innovative sustainable alternatives;* 3c: *Use the sustainability assessment approach (Objective 3a) to compare the current management policy in the Dysynni valley with potential alternatives identified in Objective 3b.*

To achieve this aim and the associated objectives, there is firstly a review of different methods used for assessing the sustainability of different processes or systems (8.2). This review informed the choice of sustainability assessment methodology to apply to the study area. The current coastal and flood-risk management context of the Dysynni valley is then examined (8.3). There is then a review of innovative, sustainable coastal and flood-risk management techniques, to inform the development of an innovative sustainable (IS) alternative management approach for the study area (8.4). The next section (8.5) applies the chosen sustainability assessment method (from 8.2) to both the current and alternative management options (from 8.3 and 8.4). This trials the chosen methodology and determines its suitability for use in the Landscape Vulnerability Framework. Finally, there is a discussion of the results of the sustainability assessment for the study area, and an evaluation of the overall sustainability assessment methodology (8.6 and 8.7).

8.2 Sustainability Assessment methods

A sustainability assessment is used to assess different potential approaches for managing the risk to the historic landscape of the Dysynni valley, and determine the most sustainable option. In order to determine what type of sustainability assessment would be most suitable for the study area, 8.2 provides a review of several different sustainability assessment approaches.

Firstly, there is an overview of what a sustainability assessment entails, and what they are generally used for (8.2.1). Subsequently, there is a discussion of different types of sustainability assessment, and the tools that are used within each (8.2.2). Finally, the chosen approach is explained and the methodology that was followed is briefly described.

8.2.1 Sustainability assessments

A sustainability assessment, or sustainability impact assessment as it is sometimes known, is a tool for assisting decision-makers in choosing the best (most sustainable) option for a policy or project, usually carried out *ex-ante* (during the design phase) (Arbter 2008; Singh *et al.* 2012). There are many different methods or tools that can be employed to undertake sustainability assessments, but there are several key themes that should be included regardless of the specific tool used.

For sustainability assessments, it is important to integrate the assessment of social, economic and environmental factors, in order to take into account all three ‘pillars’ of sustainability (see Chapter 3; Ness *et al.* 2007; Connor 2008; Stevens 2008). Balkema *et al.* (2002) argue that cultural aspects should be incorporated alongside social aspects, as threats to cultural values are as important as, if less tangible than, threats to social factors. They state that a measure of the actual effectiveness of each alternative in meeting the objectives (for instance for flood protection) is an important consideration for all approaches to sustainability assessments. However, there are difficulties associated with attempts to integrate all three (or more) aspects of sustainability into a single assessment. Giving equal weight to environmental, economic and social impacts, and including the ways in which they interact, can be difficult if there are more known indicators to measure one aspect over the others, or due to the availability of data in certain contexts (Kasperczyk and Knickel 2006; Stevens 2008). Furthermore, the integration of both qualitative and quantitative data can prove a challenge. This is addressed in different ways by different sustainability assessment tools, each with strengths and weaknesses.

The intergenerational and intragenerational equity aspect of sustainability is also an important consideration, so it is necessary to incorporate both long-term and short-term impacts within sustainability assessments (Ness *et al.* 2007; Stevens 2008). Assessments that continue beyond the project implementation and involve reflection and adaptation are particularly useful for detecting and addressing longer-term or cumulative impacts (Kasperczyk and Knickel 2006), however these are especially time-consuming and costly (Dijk *et al.* 2006; Hinterberger and Jäger 2008).

Regardless of the tool chosen to undertake a sustainability assessment, it is important to acknowledge the synergies and trade-offs that occur between the environmental, social and economic objectives. This raises the question of whether the assessment is based on the acceptance of *weak sustainability*, or whether it demands *strong sustainability*. Weak sustainability is the premise that human capital can be substituted for natural capital, so ecological or environmental damage would be acceptable if the project provided adequate economic or social benefits (Arbter 2008). In contrast, the idea of strong sustainability is based on the assumption that natural and human capital are non-compensatory, so one cannot be substituted for the other. The results of a sustainability assessment are influenced by the stance taken on the weak versus strong sustainability debate (Arbter 2008). It is important for projects to be explicit and transparent regarding the approach taken, so that it is clear what is accepted under the banner of sustainability within the sustainability assessment (Kasperczyk and Knickel 2006).

8.2.2 Different methods used

There are various different tools that can be employed in sustainability assessments. Although there is no consensus over which approach is best, some are more suited to certain types of project than others (Von Raggamby 2008; Van Herwijnen 2010; Zijp *et al.* 2015). Two types of sustainability assessments mentioned by Ness *et al.* (2007) are product-related assessment tools, and integrated assessment tools. The following section explains these two different types of sustainability assessment method, and give examples of the tools used within each.

Product-related assessment tools

Product related assessment tools focus on the environmental impacts throughout the production, use and discarding of a product (Ness *et al.* 2007). The two most common product-related assessment approaches used are ecological footprint analysis and lifecycle assessment analysis.

Ecological Footprint Analysis

An ecological footprint is a measure of the amount of natural resources that would be required to create a product or sustain a population, for example. Ecological footprint analysis essentially aims to measure the area of productive land that would be 'used' in the project or product (Van der Veen 2006). This includes both the amount of land required to provide the necessary resources, but also the amount of land needed to absorb the waste created by the project or product (Schianetz *et al.* 2009).

A benefit of using ecological footprints is that the use of land area as a measure of environmental impact allows the environmental impact of very different projects or products to be compared easily. It is most commonly used retrospectively for assessing the environmental impact of projects that have already been carried out, so is not often used for informing decision-makers (Schianetz *et al.* 2009). Another weakness is that it is not fully understood how ecosystems deal with waste or emissions, or exactly how much land would be required, so it is based on assumptions rather than actual data (Van der Veen 2006).

Lifecycle Assessment Analysis

A lifecycle assessment analysis assesses the environmental impact of a product or project across its entire lifetime from 'cradle to grave', i.e. from sourcing the natural resources to use, recycling, and disposal. It is a very complex process, as it aims to consider all possible energy and material inputs and outputs, and is usually undertaken retrospectively, so the product or project has already been created.

Lifecycle assessments are particularly useful for avoiding problem shifting, where an environmental problem in one sector or life stage is solved in a way that moves the problem elsewhere, either spatially or temporally. As lifecycle assessments take all stages and processes into account, any problem shifting would be detected (Schepelmann 2006; Schianetz *et al.* 2009). Cumulative impacts are also more easily detected through this method. However, the vast amount of data required to undertake a lifecycle assessment means that it can be very costly and time-consuming to carry out, and the calculations involved can be very difficult (Schianetz *et al.* 2009). Moreover, missing data can cause the accuracy of results to suffer (Schepelmann 2006). Finally, neither lifecycle assessments nor ecological footprint analyses include consideration of any socio-cultural or economic impacts, or impacts that are not quantifiable. This means that a significant proportion of the negative impacts of a project or product are not taken into account (*ibid.*). Therefore, lifecycle assessment analysis is not really a suitable method for assessing sustainability, which requires the consideration of all three 'pillars'

Integrated assessment tools

Integrated assessment tools are generally undertaken *ex-ante*, and aim to incorporate a mixture of environmental, social and economic factors. This contrasts with the product-related assessment tools, which mainly focus on environmental impacts. Examples of this include cost-benefit analysis and multi-criteria decision analysis.

Cost-Benefit Analysis

The aim of cost-benefit analysis is to directly compare all of the costs and benefits of a project. To do this, all impacts and outcomes of a project are translated into monetary terms, so that the net benefits (benefits - costs) can be easily calculated (Kuik 2006). The costs that are often factored into a cost-benefit analysis include: cost of resources, regulatory costs, social welfare costs (i.e. potential price increases), transitional costs (i.e. job losses, firm closures), indirect costs (i.e. discouragement of investment or tourism, changes to markets), and environmental costs (i.e. pollution, impact on biodiversity or habitats). Often included in the calculation of benefits are: reduction of risk to human health, reduction of threat to heritage, food and fuel for market, fishing and hiking for recreation, flood moderation and CO_2 sequestration of ecosystem services, and the intrinsic value of the ecosystem (Kuik 2006).

Cost-benefit analysis is an easy way to factor in all strengths and weaknesses of a project and compare a wide range of different projects. There are several criticisms of this approach, primarily relating to the difficulty in translating qualitative or intangible costs and benefits into monetary values. It is unlikely that the calculated monetary value of social and environmental factors is accurate or able to consider all aspects (Von Raggamby 2008). Willingness to pay, where people are asked how much they would be willing to pay for the benefit or to avoid the cost, is often used as a way to determine the monetary value of products or services. However, it is based on hypothetical situations, and may not actually reflect how much people would be willing or able to pay in reality (Kuik 2006). Another criticism is that the idea that environmental and social assets can be simplified into economic terms may cause the intrinsic value of things like nature and culture to be lost (Kuik 2006; Von Raggamby 2008). It also implies that the loss or substitution of social and environmental assets would be acceptable if the right price was found (*ibid*.). Finally, Kuik (2006) argues that cost-benefit analysis does not consider the potential inequalities in the distribution of costs and benefits, and so does not take into account the intra- and inter-generational equity aspect of sustainability.

Multi-criteria decision analysis

Multi-criteria decision analysis (MCDA), also known as multi-criteria analysis or multi-criteria decision making, is a tool that compares alternative options using various criteria, in relation to one or more objectives. The overall aim is to be able to rank the alternatives from 'best' to 'worst' based on how they meet the objectives, or identify options that are acceptable or unacceptable for the project in question (Van Herwijnen 2006; Girard and De Toro 2007; Ferretti *et al.* 2014). This approach is very flexible, as the criteria chosen to assess the alternatives can be changed to suit specific contexts and projects. Furthermore, MCDA can take into account both quantitative and qualitative factors, making it particularly suitable for assessing projects relating to historic assets, as they have both use- and non-use values (Mendoza and Martins 2006; Schianetz *et al.* 2009; Giove *et al.* 2010). There are several different types of MCDA tools, for instance multi-attribute value theory, analytical hierarchy process, and dominance-based approaches.

The multi-attribute value theory (MAVT) approaches calculate an overall score for each alternative by aggregating the scores awarded for each criterion. As with the indices approach, this requires the criteria scores to be normalised onto a common scale (Dutta and Husain 2009). This approach is most suitable when there is a discrete number of alternatives that must be evaluated based on conflicting objectives (Ferretti *et al.* 2014). It is very suitable for assessing the sustainability of projects or policies, as sustainability is defined by the conflicting objectives of environmental, economic and social benefits (Wang *et al.* 2009).

Analytical hierarchy process (AHP) is another MCDA method in which the criteria are organised into a hierarchy framework so that each sub-problem within the overall objective can be analysed separately (Cinelli *et al.* 2014). Pairwise comparisons are made between alternatives for each criterion, and then represented as a matrix of comparisons expressed as ratios. This can then be translated into scores that are more easily comparable (Yau 2008; Cinelli *et al.* 2014).

Dominance-based approaches are another MCDA method, in which alternatives are eliminated if they are dominated by another option. An option is eliminated if another alternative performs better than it on one or more criteria, and no worse on any other (Van Herwijnen 2006; Cinelli *et al.* 2014). Dominance-based approaches are the only MCDA methods discussed here that are non-compensatory, and so support strong sustainability. With AHP and MAVT, a weak score for one criterion can be offset by a strong score for another, if the criteria scores are aggregated before comparison. In contrast, dominance-based approaches compare alternatives based on individual criterion scores, so a weak score for any criterion can make an alternative more at risk of being eliminated (Van Herwijnen 2006; Ferretti *et al.* 2014). In reality, it is uncommon for many of the alternatives considered to be fully dominated across all criteria, as there are many different criteria that must be taken into account. Therefore, it is not the most useful approach for informing decision-making, as several alternatives may remain at the end (Van Herwijnen 2006).

All MCDA approaches require the definition of criteria by which the alternatives are judged, which allows a variety of conflicting requirements to be incorporated. These criteria can be sub-divided into categories. Wang *et al* (2009) divides criteria into economic criteria (e.g. investment cost, operation and maintenance cost), environmental criteria (e.g. emissions produced, land use, local pollution), social criteria (social acceptability, job creation) and project-specific criteria (e.g. effectiveness of flood protection, impact on cultural landscape). It is important to ensure that the criteria chosen are relevant to the research question and objectives of the assessment, otherwise the alternative that scores the most may not actually be the 'best' approach for the project (Dutta and Husain 2009). The selection of criteria, and whether or not they are weighted, introduces an element of subjectivity into MCDA (Schianetz *et al.* 2009). Some projects give some criteria a greater weight than others during the scoring and aggregating stage, in order to take into account the fact that they are more important for the sustainability of a project. Due to the complex nature of the systems being assessed, it can be difficult to establish exactly how important criteria are in relation to one another. The weights given to criteria may therefore be arbitrary and based on subjective opinions or assumptions by the decision-maker. Most projects use the *equal weights method*, wherein all criteria are given the same weighting (Wang *et al.* 2009).

8.2.3 Selection of a sustainability assessment tool

This research uses MCDA to assess the sustainability of different management alternatives for cultural heritage at risk from climate change, and the tool used was the MAVT approach. This is because there was a discrete set of alternatives that must be assessed based on conflicting objectives, which is what MAVT is suitable for. This method is more suitable than a dominance-based approach, as dominance-based approaches eliminates some options, but do not rank the 'acceptable' alternatives from most to least suitable. Ranking provides greater transparency regarding the performance of each alternative, and is useful for further narrowing down the most appropriate option. The MAVT method was chosen over the analytical hierarchy process as the process involved is more simple, and does not require the construction of a hierarchy of criteria or pairwise comparisons of alternatives for each criterion. Instead, each alternative is scored for each criterion, and only the final aggregated scores compared.

The approach taken in this research is influenced by that of Giove *et al.* (2010) in their assessment of the sustainability of different options for the re-use of an historic waterfront. They defined only three criteria (intrinsic sustainability, context sustainability, economic and financial sustainability), which they divided into attributes, and divided further into parameters. Each parameter was ranked between 0-100 based on the potential impact on it under each alternative scenario. The attribute score was calculated as the average of the parameter scores, while the score for each criterion was calculated as the average of the attribute scores. This allowed the alternatives to be compared not only on the overall score, but also by each attribute. For this assessment, the criteria used were *economic sustainability*, *socio-cultural sustainability*, *environmental sustainability*, and *functionality.* As in the assessment by Giove *et al.* (2010), each was divided into attributes, and further sub-divided into parameters. The purpose of this is to be able to compare the alternatives for each 'pillar' of sustainability, rather than only based on an overall score. It therefore reveals alternatives that perform particularly poorly on certain criteria rather than, for example, a poor performance in environmental sustainability being compensated for by a strong economic sustainability score. This approach goes some way towards addressing the fact that normal MAVT approaches only support weak sustainability. The underlying approach within this thesis is based on the idea that all three 'pillars' are crucial to the realisation of sustainability, and that they cannot be wholly substituted for one another. In contrast, other MAVT studies used in heritage and archaeology (see Dutta and Hussain 2009; Ferretti *et al.* 2014; Ferretti and Comino 2015) do not group the attributes into different criteria, but instead produce only one score for the whole MAVT. This means that any compensation between criteria is not evident, so this only supports weak sustainability. Furthermore, the above authors focussed predominantly on socio-cultural attributes, with little mention of wider economic impacts, and no consideration of environmental or ecological factors. Of the studies reviewed, only Giove *et al.* (2010) used methods that covered a range of factors sufficient for assessing sustainability. Finally, the above authors all compared many (50+) single buildings for renovation or re-use, but this thesis is assessing fewer but larger, more complex systems and solutions. The approach taken by Giove *et al.* (2010), which compares only 2 alternatives which are complex and involve a wide area (~45 ha), is more suitable for application to this thesis. All parameters were weighted equally within this assessment, due to the difficulties with accurately establishing the relative importance of some factors over others when the assessment is being carried out *ex-ante*.

8.2.4 Summary

MAVT, a type of MCDA, was chosen as the sustainability assessment method for this thesis, as it is designed to compare alternatives for a project with conflicting objectives; a feature of sustainability. MAVT can include consideration of both qualitative and quantitative factors, meaning that the economic, environmental and socio-cultural impacts of each alternative can be assessed.

As per the MAVT steps laid out above, the next part of this thesis identifies the coastal and flood risk management alternatives for addressing the identified threat to the historic environment that were compared in the MAVT. There is first a review of the current approach to coastal governance in the UK and the existing management approaches and policy in the study area (8.3). Section 8.4 explores what sustainable coastal and flood-risk management entails and reviews several innovative sustainable alternatives that could be compared.

8.3 Current Coastal and Flood Risk Management in the Dysynni Valley

In order to assess the most sustainable and suitable approach for management of the climate change impacts on the Dysynni valley, it is important to first discuss the way in which the risk of erosion and flooding along coastline and in the valley is currently being managed. It is also important to understand the current coastal and flood risk management paradigm in the UK, and the way in which coastal and flood risk management projects are designated and organised. Therefore, 8.3 provides an overview of the existing coastal and flood risk management projects and infrastructure in the study area, with a focus on the Victorian sea-wall and promenade, the 2011 Tywyn coastal defence scheme, and the Dysynni Low Level Drain. Subsequently, there is a brief appraisal of the way in which future coastal management policy is planned and designated in the UK, namely through Shoreline Management Plans (SMPs), and the different types of coastal management they recommend. There is finally an overview of the SMP that was developed for the Dysynni coastline in 2012.

8.3.1 Existing coastal defence and flood risk infrastructure

This section reviews the current coastal defence and flood risk infrastructure in place in the study area, with a focus on the historic and modern defences at Tywyn, and the Dysynni Low Level Drain.

Figure 8.1. *Late-20th century sea wall built along the Tywyn frontage to protect the Victorian promenade. Present defences visible now also include wooden groynes. Photograph Copyright Penny Mayes*

Victorian Promenade and Sea Wall

The original promenade on the Tywyn coastal frontage, stretching 465m, was constructed in 1889 under the patronage of John Corbett of the Ynysymaengwyn estate. An additional promenade was built further north, near Bryn-y-mor, but was destroyed in a coastal storm in 1935 (Atkins 2009). A modern sea wall and promenade were built it its place around 1980 (Smith 2004a). Further coastal defence structures were constructed during the 20th century, including a detached breakwater, rock armour, wooden groynes and a sea wall (see Figure 8.1).

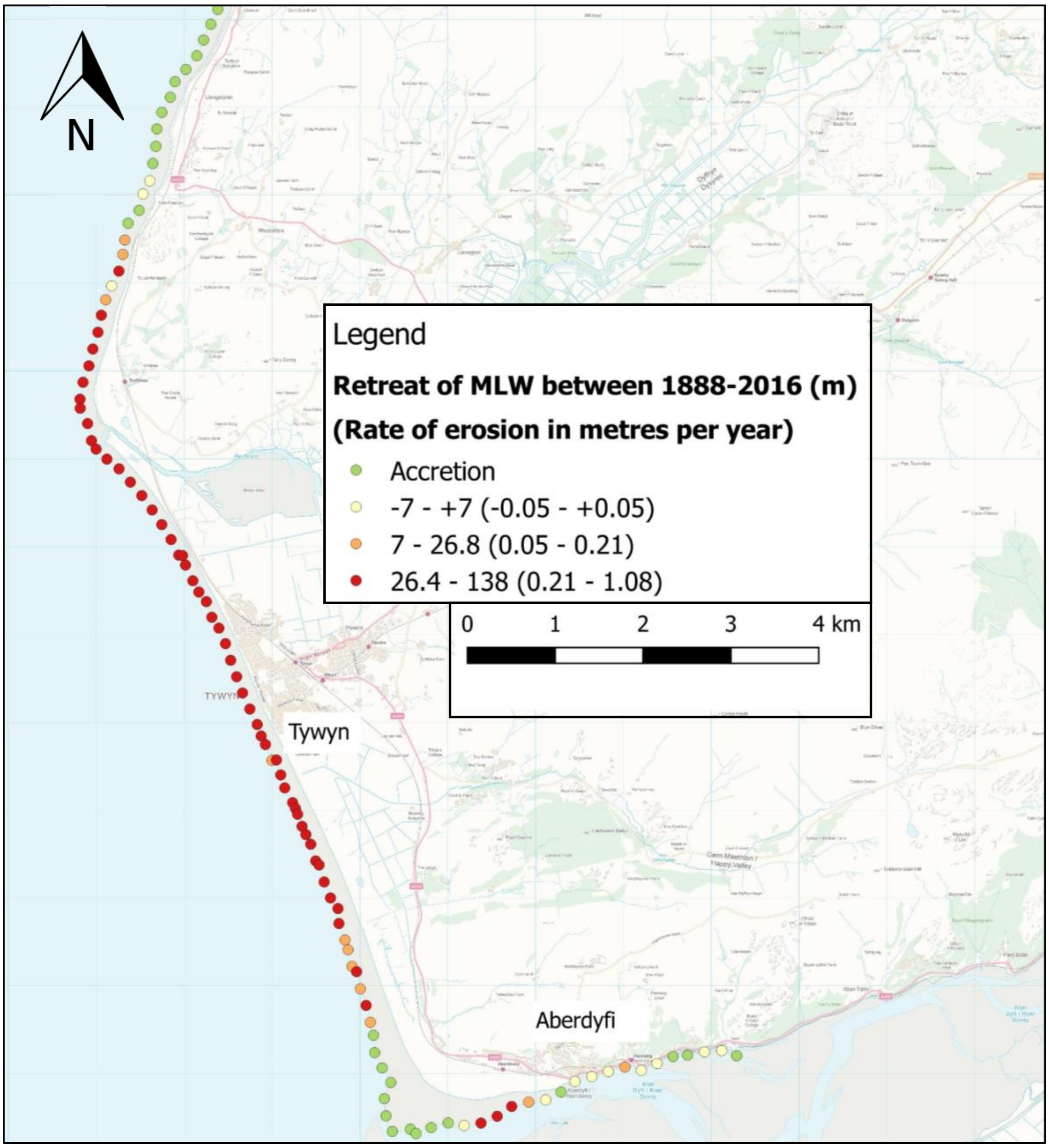


Figure 8.2. *Map displaying the rate of retreat of the MLW mark between 1888 and 2016 (above), indicating beach narrowing, and images demonstrating evidence of beach lowering and undermining of defences at the slipway (A), sea wall (B) and wooden groynes (C) at Tywyn (below). Crown copyright and database right 2019 Ordnance Survey 100025252*

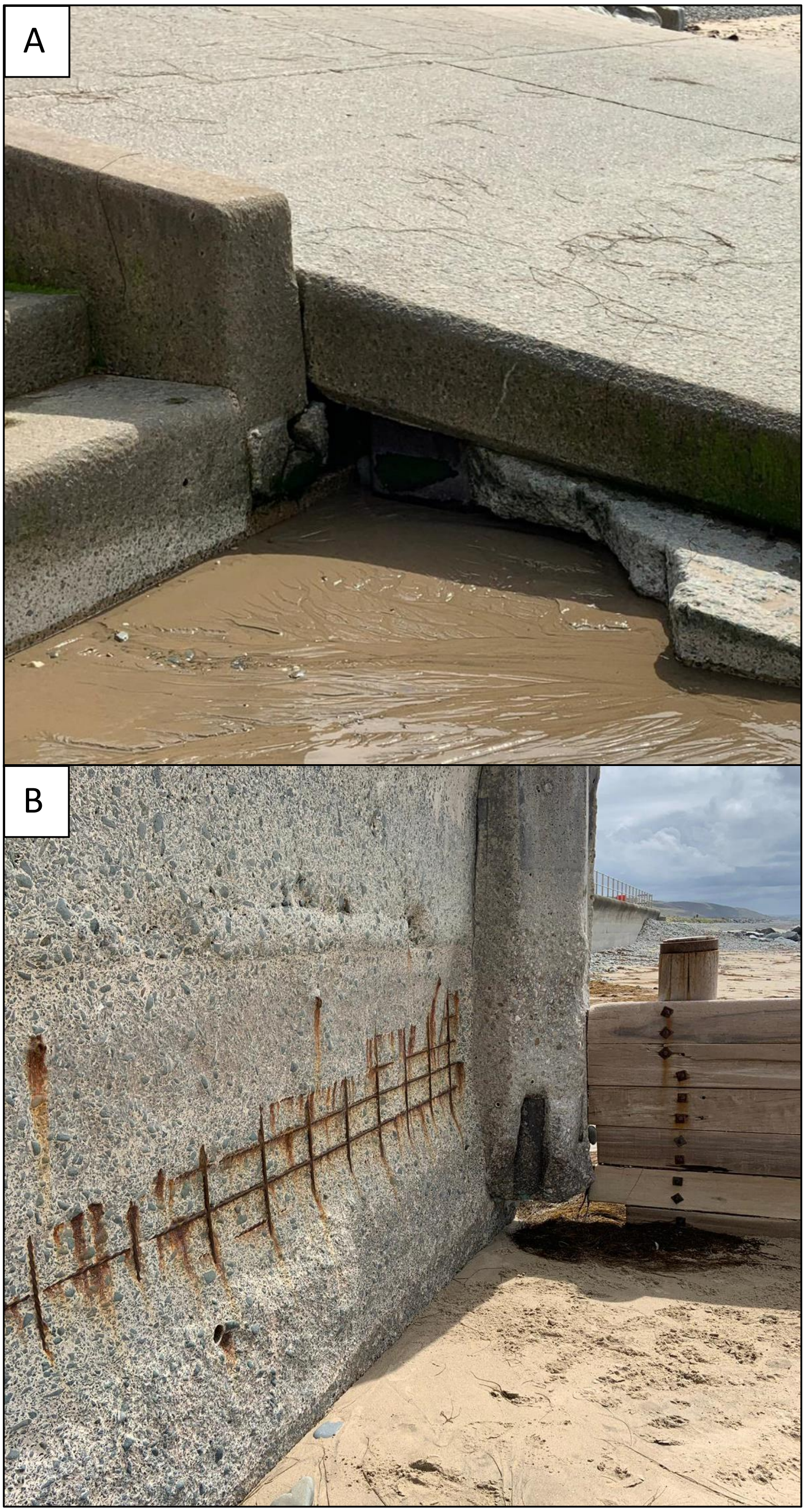


Figure 8.2 cont. *Evidence of beach lowering and undermining of defences at the slipway (A) and sea wall (B) at Tywyn.*

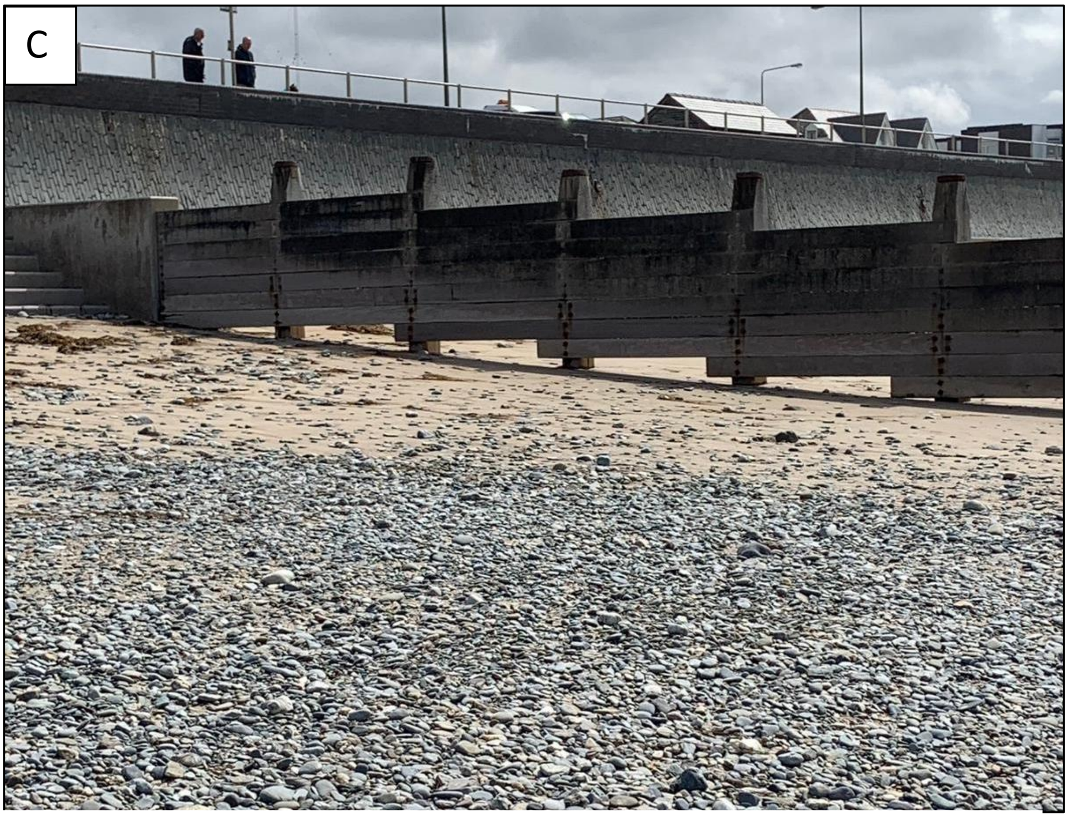


Figure 8.2 cont. *Image demonstrating evidence of beach lowering and undermining of defences at wooden groynes (C) at Tywyn.*

Despite the existing defences, conditions at the start of the 21st century indicated that further work was required to maintain Tywyn beach and frontage. The groynes built in the 1970s had become dilapidated and less effective at preventing beach recession. This meant that in the first decade of the 21st century beach levels dropped by 3 metres, a higher rate than the long-term average, which caused increased erosion and undermining of the defence structures (see Figure 8.2) (McDougall and Boyd 2009; Maslen Environmental 2011;YGC 2011). A loss of beach material can be seen in Figure 8.2, which shows the amount of retreat of the MLW mark between 1888 and 2016. This was calculated by measuring the difference in the MLW position on the 1853-1904 1:2,500 County Series 1st Edition map (last edited in 1888) and on the 2016 Ordnance Survey map. As the land behind the sea wall is low lying, any water that overtops the defences can easily flow inland. This reduction in beach levels worsens the risk of overtopping of sea walls due to the increased water depth at the foot of the structure (Sutherland *et al.* 2003; McDougall and Boyd 2009).

Accessibility issues were caused by the groynes, which obstruct access along the beach, by the erosion of steps down to the beach built into the sea wall, and by the collapse of some sections of the promenade footpath (Atkins 2009; Maslen Environmental 2011). As a result of these issues, Tywyn beach lost its Blue Flag status in 2009 (Atkins 2009). Emergency repair works have been required several times after storm events, but this is an uneconomical approach in the long-term. Future sea-level rise combined with lowering beach levels are likely to significantly increase the risk of overtopping and flooding, and the potential for the natural defences to the north and south of Tywyn to be breached (McDougall and Boyd 2009).

Tywyn Coastal Defence Scheme

A coastal defence project was designed by Atkins in 2009, and completed by Jones Bros (Ruthin) Co. Ltd in 2011. Before this defence project was agreed, several other coastal defence projects were proposed for the Tywyn frontage, but rejected for a wide range of reasons including cost and public opposition (see Stevens 2002; Maslen Environmental 2011). The successful project was co-funded by the European Regional Development Fund and the Welsh Government, who contributed £3.5million and £4.1million respectively, totalling £7.6million (Maslen Environmental 2011). Atkins consulted a range of stakeholders, including Tywyn Town Council, the Countryside Council for Wales, Environment Agency Wales, Tywyn and Aberdyfi Coast Protection Public Group, Welsh European Funding Office, Snowdonia National Park, and the general public (Atkins 2009).

The main project objectives were to protect public assets by reducing the risk of overtopping and erosion, maintain safe beach access, maintain or improve the amenity of the beach, and ensure that it is environmentally acceptable and economically viable (McDougall and Boyd 2009; Maslen Environmental 2011). The main works included in this project were an intertidal rock breakwater at the south end of the promenade, two rock groynes, one at each end of the promenade, a rock revetment in front of the Bryn-y-mor section of the frontage, and beach nourishment behind the new breakwater (See Figure 8.3) (Atkins 2009). Also included was the replacement of 27 timber groynes with new groynes made from recycled timber, repairs to the concrete steps that run the length of the promenade, an extension of the blockstone revetment near the south end of the promenade, and repairs to the slipways and promenade itself (*ibid*.). The project aimed to reduce flood risk to a 1-in-100 year return, so while this does not eliminate the risk of flooding entirely, it will reduce the frequency and intensity of flood events (Maslen Environmental 2011).

Figure 8.3. *New defences built at Tywyn, including a detatched breakwater (A) and a rock revetment (B). Photographs Copyright Penny Mayes*

The ecological impact of the project was addressed by installing artificial pools and crevices in the breakwater surface by drill-coring Evans *et al.* (2015) (Figure 8.4). Evans *et al.* (2015) found that there was greater species richness in the artificial rock pool habitats than the surrounding rock surfaces after only a few months, and after 18 months there was no significant difference between the artificial and natural rock pools in terms of species richness. Crevices and rock pools for this purpose were not included in the original design for the breakwater, groynes and sea wall, but as demonstrated by Evans *et al.* (2015), they can be installed retrospectively.

***Figure 8.4**. Evidence of ecological engineering features retroactively installed onto Tywyn breakwater by Evans et al. (2015).*

The construction of the ecological engineering project is predicted to have impacted beach and marine species through sediment disturbance, noise and vibration (McDougall and Boyd 2009). Firth *et al.* (2013b) warn that introducing new areas of hard substrate into areas without natural rocky substrate can allow new, potentially invasive species to colonise the area. However, as this stretch of coastline has had artificial hard substrate for over a century, the new developments are unlikely to create any additional risk. The role of ecological engineering projects such as this in sustainable coastal management is discussed further in 8.4.1.

8.3.2 Dysynni Low Level Drain

This section discusses the Dysynni Low Level Drain (DLLD), a drainage scheme undertaken by local wealthy estates in the 18th and 19th centuries, and the way that this infrastructure was used and managed both in the past and present. This expands upon the discussion of the drainage scheme in sections 4.4.8 and 5.2.2. In the 1740s, the Peniarth and Ynysymaengwyn estates established a construction project to develop an extensive low-level drainage system in the Dysynni valley, including tidal gates and outfalls which are still extant today, and became the DLLD (Dunderdale and Morris 1996; Smith 2005). The scheme was completed in the 1860s, and allowed large areas of land, previously underwater for much of the year, to be used productively for farming (North Wales Daily Post 2004). This network of drainage ditches, culverts and drains remains an important feature of the current landscape, in terms of both its visual character and the economic productivity of the land (Smith 2004a; Wales Farmer 2017).

Despite the DLLD, archive research (section 5.2) revealed that there were continuing problems with flooding in the low-lying areas of the Dysynni valley during the 20th century. A letter from the Ministry for Agriculture and Fisheries to the River Dysynni Catchment Board dating to 8th December 1942 states that the drains in the area were badly choked and required excavation, and that a number of sluices were obstructed and required maintenance. In order for the required work to be funded centrally as part of the existing outfall scheme, the affected watercourses were 'mained'. This means that they were officially considered part of the River Dysynni main channel, so the work could be funded under Section 55 of the Land Drainage Act 1930 (Gardner 1950a). This eased the financial burden of management from the landowners (Houghton 1944). Subsequently, six further watercourses were added to the River Dysynni main channel between 1944 and 1950, including channels near Tywyn, Llanegryn, Pont Dysynni and Peniarth (see Figure 5.3) (Houghton 1944; Dobson 1944; Gardner 1950a,b). Minutes from a meeting of Merioneth Rivers Catchment Board in 1948 state that 23 farms on the Peniarth Estate were subject to flooding, and that conditions had deteriorated significantly in the previous few years.

In the 1990s, research was undertaken into the DLLD for the National Rivers Authority (NRA) by

Dunderdale and Morris (1996). At this time, 25% of the area served by the drainage system was still often or permanently waterlogged during the spring, with the figure rising to 63% during the autumn. This was attributed to high water level in the DLLD due to high rainfall events, and weeds and blockages in the channel.

Despite the significant efforts to improve the drainage network and reduce the incidents of flooding during the 20th century, recent reports indicate that standing water in fields and weak flow in ditches due to weed congestion is still, or has once again become, an issue in the Dysynni valley (see Figure 8.5) (Wales Farmer 2017). The fourth most vulnerable LCA, Regular Drained Land, is characterised by the DLLD and associated drains, ditches and culverts. The existence of this drainage infrastructure is instrumental in the existence of a key LCA in the study area, and without continual or increased maintenance of the DLLD system there is a risk that this LCA could return to marshland. Not only would the economic consequences of this be disastrous for the area, but the character of the Dysynni historic landscape lowlands would be dramatically affected.

Figure 8.5. *Evidence of waterlogging in a field in the Dysynni Valley. Copyright NorthWalesLive 2017*

Other maintenance work carried out to reduce flood risk includes the removal of gravel from the Dysynni valley. In 2015, a build-up of gravel reduced the river flow and increased water levels around three miles upstream, as far as Bryncrug (DredgingToday 2015). In response, NRW removed

60,000 tonnes of gravel from the river as it entered Broadwater in order to protect 26 properties from flooding (ITV 2015). This clearance was previously undertaken in 2012, and the recurrence of the gravel is attributed to winter storms and high-tides carrying gravel into the estuary (*ibid*.).

8.3.3 Future coastal management policy planning in the UK: Shoreline Management Plans

The British coastline is divided into sediment cells based on patterns of erosion, transportation and deposition of sediments (Cooper and Pontee 2006). The coast of England and Wales comprises 11 cells, each of which can be further partitioned into subcells (see Figure 8.6). SMPs are non-statutory policy documents developed by local councils and the Environment Agency, designed to inform strategic coastal planning and management (South East Coastal Group 2010). SMPs develop a policy framework for coastal management, based on an assessment of the threats posed by changing coastlines to society and the natural, developed and historic environment (*ibid*.). The first round of SMPs was developed in the earlier 21st century, and since then additional guidance published by Defra (2011) and new understandings of coastal processes and threats led to the updated SMP2s. The SMP2 process has involved greater stakeholder engagement throughout the process (Earlie and Brunner 2012).

A key characteristic of SMPs is the focus on the interaction of coastal processes between areas and across different spatial and temporal scales (Guthrie and Clipsham 2011). They consider the impact of management processes on sediment transport systems, which could change erosion or sedimentation patterns elsewhere along the coast (*ibid.*).

In the SMPs, the coastline is divided into sediment cells, which are the subdivided into Policy Development Zones (PDZs). Each PDZ is subdivided into Management Areas, which are further divided into Policy Units (Earlie *et al.* 2012b). The Dysynni valley coastline is within the West of Wales Sediment Cell, and PDZs 10 and 11. The northern shore of the Dyfi valley and the coastline up to Tonfanau is within Management Area 20, and constitutes Policy Units 10.10-10.19 (see Figure 8.7)

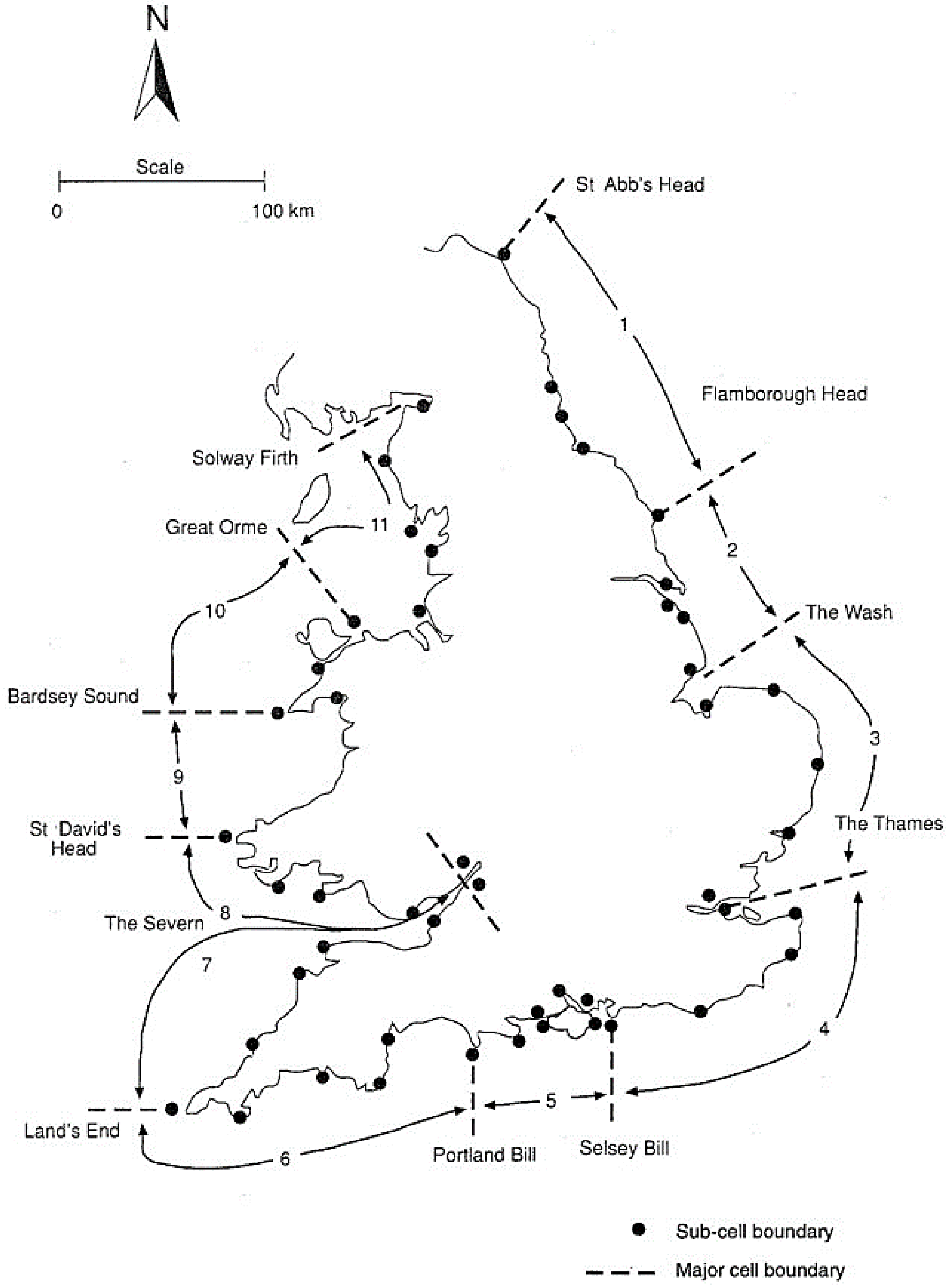


Figure 8.6. *Sediment cell divisions along the coast of England and Wales. The Dysynni valley study area falls into Sediment Cell 9, between St David's Head and Bardsey Sound. Source: Ministry of Agriculture, Fisheries and Food 1995.*

Shoreline Management Plan approaches

SMPs are based on the view that coastal management should be as 'sustainable' as possible, and that the defence options pursued should be those that do not tie future generations into expensive, long-term defence projects (Guthrie and Clipsham 2011). Some consider the most sustainable approach to coastal defence to be 'no active intervention' (NAI), as this allows the coastline to respond dynamically to natural processes (*ibid.*). The high cost of building and maintaining defensive structures means that the Welsh Assembly Government is promoting alternative flood risk strategies, such as increasing the flood resilience of individual properties and establishing an effective flood warning system (*ibid.*).

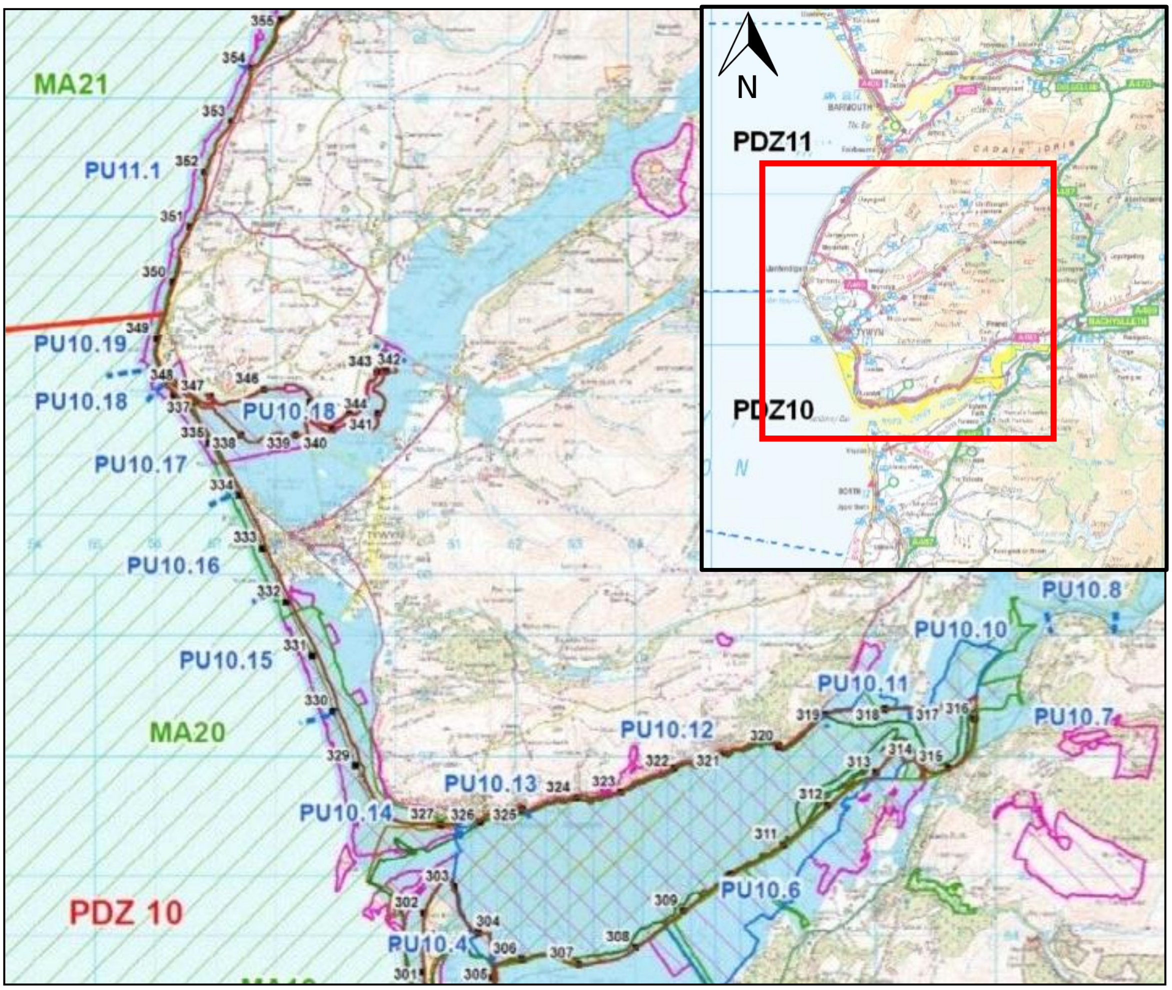


Figure 8.7: *SMP2 policy divisions that apply to the Dysynni valley (red square in inset). Policy Unit divisions indicated by blue dashed lines. Source: Earlie et al. 2012b, c, d.*

For each different PDZ, several management scenarios are explored. An 'Unconstrained Scenario' is assessed, in which the behaviour of the coast is modelled as if no man-made defences existed. This is a purely theoretical standpoint, but is used to give an insight into how the existing defence structures may already be influencing coastal processes (Earlier *et al.* 2012b). There are then four generic coastal defence options that can be considered for each Management Area (Environment Agency 2013): Hold the Line (HTL); Managed Realignment (MR); Advance the Line; No Active Intervention (NAI). Advance the line involves the construction of defences further out to sea in order to reclaim land. This is very expensive and extremely uncommon, so is not discussed further in this thesis.

Hold the Line

The aim of this approach is to maintain the position of the existing shoreline. This is achieved through either hard engineering solutions, such as sea walls, breakwaters, and groynes, or soft engineering solutions like beach nourishment, and is mainly employed along shorelines with valuable assets, such as business, industry or significant urban development.

HTL approaches can allow a business-as-usual approach to land-use, and provide reassurance for residents whose homes have been protected. However, there are significant financial costs associated with the construction and maintenance of defences, making them unsuitable for low-value coastal areas (King and Lester 1995; Ledoux *et al.* 2005; Milligan and O'Riordan 2007; Westley *et al.* 2011). Furthermore, significant changes to tidal range, wave height and power, and storm surge frequency due to climate change may require engineered defences to be upgraded in the future, which would further increase the cost (Hallegatte 2009; Temmerman *et al.* 2013).

There are numerous environmental impacts of fixed coastal defences. Firstly, the prevention of sediment erosion and transport by hard defences causes sediment starvation within the sediment cell. This can cause an increase in erosion along other areas of coastline within the sediment cells which are undefended (Airoldi *et al.* 2005; Bromhead and Ibsen 2006). Therefore, the threat of erosion has not been reduced overall, merely displaced. Coastal squeeze is another phenomenon caused by sea walls, whereby wetland habitats seaward of the defence, such as saltmarsh, are eroded as they are unable to accrete and migrate landwards in response to sea-level rise (Bromhead and Ibsen 2006; Pontee 2013). For instance, the fixed coastal defences along the Essex coastline have resulted in the loss of 1000 ha of saltmarsh between 1973 and 1998, with up to 75% of the remaining saltmarsh predicted to be lost by 2050 (Parrott and Burningham 2008). Finally, the replacement of soft-bottomed habitats with hard-bottomed conditions due to the construction of defences could cause a reduction in biodiversity or a change in the species mix (Airoldi *et al.* 2005).

Beach nourishment can also cause environmental issues; sand extraction can damage ecosystems and affect erosion and sedimentation patterns within the sediment cell of the mine site. Moreover, the additional available sediment can cause siltation of offshore ecosystems, while the deposition of the sand with heavy machinery can damage sand-dwelling species (Greene 2002).

Despite these economic and environmental limitations, HTL has still been a popular approach in many areas. This is partly due to the high value of protected assets in some areas, but can also be politically motivated. As political cycles are relatively short in the UK, coastal defence policy may be geared towards solutions that gain favour in the short term, despite a lack of sustainability in the long term (Bray *et al.* 1997). Although the government is not obliged to construct flood and erosion defences, there is often an assumption that public authorities will provide protection for settlement areas (Mulligan and O'Riordan 2007). A reduction in the amount of coastal defence provided by authorities could result in public anger towards, or distrust of, authorities (Few *et al.* 2007a; Stocker *et al.* 2012). It is likely that HTL approaches will become less widely used, due to the high costs involved; Ledoux *et al.* (2005) calculated that the amount currently spent on the maintenance of defences would have to double in order to maintain the shoreline along all defended coastlines.

Managed Realignment

Also known as Managed Retreat, this is where existing defences are removed, breached, or allowed to breach naturally, in order to allow the shoreline to retreat (Esteves and Williams 2017). This can create saltmarsh habitat behind the breached defence, solving the issue of habitat loss due to coastal squeeze (Bray *et al.* 1997; Dafforn *et al.* 2015). Sometimes a new line of defence is erected shoreward of the breached defences in order to maintain protection for certain assets further inland (Esteves 2013).

Saltmarsh can attenuate wave energy, store flood waters, and accrete in line with sea-level rise, so the creation of intertidal habitats can provide a level of flood protection (Bray *et al.* 1997; Ibàñez *et al.* 1997; Milligan *et al.* 2009; Sutton-Grier *et al.* 2015; Masselink *et al.* 2017). This approach is favoured by conservationists as the newly created habitat can be beneficial for coastal ecosystems. However, Temmerman *et al.* (2013) argue that, as few MR projects have been carried out and monitored, the effectiveness of MR along different types of coastline is not yet well understood. One of the reasons that so few MR projects have been undertaken is the lack of popularity with land-owners. Under the Environmental Stewardship Scheme, there are subsidies available for land-owners who create saltmarsh through MR on their land. The permanence of this change in land use, and the 20-year limit on subsidies, has made this a very unpopular option compared to other agri-environment schemes (Ledoux *et al.* 2005; Parrott and Burningham 2008).

No Active Intervention

NAI is a hands-off approach, in which no further defence for flooding or erosion are invested in, regardless of whether built defences exist there already. This approach is generally chosen for stretches of coastline that are either not threatened by flooding or erosion (e.g. hard rock cliffs), or those in which there are no valuable assets at risk. While popular with conservationists, as it allows natural processes to act unhindered in the coastal system, NAI can be very unpopular with residents of rural coastal areas who risk losing their homes. The UK Government has no obligation to provide compensation to people who lose their property as a result of coastal flooding or erosion. This can cause anger, distrust and conflict between the public and coastal management authorities (Ledoux *et al.* 2005; O'Riordan *et al.* 2008).

SMP2 policy for the Dysynni coastline

The West of Wales SMP2 covers the area of this research. The SMP2 is divided into Policy Development Zones (PDZs), which are further divided into Management Areas (MAs), then Policy Units (PUs) (see Figure 8.7). The southern section of the coastline included in the study area of this research, from the Dyfi estuary to Tonfanau, is included in PDZ 10, MA 20, PU10.11-10.19. The northern section of the study area, from Tonfanau to just south of Llwyngwril, is included in PDZ 11, MA 21, PU 11.1(see Figure 8.7).   For each PU, policy plans were developed for the short-, medium-, and long-term (2011-2025; 2025-2055; 2055-2105). It is worth noting that the allocation of different policy approaches in the SMP2 does not indicate that funding for these policies has been secured, they are just guidance for local authorities

The SMP2 policy plan is summarised in Table 8.1 and Figure 8.8. The main considerations in developing the SMP2 for this area were the small coastal towns of Tywyn and Aberdyfi, and the railway line that is situated in close proximity to the shoreline in some areas, as it is particularly important for transport in the region. HTL was chosen as the policy for all time periods for the following areas (Earlie *et al.* 2012 c, d):

- The north shore of the Dyfi estuary from Gogarth Hall to Aberdyfi (PU 10.11-10.13)
- Tywyn frontage (PU 10.16)
- Morfa Gwyllt (the gravel spit seaward of Broadwater, along which the railway line is situated). (PU 10.17)
- Rola (the stretch of land north of Tonfanau) (PU 11.1)

Table 8.1: *Summary of the SMP2 policy plan information for the Dysynni coastline*

Policy Unit		Policy Plan		
		Present - 2025	2025-2055	2055-2105
10.11	Gogarth	HTL	HTL	HTL
10.12	Dyfi North	HTL	HTL	HTL
10.13	Aberdyfi	HTL	HTL	HTL
10.14	Aberdyfi Dunes	MR	MR	MR
10.15	Penllyn	MR	MR	MR
10.16	Tywyn	HTL	HTL	HTL
10.17	Morfa Gwyllt	HTL	HTL	HTL
10.18	Dysynni Estuary	HTL	MR	MR
10.19	Tonfanau	MR	MR	NAI
11.1	Rola	HTL	HTL	HTL
Key: HTL – Hold the Line; MR – Managed Realignment; NAI – No Active Intervention				

Most of the areas in which the Hold the line policy is proposed on the Dysynni coastline already have coastal defence structures. The north shore of the Dyfi estuary (PU10.11-10.12) is protected by a sea wall, and Aberdyfi town (PU 10.13) is fronted by a harbour. The Tywyn coastal frontage (PU 10.16) is dominated by a promenade protected by a sea wall, wooden and rock groynes, a breakwater and rock revetments. Along the shoreline in front of Tywyn sewage works and Morfa Gwyllt (PU 10.17), the railway line is protected by a coastal embankment and rock armour, although the spit extending to the mouth of the Dysynni (also PU 10.17) is only protected by a natural shingle bank. Further north, Rola (PU 11.1) is protected naturally by a coastal cliff (Lle 2016). In order to maintain the coastline in its current position in these areas, the existing defences along this coastline will be maintained. In addition, areas that are not currently protected by engineered defences may need further investment in the near future to maintain the standard of protection. Earlie *et al.* (2012d) predict that the Rola cliffs may erode by 10-20m by 2100, which would potentially impinge upon the railway line. Furthermore, Earlie *et al.* (2012b) predict that sea-level rise may cause the shingle shoreline barrier across the mouth of the Dysynni to breach. These areas will need additional defence in order to meet the Hold the Line policy.

MR was the chosen policy plan for the following areas (Figure 8.8) (Earlie *et al.* 2012b):

- Aberdyfi dunes seaward of the golf course (PU 10.14)
- Penllyn frontage (PU 10.15)
- Tonfanau (with a move to NAI in the 2055-2105 epoch) (PU 10.19)

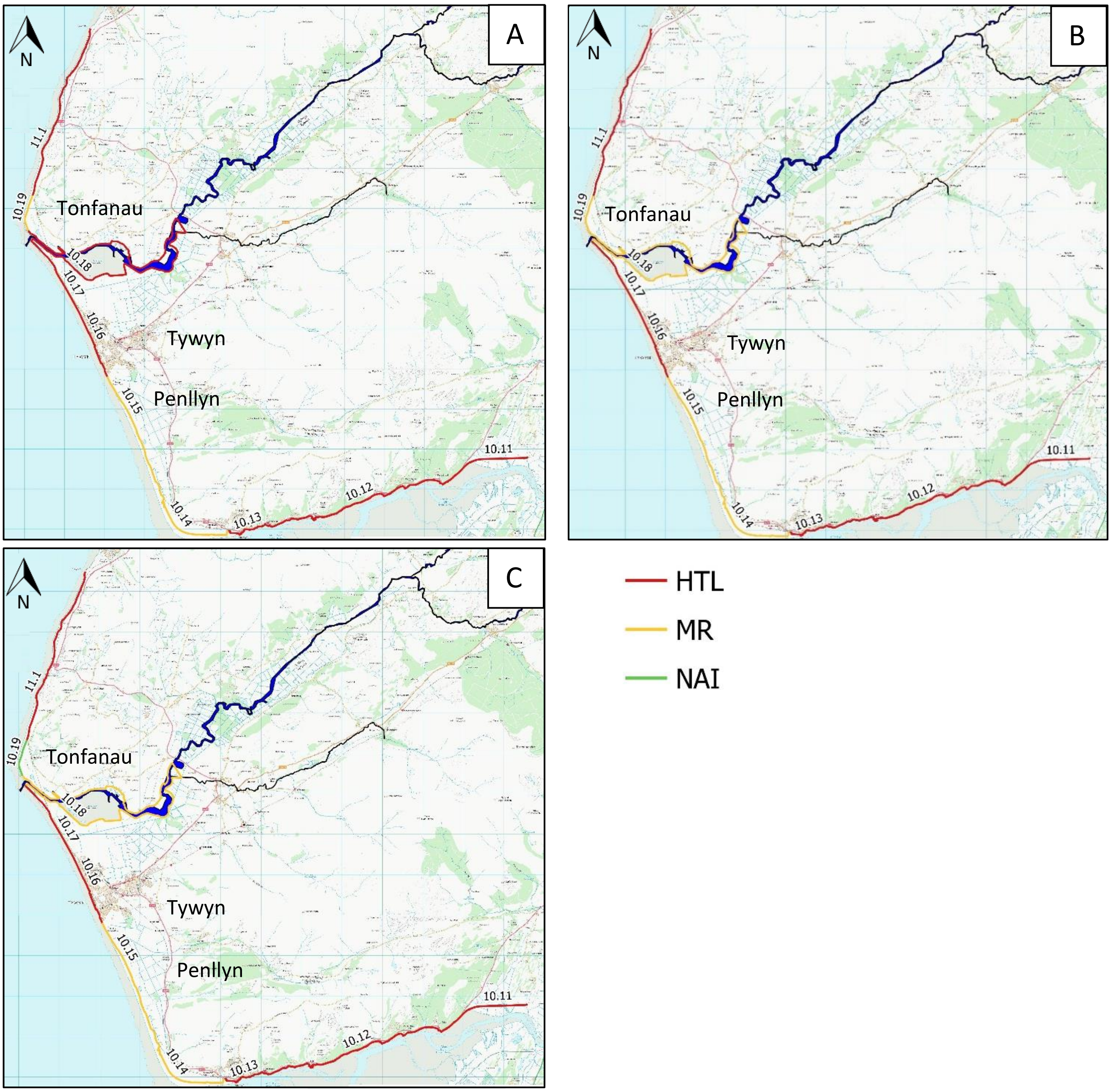


Figure 8.8. *SMP policy plans for each PU along the Dysynni coastline and estuary for 2011-2025 (A), 2025-2055 (B) and 2055-2105 (C). Crown copyright and database right 2019 Ordnance Survey 100025252*

The policy plan for the Dysynni Estuary, which comprises Broadwater and the stretch of the river to Pont Dysynni (PU 10.18), is HTL for the short-term but changes to MR from 2025-2105 (Earlie *et al.* 2012b). The land that would be suitable for a MR scheme at the Dysynni Estuary covers around 250ha and is located mainly to the south of the river and existing estuary, Broadwater. There are currently embankments protecting this low-lying ground from inundation from the river, as well as a low-level drainage system. The other areas earmarked for MR by the SMP2 in the study area are just less than 5km long in total, and comprise the Penllyn frontage (PU 10.15) and the sand dune system to the south (PU 10.14), which currently acts as a coastal barrier for Aberdyfi golf club. Behind the low coastal barrier at Penllyn, there is a low-lying area of around 200ha that could be suitable for a MR scheme should the existing barrier be breached.

With this proposed management plan, Earlie *et al.* (2012a) predict that coastal erosion would cause no damage to commercial or residential properties in the next 100 years. However, the economic damage of a 1-in-10 year tidal flood would increase from £36,000 (217 properties affected) in 2010, to £216,000 (365 properties) by 2110.

8.3.4 Summary

As evidenced by this section, the dominant approach to coastal management in the study area has been through hard defence construction, particularly along the Tywyn frontage. In most areas that are currently defended, a HTL approach will continue to be used, while in other areas the proposed approach is MR or NAI. The current flood risk infrastructure in the study area, the DLLD, seems to have been underperforming for around the last century

The purpose of Chapter 8 was to develop a sustainability assessment methodology to apply to different coastal and flood-risk management approaches in the study area. One of the approaches that was assessed using the methodology is the current SMP2 policy plan described in this section. Other approaches included in the sustainability assessment are identified in 8.4.

8.4 Sustainable Coastal Management, and Developing an 'Innovative Sustainable' Option

Section 8.4 develops an 'Innovative Sustainable' (IS) option to compare to the SMP2 policy plan. The IS option is comprised of new or innovative sustainable management techniques for estuarine, riverine and coastal areas. The main purpose of creating this IS option is to test the sustainability assessment methodology and how well it compares between different alternatives based on conflicting criteria.

Prior to the establishment of which management approaches were included in the IS option, there is a brief discussion regarding what sustainable coastal and flood risk management entails (8.4.1). Subsequently, there is a review of several different sustainable coastal and flood risk management techniques, including evidence of the strengths and weaknesses of each (8.4.1). This was used to identify the techniques that were included in the IS option.

8.4.1 Sustainable coastal and flood risk management

For a project to be sustainable, it must incorporate consideration of social, economic and environmental factors, and aim to provide a solution that is equitable across both present and future generations (Brundtland and Khalid 1987; Stocker *et al.* 2012; Sánchez-Arcilla *et al.* 2016). Sustainable coastal management would "provide the maximum possible social and economic resilience against [threats such as erosion and] flooding, by protecting and working with the environment, in a way which is fair and affordable, both now and in the future" (Werritty 2006, p.19).

While this section and the sustainability assessment focuses on specific management tools (such as sea walls, beach nourishment, and MR projects), it is acknowledged that the overall governance frameworks in place influence the sustainability of coastal and flood risk management. Firstly, conflict and inefficient use of resources can occur when there are overlaps in jurisdiction and confusion of responsibilities between organisations and authorities that have different levels of power, such as the Environment Agency, local and regional flood defence committees and drainage districts, DEFRA, and landowners (Shi *et al.* 2001; Ledoux *et al.* 2005; Flatman 2009; Hall *et al.* 2016).

Scale issues can cause limitations in the efficiency and efficacy of coastal management. Decisions on coastal defence strategy are usually made on a national level, while the design and implementation of coastal management occurs on a local level. There can be difficulties in translating the national frameworks into individual project plans, due to the context-specific nature of coastal issues, and limited local budgets (Few *et al.* 2007a; Milligan and O'Riordan 2007; Tribbia and Moser 2008). SMPs are designed to align with the location of sediment cells, in order to address the scale mismatch between the jurisdictional scale of coastal management and the spatial scale of environmental processes (Milligan *et al.* 2009; Termeer *et al.* 2010). Finally, the establishment of national strategies and SMPs in a top-down approach can result in unforeseen conflicts with other stakeholders (Guariguata *et al.* 2012), so this may not be the most socially sustainable method for controlling the governance of coastal zones.

In terms of management tools, a move from fixed, hard defences towards more flexible strategies is often suggested as a way to reduce the cost and environmental impact of coastal management (Turner *et al.* 2007). Hallegatte (2009) promotes *no-regret* strategies, such as working with natural processes, restricting land-use planning away from flood-prone areas, enhancing drainage systems, and developing warning and evacuation schemes. The idea behind these is that they would be useful even if climate change did not occur, and so will provide benefits regardless of the realised emission scenario (see also Turner *et al.* 1998; National Trust 2015b). The following section reviews several different sustainable, innovative, no-regret coastal and flood risk management tools that could be included in the IS option, namely ecological engineering, sand engine beach nourishment, controlled tidal restoration, and floodplain reconnection. This includes reference to the impacts of each tool on the archaeological resource, as well as social, environmental and economic considerations.

Ecological engineering

Ecological engineering exploits the characteristics of natural processes by creating or manipulating ecosystems to provide coastal defence or other socio-economic benefits (Firth *et al.* 2014). Research by Firth *et al.* (2013a, b, 2014) indicates that species diversity on artificial structures can be increased by creating crevices and surface roughness on structures. Many species are more likely to colonise the structure if it has a heterogeneous surface like a natural rocky shore. Water retaining features, emulating the characteristics of rock pools, can be designed into the defence structure, or fitted retroactively. These water retaining features provide refugia for intertidal organisms at low tide, and have been shown to have greater biodiversity than emergent substrata (Firth *et al.* 2013a). However, other than the ecological benefits, these structures still cause the same problems as traditional hard defences (see 8.3.3). Ecological engineering has been retro-fitted to the breakwater defence in Tywyn by the drilling of small rock pools (see 8.3.1, Figure 8.4)

A more drastic approach to ecological engineering is to use natural structures like coral reefs or oyster reefs to attenuate wave height and energy in a similar way to submerged or low-crested breakwaters (Dafforn *et al.* 2015; Cunnliff 2016; Morris *et al.* 2018). Coral reefs have been shown to reduce wave height by 70%, comparable to wave reduction rates of low-crested breakwaters (Ferrario *et al.* 2014; Narayan *et al.* 2016). Research indicates that oyster reefs reduce wave height by 25%, but when used in conjunction with saltmarshes, they can provide wave height attenuation of 67.3% (Garvis 2012; Morris *et al.* 2018). Piazza *et al.* (2005) argue that although oyster reefs can reduce erosion along low-energy shorelines, they are less effective along high-energy shorelines. A key weakness of hard built defences is that, due to sea-level rise, the level of defence provided will reduce over time unless costly upgrades are undertaken (Nørgaard *et al.* 2013). In contrast, oyster reefs can grow in height quickly enough to keep pace with projected sea-level rise, so the level of defence that they provide remains constant (Sutton-Grier *et al.* 2015). Research by Sumer *et al.* (2002) showed that the permeability of reefs caused less reflection than traditional breakwaters, and therefore less scour on the bed seaward of the structure. This means that utilising natural reefs could have less potential impact on submerged archaeological features such as wrecks, fish-traps, and submerged landscapes. Furthermore, the natural appearance of such reefs would have little impact on the character of the coastal historic landscape.

In terms of the economic aspect, natural reefs are cheaper to create than standard built defences; oyster reef breakwaters cost around $1m per mile (≈£460,163 per km) whereas rock breakwaters cost $1.5-3m per mile (≈£690,245 - £1,380,490 per km) (Cunnliff 2016). Utilising oyster reefs in coastal defence also gives a higher return on investment than traditional built defences, as additional ecosystem services such as biodiversity and water filtration are provided alongside the coastal protection (Cunnliff 2016). In the Gulf of Mexico, a 5.6km-long oyster reef was installed as a submerged breakwater and provided over 3 tonnes of catch per year (Sutton-Grier *et al.* 2015). The oyster reef also removed 1.9 tonnes of nitrogen per year from the surrounding waters, which helped reduce the risk of eutrophication behind the breakwater (*ibid*.). These secondary benefits could help coastal communities in the areas in which coastal defences are installed (Morris *et al.* 2018). However, this oyster reef was comprised of *Crassostrea virginica*, or Eastern Oyster, which is mainly distributed in warm waters along the east coast of North and South America (Kemp and Hanson 2007; La Peyre *et al.* 2014). Reef building species that are found in British waters may not provide the same level of protection, the same economic benefit, or the same rate of water purification shown by this study. Furthermore, there is still some uncertainty about how ecosystems may react to climate change, for instance coral is at risk of bleaching due to ocean acidification and sea-level rise (Morris *et al.* 2018). There is a seasonal variation in the biomass in coral reefs, so the level of protection available may vary (*ibid*.). This level of uncertainty can form a barrier to the wider use of natural systems for coastal defence.

There are a few disadvantages to using natural systems for coastal defence. Primarily, as mentioned above, the exact level of protection provided by natural reefs or dunes is not as well defined as that of built defences, as it can be influenced by the ecosystem maturity and species density, among other things (Sutton-Grier *et al.* 2015). This means that there is generally lower confidence in natural defences in areas with high value land and assets, such as urban waterfronts. It can take some time for the ecosystem to become properly established, meaning that the area of coastline is undefended at the beginning of the project (*ibid*.) Sutton-Grier *et al.* (2015) suggest that natural and built defences can be used in conjunction in order to benefit from the strengths of each approach. For instance, when combining an offshore oyster or coral reef with a sea wall, the sea wall provides coastal protection while the reef is developing, and when established the reef reduces the height and power of waves reaching the sea wall, thus reducing structural damage and maintenance requirements. Hybrid approaches like this can have the same disadvantages as both natural and hard defences, such as negative impacts on sediment transport, and biodiversity (*ibid*.).

Due to the uncertainty surrounding the potential for oyster or coral species to recruit and survive in the study area, and whether the conditions would be suitable to grow an oyster or coral reef, this technique is not included in the IS option for comparison against the SMP2 option. Furthermore, a key threat to the study area is the flood risk to the lowlands and a reef breakwater would mainly provide protection against erosion rather than high water levels.

Beach nourishment and sand engines

Beach nourishment reduces the impacts of coastal erosion by depositing sediment on the intertidal, dune, or nearshore subtidal area, which widens beaches, dissipates wave energy, reduces beach profile lowering, and improves visual amenity (Phillips and Jones 2006; Ostrowski *et al.* 2013; Marinho *et al.* 2017).

Research by Marinho *et al.* (2017) shows that the same equilibrium state is reached on beaches following nourishment regardless of where on the beach profile the sand is deposited. This means that near-shore nourishment is just as effective as intertidal and dune nourishment but is much cheaper, and as the construction process can happen by sea it is less intrusive to the beach environment and has greater public acceptance (Stive *et al.* 2013; Burcharth *et al.* 2015). In the short-term, dune nourishment can provide protection against flooding, as dunes are often higher than sea walls, so can protect against high water levels (Rhind and Jones 2009). Research by Bayas *et al.* (2013) indicated that dunes are slightly less effective than sea walls at reducing flood risk, but dunes reduced wave strength so the resulting floods caused less structural damage than those at sea walls (Morris *et al.* 2018). Grey dunes (fixed dunes with a herbaceous vegetation cover) are at less risk of erosion compared to unvegetated dunes, and are a Biodiversity Action Plan (BAP) priority habitat, and so must be conserved under the European Commission's Habitats Directive (Rhind and Jones 2009). Restoring grey dunes therefore provides defence against coastal erosion and storm surges, as well as meeting conservation targets. Other secondary benefits of sand dunes include space for grazing, visual amenity, and recreation. Dune restoration is likely to have less of a direct impact on any archaeological remains compared to the construction of fixed defences, as there is no disruption of the subsurface.

Generally beach nourishment schemes have a design life of 3-5 years, although in some areas it is undertaken annually, so the cost of management is ongoing (Stive *et al.* 2013). There is a novel beach nourishment project, called the Sand Engine, which utilises natural coastal processes to help provide the coastal protection. The project commenced in 2011 on the Delfland Coast in South Holland (see Figure 8.9). It is considered a mega-nourishment scheme, as it involved the deposition of 21.5 million m^3 of sand, ten-times greater than most nourishment projects (Stive *et al.* 2013;

Vikolainen *et al.* 2017). All of the sand was placed in a single area and will be redistributed along the coast by longshore drift over the next 20 years (Stive *et al.* 2013; Vikolainen *et al.* 2017). This provides the same benefit as normal beach nourishment projects, such as wider beaches and erosion protection, but causes less ecological stress in the receiving coastline as it only needs to be undertaken every 20 years. In the Dutch Sand Engine project, the sand was deposited in a hook-shaped peninsula, which has created a shallow lagoon to support organisms such as flatfish (see Figure 8.9; Stive *et al.* 2013).

Figure 8.9*. Photographs of the initial sand engine deposition in the Netherlands in 2011 (top-left), and subsequent evolution of the sand peninsula. Photographs Copyright Julian Brobbel*

It is expected that the Sand Engine will stabilise 10km of the Dutch shoreline for 20 years, and monitoring of the first 18 months using satellite imagery has shown that almost all of the observed retreat of the peninsula has been compensated for by accretion in the adjacent coastline (De Schipper *et al.* 2016). The Sand Engine is one of the approaches that was assessed by the MAVT sustainability assessment for its suitability for the Dysynni valley. A wide, sandy beach and dune system already characterises a significant section of the study area coastline, so the establishment of a wider beach along the entire coastline would not dramatically alter or damage the character of the historic landscape in the coastal area. It would also provide protection against erosion for archaeological features that are currently seaward of the hard defences at Tywyn, such as fish-traps, peat cuttings and submerged forest, and reduce the erosion pressure on the existing defences. The trajectory of the sand engine towards an equilibrium on the coastline means that this project would not cause policy lock-in, and is essentially a no-regret option.

Controlled tidal restoration

A relatively new technique that can be used as a form of MR in both coastal and estuarine/riverine areas is controlled tidal restoration (CTR), often referred to as regulated tidal exchange (RTE) or controlled reduced tide (CRT). In CTR the existing line of defence is maintained, and the tidal flow is restored into an embanked area (flood control area – FCA) behind the defence by creating sluices and culverts (see Figure 8.10) (Johnstonova 2009; Environment Agency 2010; Esteves and Williams 2017). CTR can be used as a precursor to defence removal, as it allows sedimentation to raise the elevation of the land behind the defence, as land that is too low-lying is unsuitable for saltmarsh development (Esteves 2013). Some CTR systems use sluices and tide-gates to control the amount of water entering the FCA, however there can be mechanical faults and high maintenance costs associated with these methods (Beauchard *et al.* 2011; Masselink *et al.* 2017). Other CTR projects use high inlet culverts and low outlet valves to recreate the tidal regime within the FCA (*ibid*.). Using CTR reduces flood risk as the tidal influx is dampened by the temporary storage of water in the FCA, while the secondary embankments can protect valuable land behind the FCA (Cox *et al.* 2006; Jacobs *et al.* 2009).

As with other MR schemes, the creation of wetlands or intertidal habitats using CTR can lead to the provision of many ecosystem services alongside flood mitigation, including biodiversity, biogeochemical cycling, habitat provision, and recreation (e.g. birdwatching) (Cox *et al.* 2006). Furthermore, CTR and FCAs can be used in places where breaching defences or reconnecting floodplains is not possible due to land scarcity or valuable infrastructure nearby (*ibid*.).

However, as the wetland created is not naturally functioning, there can be limitations with the CTR in terms of habitat succession and ecosystem service provision. Research by Masselink *et al.* (2017) into a CTR system in Dorset showed that sedimentation rates in the FCA were ten times lower than in a natural saltmarsh nearby. This would reduce the ability of the saltmarsh to adapt to rising sea levels like natural marshes, as the sediment supply and water levels are controlled by the inlets rather than by the site elevation relative to the tidal frame (Oosterlee *et al.* 2018). Moreover, due to the nature of the inlet and outlet valves, and the lower tidal range, the duration of high tide is greater in the FCA than the surrounding coastline (Beauchard *et al.* 2011). This extended flood duration compared to natural marshes could cause waterlogging or prevent succession to a mature saltmarsh community (Cox *et al.* 2006; Masselink *et al.* 2017; Oosterlee *et al.* 2018).

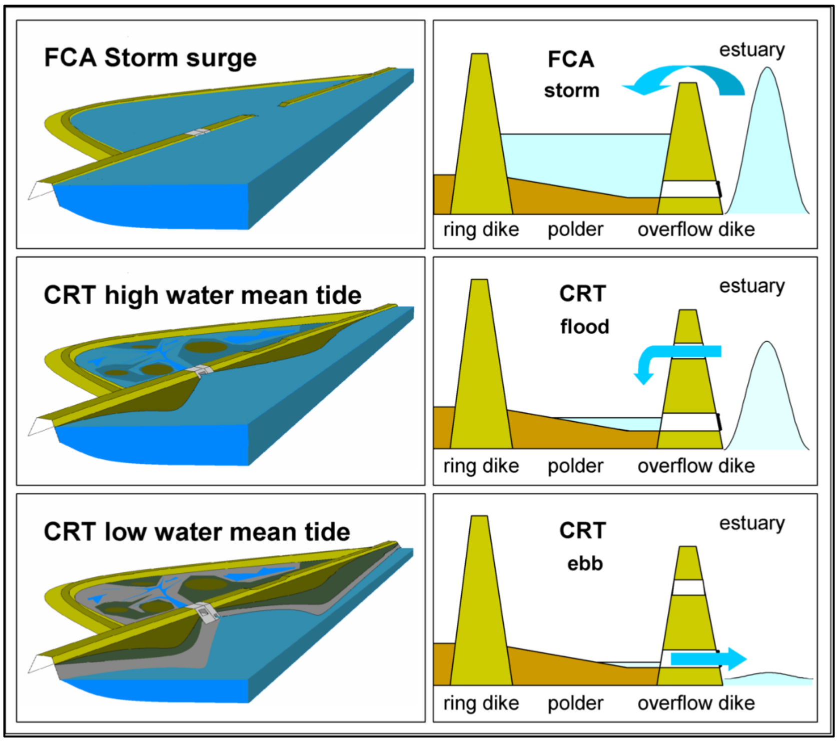


Figure 8.10. *Diagram showing how a CRT system prevents flooding behind the defence (ring dike) by controlling the amount of water that can enter the embanked area. A wetland ecosystem can be created in the embanked area (polder) through the gradual deposition of sediment, and protection from erosion. Source: Ecosystem Management Research Group, University of Antwerp (CC BY-SA 4.0)*

In terms of archaeology, CTR is incompatible with *in situ* preservation of any remains that are within the area of surrendered land. The subsurface environment will change due to more frequent inundation, so it is not possible to maintain the static conditions required for *in situ* preservation. Any above-ground features are also likely to be affected by frequent inundation. Salt water is more damaging to some archaeological materials than freshwater, and causes corrosion of metals, calcium carbonate concretions on materials, rapid deterioration when exposed to the air, and the saturation of artifacts with salts (which leads to crystalisation, flaking and disintegration) (Hamilton 1996; Storch 1997; Hamilton 1999; Nautical Archaeology Programme 1999; Minnesota Historical Society 2006). Therefore, any features affected by CTR would have to be excavated and preserved by record as a precaution.

Finally, as the habitat within FCAs is subject to different hydrological conditions compared to exposed intertidal areas, it is possible that the climax community that would develop would be different to that of a natural intertidal community in the same area (Cox *et al.* 2006; Maris *et al.*

2007; Oosterlee *et al.* 2018). This could impact the ecological functioning of the created habitat, and the potential ecosystem services that it could provide (Oosterlee *et al.* 2018). Oosterlee *et al.* (2018) suggest that more research should be done on the implications of CRT projects on ecosystem service provision.

Due to the various limitations cited above, the CTR tool is not included in the IS option for comparison against the SMP2 policy plan. CTR requires the construction of significant infrastructure which would be very costly, and could have negative environmental impacts, meaning that it is not a no-regret option, and is not necessarily sustainable. There is no stretch of the Dysynni coastline for which it would be suitable, as either an area already fronted by a sea wall would have to be sacrificed for the creation of wetland, or a hard defence structure would have to be built in an area that is currently undefended. Furthermore, if it were employed in the Dysynni estuary, it would require investment in significant defensive infrastructure and sluice systems which would disrupt some of the natural estuary processes occurring there.

Floodplain reconnection

Floodplain reconnection is a less controlled method of MR than CTR. Rather than water being introduced into a single area, all river embankments are removed in order to reconnect the river channel to the natural floodplain (Environment Agency 2010). This allows the river water to extend over the floodplain during periods of high water, thus reducing the risk of flash-flooding downstream, for instance in urban areas (Wharton and Gilvear 2007; Risc-Kit 2017a). Floodplain reconnection can also include the re-naturalisation, or re-meandering, of river channels that have been channelised (Wharton and Gilvear 2007; Environment Agency 2010). Recreating river meanders effectively makes the river longer, and delays the time that peak flow reaches downstream (Environment Agency 2010). The creation of new wetland floodplain habitat provides ecological benefits, for instance by providing habitat for invertebrates, wading birds and fish nurseries (Opperman *et al.* 2009; Paillex *et al.* 2009; Guida *et al.* 2014). Reconnection can improve biogeochemical fluxes and river water quality as channel erosion is reduced, and nutrients and pollutants are sequestered or stored in sediments and vegetation within the floodplain rather than kept within the river channel (Volk *et al.* 2004; Johnstonova 2009; Paillex *et al.* 2009; Ledford and Lautz 2015). This reduces the risk of eutrophication in the river and estuary (Ebert *et al.* 2009). Overbank deposition and the development of floodplain wetland habitats can also increase carbon sequestration (Tilman *et al.* 2006).

Another benefit of floodplain reconnection is that it can increase the level of flood protection to protected areas, as larger areas are provided for water storage, and the river channel is not channelised and at risk of overtopping during storm surges or high water (Wharton and Gilvear 2007; Environment Agency 2010; Rick-Kit 2017). This removes the requirement for periodic maintenance and updating of defence and levee systems (Zhu *et al.* 2007).

Finally, much of the floodplain may only be needed to attenuate flood waters a few times a year, so land will not be completely unprofitable to farmers, unlike with coastal managed retreat projects (*ibid*.). Morris *et al.* (2008) state that extensive grazing on washland (i.e. areas occasionally flooded) compared to grassland would not reduce the net margin of combined beef and sheep farming (the main type of farming in the Dysynni valley), although the net margin of beef farming alone would reduce by £80$ha^{-1}a^{-1}$. Furthermore, outdoor recreation and tourism industries can be developed in an area following floodplain reconnection (Sparks and Braden 2007). This diversifies local livelihoods, leading to a more robust local economy (Ebert *et al.* 2009). Schwartz *et al.* (2006) estimate that the value of the ecosystem services generated by floodplain restoration can be much greater than the cost of the project itself, while Guida *et al.* (2016) state that the value of wetland habitat can be greater than the profits from agriculture in some areas. Therefore, in spite of significant upfront cost and economic losses, the long-term economic impact of floodplain reconnection can be positive. Despite this, public acceptance is often low in the areas immediately affected by reconnection schemes, as landowners worry about financial losses, and individual properties outside urban areas may be more at risk from flooding than before (Esteves and Williams 2017; Rulleau and Rey-Valette 2017).

In terms of archaeology, areas that become permanently waterlogged due to a floodplain reconnection scheme may result in greater levels of preservation of archaeological remains. This is particularly important in areas that are extensively drained, such as the Dysynni valley, as the lowering of groundwater due to both drainage and climate change, and subsequent desiccation of subsurface features, could cause significant damage to the archaeological resource. However, the introduction of new water into a previously stable burial environment can initiate or exacerbate decay of archaeological deposits. Therefore, the overall impact is context specific and may be difficult to predict. The re-meandering of river channels may threaten any buried archaeological remains nearby, as the excavation of a new river channel may disturb deposits, or introduce oxygen or water into the burial environment (del Val and Domínguez-Rodrigo 2017). Allowing a river channel to naturally migrate within a floodplain may also expose and erode subsurface deposits, as the river banks erode and accrete (Speakman and Johnson 2006). In terms of the historic landscape, reconnection of the floodplain and re-naturalisation of the river channel may return the lowland areas to the state that they were in prior to the 19th century, and may give the landscape a more 'natural' character. Whether this is a positive or negative (or neutral) impact depends on the landscape in question and opinions on the importance of 'naturalness'/environmental authenticity or the importance of respecting all human influence on the landscape, both recent and historical.

Floodplain reconnection was included alongside the sand engine approach in the IS option. The Dysynni River could be a promising candidate for floodplain reconnection; a section upstream of the Peniarth Estate has been channelised, and the lowest 10km of the river from Broadwater is embanked on at least one side. The DLLD scheme requires maintenance more frequently than is currently possible, so low-lying fields are already waterlogged or inundated during wet periods (see section 5.2). Farming practices and land use are evidently already being affected by wet conditions. Although re-meandering of the canalised stretch may require more investment, floodplain reconnection requires little engineering works, so floodplain reconnection costs could be relatively low. The water quality is poor along several stretches of the River Dysynni, and there is a requirement for periodic dredging (see Campaign for the Protection of Welsh Fisheries 2009; NRW 2016b), so floodplain reconnection that allows overbank deposition may ameliorate these issues. Finally, floodplain reconnection is a no-regret option, as its lifespan is essentially infinite, and would mainly require the blockage of drainage ditches, which could easily be reversed.

8.4.2 Innovative sustainable option

Section 8.4.1 has provided a brief overview of different innovative coastal and flood risk management approaches which may be seen to be more sustainable than traditional defence techniques. The purpose of this was to identify some techniques that could be included in the IS option, which was compared against the SMP2 policy option using a MAVT sustainability assessment methodology. The methods chosen to include in the IS option are as follows:

a) A Sand Engine project along the coast of the study area for coastal erosion and flood defence
b) Floodplain reconnection in the lower reaches of the Dysynni valley for flood defence

The following section (8.5) applies a MAVT methodology to the IS option and SMP2 policy option. The MAVT method determines which approach is most sustainable for managing the threat posed by climate change to the most vulnerable LCAs in the Dysynni Valley, as well as including economic, environmental, and social considerations. This method scores each approach on a variety of different economic, environmental and socio-cultural variables, and can include both qualitative and quantitative factors. The approaches are then ranked by their overall score, but they can also be ranked based on their score for different types of variable (e.g. the most environmentally sustainable, or the most socially sustainable approaches).

8.5 Application of the Multi-Attribute Value Theory to the Dysynni valley

The sustainability assessment method chosen for the research proposed is MAVT, a type of multi-criteria decision analysis (see 8.2). This approach was chosen because there are a discrete set of alternatives that must be assessed based on conflicting objectives, namely achieving management of the impacts of climate change in an economically, socio-culturally and environmentally sustainable way. In this chapter, 'alternative' refers to each of the different coastal management approaches being compared in the MAVT, namely the SMP2 policy option and the Innovative Sustainable (IS) option (see 8.4.2).

8.5.1 Methodology

The structure of the MAVT methodology is based on recommendations from Van Herwijnen (2006), Giove *et al.* (2010) and Ferretti *et al.* (2014), and involves the following steps:

1. Define the overall objectives and desired attributes for the 'best' potential option out of the alternatives that will be compared.
2. Identify the alternatives that will be compared
3. Select and define the criteria that will be used to assess each alternative, based on the objectives
4. Select and define the attributes that will be used to measure each criterion
5. Select and define the parameters that will be used to measure each attribute
6. Give scores to each alternative for each parameter
7. Aggregate the scores to calculate the overall score and separate criteria scores for each alternative
8. Rank the alternatives based on their overall score.

Steps 1 and 2 were completed in 8.2-8.4. This section describes the MAVT methodology used in this thesis in more detail. The scoring system is explained, followed by a definition of the criteria, attributes and parameters that were used (Steps 3-5). The results are detailed in section 8.6 (steps 6-8).

Multi-attribute value theory framework

The structure, or framework, of the MAVT assessment that was used in this thesis is based on that developed by Giove *et al.* (2010), which uses MAVT to compare two options for the sustainable re-use of a historic area of Venice. This decision was made because the focus of Giove *et al.* (2010)'s study was on achieving economic, socio-cultural and environmental sustainability in the rejuvenation and re-use of a coastal area, which mirrors the aim of this study.

Table 8.2 demonstrates the hierarchic MAVT framework that was used in this thesis. Four criteria were determined for assessing the sustainability of the alternatives: Economic sustainability, Socio-cultural sustainability, Environmental sustainability, and Functionality. Each criterion is divided into several attributes, each of which is defined by one or more parameters. The criteria, attributes and parameters are defined in more detail below.

Scoring System

This research uses the same scoring method as Giove *et al.* (2010), who score each parameter on a scale from 0-100, with 0=worst/strongly negative, 50=medium/neutral, and 100=optimal/strongly positive. The attribute score is calculated as the average of the parameter scores, and the criteria scores are the average of the attribute scores. The overall sustainability score for each alternative can be calculated as the average of the criteria scores. The alternatives can also be compared by their score for each attribute, for instance to identify the option that is 'best' from a functionality perspective, or in terms of environmental impact.

Table 8.2: *Multi-attribute value theory framework adapted from Giove et al. (2010)*

Criteria	**Attributes**	**Parameters**
Economic sustainability	Financial feasibility	Cost compared to approved project for Dysynni valley
		Maintenance requirements
	Impact on local businesses	Impact on the tourist industry
		Impact on farming practices
		Impact on other local industry
Socio-cultural sustainability	Public perception	Impact on current way of life
		Impact on space available/opportunities for recreation activities
	Impact on the historic landscape	Impact of construction on LCAs with 'High' or 'Very High' vulnerability

		Impact of the finished project on the historic character of the immediate vicinity of the project
		Impact of the finished project on the historic character of the Dysynni landscape as a whole
		Accessibility of historic sites and features following the project
		Level of protection for LCAs with 'High' or 'Very High' vulnerability
Environmental sustainability	Ecological impact	Impact on existing terrestrial ecosystems
		Impact on existing intertidal ecosystems
		Impact on existing marine ecosystems
		Potential for new ecosystem creation
	Sustainability of sourced materials	Locality of materials used
		Environmental impact of material extraction/production
	Impact on carbon emissions	Is the project a net source or net sink of carbon emissions?
Functionality	Impact on flood risk	Impact on terrestrial/inland flash-flood risk
		Impact on coastal flash-flood risk
		Impact on long-term inundation of inland areas
		Impact on long-term inundation of coastal areas.
	Impact on coastal erosion	Impact on coastal erosion
	Flexibility	Can the project be altered if new conditions or information come to light?
	Longevity	Lifespan of project
		Amount of maintenance required
		Likelihood of failure

Assessment criteria

Four criteria were used in this MAVT (see Table 8.2): Economic sustainability, Socio-cultural sustainability, Environmental sustainability, and Functionality. As a sustainability assessment, the MAVT incorporates the three pillars of sustainability. In order to include cultural aspects, such as the impact on archaeology and the historic landscape, 'socio-cultural sustainability' was used instead of 'social sustainability'. Functionality was also included to ensure that the coastal management approach was being assessed based on its ability to perform its primary function as a defence against the impacts of climate change, as well as its sustainability. This section explains and justifies the choice of each of the attributes for each criterion.

Criterion: Economic sustainability

Attribute: Financial feasibility

The financial feasibility of an alternative is of critical importance, as a management approach cannot be implemented if it is unaffordable. On the coastal frontage of Tywyn, several coastal management projects were recently rejected due to the projected cost, and only one was approved (see 8.3.1). The potential cost of each alternative was based on the costs of similar projects elsewhere. This estimated cost was compared to the cost of the approved project along Tywyn and the projected cost of the MR scheme at Penllyn, in order to establish whether it would be considered an acceptable cost.

Another aspect of financial cost is the management requirements of each alternative. Projects with frequent or high intensity maintenance requirements may be less financially feasible. The acceptable or 'neutral' level of maintenance requirement was based on the current level of maintenance of the coastal defence infrastructure and the Dysynni Low Level Drainage scheme. Managed realignment schemes may require subsidies for participating/affected land-owners, which would increase the total cost of the project.

Attribute: Impact on local business

Coastal management projects can have secondary economic impacts. For instance, an alternative that increases space for recreational activities and improves the amenity of the area could result in an increase in tourism, which would benefit local business such as shops, hotels, and restaurants. However, an alternative that would reduce beach accessibility could result in a reduction in tourism, which would have negative economic impacts on the area. Local construction companies would benefit economically from being commissioned for work. An alternative that would cause a loss or change in land use would impact the ability of the landowner to continue that land-use practice, for instance farming, and therefore result in economic losses.

Criterion: Socio-cultural sustainability

Attribute: Public perception

The public perception of an alternative is an important consideration, as a lack of acceptance of an alternative may lead to conflict and mistrust in local authorities (POST 2009). Public perception can be affected by the influence that the project may have on current ways of life and the way people are able to interact with their landscape or coastline. The impact of an alternative on recreation is also considered to be particularly important for the public acceptance of a project (see Myatt-Bell *et al.* 2002). Recreation can include activities such as golf, bird-watching, beach activities, walking and hiking, water sports, and horse-riding. Ideally, public perception parameters would be generated, and the alternatives assessed, through public participation measures such as public forums and interviews. This could be undertaken if this method was applied to another area in the future. It is acknowledged that the impact of alternatives on the character of the area and wider landscape can be important for the public perception, but this parameter is included in the Impact on historic landscape attribute.

Attribute: Impact on the historic landscape

The impact of alternatives on the historic landscape was focussed on the LCAs that were found to be most vulnerable to the impacts of climate change, namely Wetland and Beach, Maritime Industry, and Military. This includes the impact of construction, which could be visually and physically damaging or disruptive, and may alter the relationship of some features to others or to the landscape as a whole. It also includes the level of protection against climate change that each alternative may provide to the LCAs. Accessibility of the historic sites and features within each LCA is another important consideration, as it affects how people are able to interact with the historic landscape. Alternatives may have a lasting impact on the character and integrity of the historic landscape, both in the immediate vicinity of the project, and the Dysynni landscape as a whole.

The scores given for this attribute assume that full mitigative actions would be undertaken for archaeological sites and features that would be damaged by the construction, or by subsequent erosion or inundation, due to the choice of alternative. This mitigation would be in the form of either excavation or full recording of a site. Preservation by record through archiving or 3D data capture may provide some level of accessibility, as it could be available in museums. However, this would not fully offset the damage that a loss of a feature would have on the integrity of the historic landscape and certain LCAs. If some of the pillboxes on Tywyn beach were at risk of destruction, the excavation or detailed recording of them would not compensate for the loss of integrity of the defensive coastal landscape that they create as a group. In the UK, *in situ* preservation for archaeological remains is prioritised where possible (Corfield 1996; Gearey and Chapman 2006). However, climate change will necessitate additional coastal and flood risk management in many areas, which may take precedence over the *in situ* preservation of some remains. Furthermore, *in situ* preservation is not a viable option for all archaeological remains. Footprints preserved in mudflats or ancient peat are usually located on beaches or coastal areas, for example those discovered in Low Hauxley, Northumberland, and are highly vulnerable to erosion (see Figure 2.4; Cosgrove 2015; Bennett *et al.* 2010). Simply burying the features in sediment is not a permanent solution, particularly along destructive coastlines, and attempting to harden the surface with resin could cause cracking (Bennett *et al.* 2010). In cases like these, preservation by record may be the only way to protect the archaeological information at risk.

Criterion: Environmental sustainability

Attribute: Ecological impact

The construction of hard defences in coastal management projects can have significant impacts on ecosystems shoreward and landward of the defences themselves (see 8.3.3). Construction activities can destroy ecosystems, and the change to coastal processes following the establishment of a new method of defence can alter the suitability of the area for different species. Managed realignment projects result in the creation of more intertidal saltmarsh, but at the loss of terrestrial habitat (Harman *et al.* 2002). Hard defences can provide additional area for hard substrate intertidal species such as bivalves, which may be seen as positive or negative; it creates the potential for new ecosystems to establish, but could cause the introduction of non-native and potentially invasive species into the area.

Attribute: Sustainability of sourced materials

The environmental impact of the creation and sourcing of materials used in coastal management projects is an important consideration when assessing their sustainability. The environmental impact of materials is influenced by the distance that they have travelled; materials sourced from far away result in higher carbon emissions, while those sourced locally have lower transport-related carbon emissions. The production or extraction process of materials can also have significant environmental impacts. Quarrying, mining and dredging can result in habitat destruction, whereas using recycled materials has less of an impact on the environment.

Attribute: Impact on carbon emission

Some aspects of the alternatives could result in systems that may become a carbon sink, such as salt marshes created in SMP2 policy MR projects, or the floodplain wetlands created in the IS option (Chmura *et al.* 2003; Laffoley and Grimsditch 2009; Artigas *et al.* 2015). Reconnecting floodplains would also result in the creation of areas of wetland, a known carbon sink. There is evidence to suggest, however, that wetlands can be a source of methane (CH_4) emissions (Whiting and Chanton 2003). This would make a coastal management project less environmentally sustainable, as it would contribute to the GHG emissions causing climate change.

Criterion: Functionality

Attribute: Impact on flood risk

It is essential that coastal management projects meet functional aims as well as providing secondary benefits. Different alternatives will have different levels of impact on the existing risk of flash-flooding, both in terrestrial and coastal areas. It is important to consider the impact of different alternatives on the long-term risk of flooding and inundation, as well as flash-flooding. While sea walls may reduce the short-term risk of flooding, unlike saltmarsh and dune systems, they are unable to migrate with rising sea levels. Therefore, both long- and short-term factors must be considered.

Attribute: Impact on coastal erosion

Different alternatives provide differing levels of protection from erosion, and the spatial variability in erosion protection is also different depending on the alternative chosen. Hard defences provide shoreline erosion protection, but their presence can exacerbate beach lowering or displace shoreline erosion further down the shore (Drummond *et al.* 2017; Beuzen *et al.* 2018). In contrast, beach nourishment or managed retreat schemes allow some erosion but protect important infrastructure and reduce the financial impact of the erosion that occurs.

Attribute: Flexibility

A defining feature of climate change is that its trajectory and impacts in the mid- to distant future are not known entities. Policy-makers aim to avoid making decisions that will result in 'policy lock-in', in which it is impossible or very difficult to change or reverse the chosen management approach if new information comes to light. Built defences are often thought to result in policy lock-in as, once built, they must be maintained and cannot be removed without significant cost.

Attribute: Longevity

The final attribute of the Functionality criterion is longevity, or how long the alternative will last before it must be renewed. Alternatives with a short lifespan will require further decisions and investment after only a short amount of time has elapsed. The amount of necessary maintenance is also important, as it dictates the amount of effort and investment that is required additional to the initial cost of the alternative. Finally, the likelihood of failure of an alternative, whether that be with regards to coastal erosion, flash-flooding, or inundation, must be taken into account. An alternative with a high likelihood of failure may have a shorter lifespan in reality than its projected lifespan, as once a defence has failed, or been damaged or destroyed, it will need significant updating or rebuilding. For instance, damage to the sea wall and promenade in Aberystwyth during the winter storms of 2014 resulted in the need for an £11 million coastal defence renewal project (BBC News 2018).

Limitations

The main limitation with the methodology as described above is the lack of stakeholder or expert involvement. As MAVT considers a wide range of often conflicting criteria, the participation of decision-makers, stakeholders and/or 'experts' is often an integral part of MAVT methods. Firstly, it can highlight context-specific issues or requirements that may not have been considered or valued as highly by an external researcher (Stefanopoulous *et al.* 2013). The inclusion of stakeholders in MAVT methods has been shown to improve the acceptance of the results (Hostmann *et al.* 2005). Using a range of experts or stakeholders helps to avoid any potential bias that may occur if one or no stakeholders are involved.

Some studies involve 'experts' or decision-makers in the initial stage of defining the evaluation criteria and attributes (e.g. Giove *et al.* 2010; Bottero *et al.* 2014), whereas others use 'experts' from a range of backgrounds to help with the scoring process (e.g. Hostmann *et al.* 2005; Stefanopoulos *et al.* 2013; Ferretti *et al.* 2014). Despite the cited importance of having a range of opinions and expertise when undertaking a MAVT assessment, the criteria and scoring of the MAVT assessment in this thesis were based solely on available grey and academic literature. Time and financial constraints meant that conducting interviews or focus groups with a range of stakeholders from the study area would not be feasible. Brandão Cavalcanti *et al.* (2017) found that they had limited access to decision makers in the relevant field. They instead used online resources such as humanitarian organisation websites and academic literature to inform their choice of criteria and scoring. Therefore, this is not a completely unorthodox approach to MAVT.

The purpose of this thesis is to develop and demonstrate a framework for the sustainable assessment and management of historic landscapes in relation to their vulnerability to climate change. Therefore, the MAVT assessment carried out here is not for informing and enacting actual landscape management policy in the study area. Rather, the aim is to create and exemplify a framework that can be used by decision-makers, applied to other coastal historic landscapes, and adapted for use in other types of historic landscape. Using academic and grey literature is sufficient for the scoring process in this example. It is strongly suggested that any future application of this framework for historic landscape management purposes should involve stakeholders and consult 'experts' during the scoring process, in order to get the fairest and most reliable results.

Summary

A MAVT tool for sustainability assessment has been developed here to aid in the comparison of different coastal and flood-risk management alternatives. The overall aim is to develop a tool that can be applied to any historic coastal landscape in the UK and beyond as part of the Landscape Vulnerability Framework. This tool has been applied to the two alternatives developed for the Dysynni valley study area (the SMP2 policy option and the IS option) in order to trial the methods and identify any further limitations. The results of this are discussed in the following section (8.6).

8.6 Results

This section discusses the results of the MAVT assessment for each criterion and attribute (summarised in Table 8.11).

8.6.1 Criterion: Economic sustainability

The IS option scored higher than the SMP2 policy plan for the Economic Sustainability criterion (SMP2 = 47.1, IS = 65.1), and on all parameters other than 'impact on farming practices' and 'impact on other local industry' parameters (attribute: Impact on local business) (See Tables 8.5 and 8.6). The IS option scored twice as highly for the *Financial Feasibility* attribute, as the projected initial cost was lower and the projected maintenance costs were negligible. The scores for *Impact on local business* attribute were very similar (SMP2 = 56.7, IS = 57.5), although the scores for different parameters within this attribute varied. The IS option scored higher for the 'Impact on tourist industry' parameter (SMP2 = 50, IS= 80), however SMP2 option scored higher for the 'Impact on other local industry' parameter (SMP2 = 75, IS = 50). Both options were calculated to have a similar impact on farming practices.

Table 8.3: *Multi-attribute value theory scores for the Economic Sustainability criterion for the SMP2 option*

Criterion: Economic Sustainability		**Score: 47.1**
Attribute: Financial Feasibility		*37.5*
Parameters	Initial Cost (compared to recent Tywyn protection scheme - £7m)	35
	Maintenance costs	40
Attribute: Impact on local business		*56.7*
Parameters:	Impact on tourist industry	50
	Impact on farming practices	45
	Impact on other local industry	75

Table 8.4 *Multi-attribute value theory scores for the Economic Sustainability criterion for the floodplain reconnection (FR) and sand engine (SE) elements of the Innovative Sustainable (IS) Option*

Criterion: Economic Sustainability		**FR**	**SE**	**IS**
Scores		**65.4**	**64.6**	**65.1**
Attribute: Financial Feasibility		*82.5*	*62.5*	*75*
Parameters	Cost compared to recent Tywyn protection scheme (£7m)	75	25	50
	Maintenance requirements	90	100	100
Attribute: Impact on local business		*48.3*	*66.7*	*57.5*
Parameters:	Impact on tourist industry	60	100	80
	Impact on farming practices	35	50	42.5
	Impact on other local industry	50	50	50

8.6.2 Criterion: Socio-cultural sustainability

The IS alternative scored higher than SMP2 for the socio-cultural sustainability criterion (SMP2= 48, IS = 57.88) (see Table 7.3). The scores for the 'Public perception' attribute were similar (SMP2 = 60, IS = 63.75), but were generated by different scores for each parameter. The SMP2 option scored highly (85) for the 'impact on current way of life' parameter, for which the IS option scored only 47.5. In contrast, the SMP2 option scored low (35) on 'Impact on space available for recreation', for which the IS option got a high score (80) (see Tables 8.7 and 8.8). The IS option scored more highly than the SMP2 option for the 'Impact on the historic landscape' attribute (SMP2 =36, IS = 52), and scored more highly on all associated parameters other than 'Impact of the finished project on the historic character of the Dysynni landscape as a whole', although the scores for this are similar (SMP2 = 50, IS = 47.5).

Table 8.5 *Multi-attribute value theory scores for the Socio-cultural Sustainability criterion for the SMP2 option*

Criterion: Socio-cultural Sustainability		**Score: 48**
Attribute: Public perception		*60*
Parameters	Impact on current way of life	85
	Impact on space available/opportunities for recreation activities	35
Attribute: Impact on the Historic Landscape		*36*
Parameters:	Impact of construction on LCAs with 'High' or 'Very High' vulnerability	25
	Impact of the finished project on the historic character of the immediate vicinity of the project	40
	Impact of the finished project on the historic character of the Dysynni landscape as a whole	50
	Accessibility of historic sites and features following the project	35
	Level of protection for LCAs with 'High' or 'Very High' vulnerability	30

Table 8.6 *Multi-attribute value theory scores for the Socio-cultural Sustainability criterion for the floodplain reconnection (FR) and sand engine (SE) elements of the Innovative Sustainable (IS) Option*

Criterion: Socio-cultural Sustainability		**FR**	**SE**	**IS**
Scores		**42**	**73.75**	**57.88**
Attribute: Public perception		*45*	*82.5*	*63.75*
Parameters	Impact on current way of life	30	65	47.5
	Impact on space available/opportunities for recreation activities	60	100	80
Attribute: Impact on the Historic Landscape		*39*	*65*	*52*
Parameters	Impact of construction on LCAs with 'High' or 'Very High' vulnerability	40	65	52.5
	Impact of the finished project on the historic character of the immediate vicinity of the project	40	80	60
	Impact of the finished project on the historic character of the Dysynni landscape as a whole	35	60	47.5
	Accessibility of historic sites and features following the project	35	40	37.5
	Level of protection for LCAs with 'High' or 'Very High' vulnerability	45	80	62.5

8.6.3 Criterion: Environmental sustainability

The IS option scored significantly higher than the SMP2 option for the Environmental Sustainability criterion (SMP2 = 42.9, IS = 64.38) (see Table 8.3). The IS option had a higher score for every parameter under the 'Ecological impact' attribute (SMP2 = 43.75, IS = 69.38) and the 'Sustainability of sourced materials' attribute (SMP2 = 35, IS = 73.75). For the 'Impact on carbon emissions' attribute, both options scored 50 because the data on whether saltmarsh and reconnected floodplain acts as a carbon source or sink is conflicting (see Tables 8.9 and 8.10).

Table 8.7: *Multi-attribute value theory scores for the Environmental Sustainability criterion for the SMP2 option*

Criterion: Environmental Sustainability		**Scores: 42.9**
Attribute: Ecological Impact		*43.75*
Parameters	Impact on existing terrestrial ecosystems	35
	Impact on existing intertidal ecosystems	40
	Impact on existing marine ecosystems	40
	Potential for new ecosystem creation	60
Attribute: Sustainability of sourced materials		*35*
Parameters	Locality of materials used	40
	Environmental impact of material extraction/production	30
Attribute: Impact on carbon emissions		*50*
Parameters	Is the project a net source or net sink of carbon emissions?	50

Table 8.8 *Multi-attribute value theory scores for the Environmental Sustainability criterion for the floodplain reconnection (FR) and sand engine (SE) elements of the Innovative Sustainable (IS) Option*

Criterion: Environmental Sustainability		**FR**	**SE**	**IS**
Scores		**75.4**	**53.3**	**64.375**
Attribute: Ecological Impact		*76.25*	*62.5*	*69.375*
Parameters	Impact on existing terrestrial ecosystems	75	80	77.5
	Impact on existing intertidal ecosystems	50	60	55
	Impact on existing marine ecosystems	90	50	70
	Potential for new ecosystem creation	90	60	75
Attribute: Sustainability of sourced materials		*100*	*47.5*	*73.75*
Parameters	Locality of materials used	100	60	80
	Environmental impact of material extraction/production	100	35	67.5
Attribute: Impact on carbon emissions		*50*	*50*	*50*
Parameters	Is the project a net source or net sink of carbon emissions?	50	50	50

8.6.4 Criterion: Functionality

As with the other criteria, the IS alternative scored higher than the SMP2 policy plan for the functionality criterion (SMP2 = 47.6, IS = 74.9) and all but one attribute (see Tables 8.3, 8.11 and 8.12). The SMP2 policy plan scored higher for the 'Impact on flood risk' attribute (SMP2 = 63.75, IS = 58.75), primarily due to the significantly higher score for the 'Impact on coastal flash flood risk' parameter (SMP2 = 90, IS = 65). For the other parameters of this attribute, the IS option scored the same or slightly higher than the SMP2 option. For the 'Flexibility' attribute, the IS option scored more than twice as high as the SMP2 option (SMP2 = 30, IS = 87.5). For the parameters within the 'Longevity' attribute, both options scored highly for 'Lifespan of the project' (SMP2 = 70, IS = 82.5), but the IS option scored significantly higher for the 'Maintenance required' (SMP2 = 30, IS = 95) and 'Likelihood of failure' (SMP2 = 40, IS = 80) parameters.

Table 8.9: *Multi-attribute value theory scores for the Functionality criterion for the SMP2 option*

Criterion: Functionality		**Scores: 47.6**
Attribute: Impact on flood risk		*63.75*
Parameters	Impact on terrestrial/inland flash-flood risk	65
	Impact on coastal flash-flood risk	90
	Impact on long-term inundation of inland areas	40
	Impact on long-term inundation of coastal areas.	60
Attribute: Impact on coastal erosion		*50*
Parameters	Will this result in an increase or decrease in overall coastal erosion	50
Attribute: Flexibility		*30*
Parameters	Can the project be altered if new conditions or information come to light?	30
Attribute: Longevity		*46.7*
Parameters	Lifespan of project	70
	Amount of maintenance required	30
	Likelihood of failure	40

Table 8.10 *Multi-attribute value theory scores for the Functionality criterion for the floodplain reconnection (FR) and sand engine (SE) elements of the Innovative Sustainable (IS) Option*

Criterion: Functionality		**FR**	**SE**	**IS**
Scores		**68**	**81.8**	**74.9**
Attribute: Impact on flood risk		*53.75*	*63.75*	*58.75*
Parameters	Impact on terrestrial/inland flash-flood risk	80	50	65
	Impact on coastal flash-flood risk	50	80	65
	Impact on long-term inundation of inland areas	35	50	42.5
	Impact on long-term inundation of coastal areas.	50	75	62.5
Attribute: Impact on coastal erosion		*50*	*85*	*67.5*
Parameters	Will this result in an increase or decrease in overall coastal erosion	50	85	67.5
Attribute: Flexibility		*75*	*100*	*87.5*
Parameters	Can the project be altered if new conditions or information come to light?	75	100	87.5
Attribute: Longevity		*93.3*	*78.3*	*85.8*
Parameters	Lifespan of project	100	65	82.5
	Amount of maintenance required	90	100	95
	Likelihood of failure	90	70	80

8.6.5 Overall Results

A summary of the overall scores for each option and for each criterion can be seen in Table 8.11. The IS option, combining a sand engine project on the coast and a floodplain reconnection project in the valley, scored higher than the SMP2 policy plan for both overall sustainability, and across each criterion. As the scores for the Innovative Sustainable (IS) option are the mean of the scores for a floodplain reconnection (FR) scheme and a sand engine (SE) project, the separate scores for each element are also listed (summarised in Table 8.12).

Table 8.11*: Multi-attribute value theory scores for each criteria for both the SMP2 and IS options*

Criterion	**SMP2 option**	**IS option**
Overall Score	46.4	65.5
Economic Sustainability	47.10	65.00
Socio-cultural Sustainability	48.00	57.88
Environmental Sustainability	42.90	64.38
Functionality	47.60	74.90

***Table 8.12**: Multi-attribute value theory scores for the floodplain reconnection (FR) and sand engine (SE) elements of the Innovative Sustainable option*

Criterion	IS option	FR	SE
Overall Score	65.9	63.3	68.4
Economic Sustainability	65.00	65.40	64.60
Socio-cultural Sustainability	57.88	42.00	73.75
Environmental Sustainability	64.38	75.40	53.30
Functionality	74.90	68.00	81.80

8.7 Explanation of Results

8.7.1 Introduction

The results of this MAVT assessment indicate that the combined Innovative Sustainable (IS) option (comprising a sand engine project and a floodplain reconnection project), would be a more sustainable coastal and flood risk management approach than the current SMP2 policy plan. This section provides an explanation of the scores for each of the attributes and criteria for both options, informed by examples of the use of each tool in other areas, as well as a review of relevant literature.

8.7.2 Explanation of multi-attribute value theory scores

The IS option scored higher than the SMP2 option across all criteria (Economic sustainability, Socio-cultural sustainability, Environmental sustainability, and Functionality), although the SMP2 scored more highly on the Impact on flood risk attribute, and equal on several parameters (Impact on carbon emissions, Impact on farming practices, impact on other local industry, Impact on current way of life, Impact on the historic character of the Dysynni landscape, impact on terrestrial flash flood risk, and impact on coastal flash flood risk). This section provides an explanation for the scores given to each option across all criteria and attributes (see Results, 8.6).

Criterion: Economic sustainability

The higher score for the IS option compared to the SMP2 option is mainly due to the high maintenance cost associated with the SMP2 policy plan, whereas the IS methods require little to no expenditure following establishment. The benefit of the IS option on the tourist industry is the economic benefit for the study area. The following section provides detailed justification of the scores given for each attribute.

Attribute: Financial feasibility

The financial feasibility attribute assesses whether the overall cost of the alternatives is feasible, taking account of both short-term investment and long-term maintenance requirements. To assess feasibility, the estimated cost of each option is compared to the successful project of updating the sea wall and groynes at Tywyn in 2011, which cost £7.6m. Other proposed projects protected a wider area including the golf course and railway embankment, or included additional features, but were unsuccessful due to the proposed costs (£11m and £23m in 2017 terms: Stevens 2002; Maslen Environmental 2011).

The SMP2 option would require further construction of hard defences along up to 5km of the coastline in order to maintain the current shoreline position. Hard defences already protect almost 5km of the coastline, which require maintenance work and updating due to erosion and rising sea levels. Based on estimates by Hudson *et al.* (2015), the protection of currently undefended Hold the Line areas on the Dysynni coastline, maintaining the standard of protection along currently defended stretches, and renewing the groynes on Tywyn beach could cost between £14.4m and £155.18m. Maintenance costs could be around £17,000 – £51,000 per year for the existing groynes, and £400,000 per year for the sea walls and rock armour (Hillen *et al.* 2010; Hudson *et al.* 2015).

MR would be a relatively cheap option as it would require little maintenance. Initial costs can be as low as £1,500 per hectare (Tinch and Ledoux 2006). However, ABPmer state that the cost of MR schemes can reach over £100,000 per ha (Scott 2015), with other estimates reaching up to £675,000 per ha (Pontee 2014). The final cost of MR schemes depends on the groundworks required, and whether the land used would be bought outright or whether landowners would receive subsidies. This wide range of potential costs makes it very difficult to determine the economic impact of a MR scheme on the Dysynni coastline or estuary. The area of Penllyn and the Aberdyfi dunes is 285ha, and the area that could be included in a MR scheme at Broadwater is around 250ha. Based on the information above, the cost of MR in the areas proposed by SMP2 could be between £802,500 and £361m. Both of these values are extremes, and it is unlikely that any scheme would use all of the available land in each area. This highlights the importance of using a range of experts and stakeholders when carrying out the MAVT.

The cost of the sand engine element of the IS option would be between £20m and £70m, based on the costs of other similar projects at Bacton (Norfolk) and The Hague (South Holland). This would be a significant initial investment (Oppla 2014; Waterbranche 2017; Hannant 2018; North Norfolk District Council 2018).

The floodplain reconnection element of the IS option would have lower initial costs than a sand engine. In the Dysynni valley, only a 1km stretch would need to be re-meandered, and a maximum of 7km^2 of floodplain reconnected (involving 10km of the river), although not all of the available floodplain would have to be included. Based on the costs of various projects in the UK and Europe (see Schwartz *et al.* 2006; Ebert *et al.* 2009; Environment Agency 2010; Guida *et al.* 2014; Tero 2014), the cost of a floodplain reconnection project in the Dysynni valley could be between £140,000 and £2,700,000. This is assuming that the entire low-lying area of the Dysynni valley would be reconnected, but the cost would be lower if a smaller area were reconnected. Re-meandering the short, canalised stretch of the Dysynni would be the most expensive part, but blocking drainage ditches and removing stretches of embankment would be low-cost. Both elements of the IS option would have few or no maintenance costs, the only expense being any subsidies paid to landowners in compensation for the more frequent flooding of their land. This may not be an insignificant sum, depending on the value of the affected land, but it could be paid over a long period of time through an agri-environment payment scheme (e.g. Turner *et al.* 2007).

Attribute: Impact on local business

Under the SMP2 scenario, the continuing maintenance of the shoreline along the Tywyn and Aberdyfi frontages would protect any businesses or industry, including cafes, hotels and caravan parks. However, Booth (2010) suggests that hard defences can reduce the visual amenity of beaches and take up beach space, which could impact tourism. Allowing MR to occur along the Aberdyfi dunes would also endanger and potentially destroy Aberdyfi Golf Club, which is an important tourist destination. The loss of this business could affect the number of tourists who choose to stay in the Trefeddian hotel adjacent to the golf club. Aberdyfi is a popular location for holiday homes and second homes (Wales Online 2013), so this industry may experience an impact with the loss of the golf course as a local amenity. Local construction industries would benefit economically from increased business due to the maintenance requirements of coastal defences constructed for HTL stretches.

Most of the fields at Penllyn and those near the Dysynni estuary are currently used for extensive grazing of sheep and some cattle, which could potentially continue following the breaching or removal of defences. There are several instances in the UK of coastal marshland being used for grazing, for instance Frampton Marsh, Lincolnshire (Ausden *et al.* 2005). Therefore, a MR scheme at Penllyn and Broadwater may not result in dramatic land-use change or economic losses at first, if the saltmarsh established successfully.

The IS option would likely benefit the tourist industry through both the creation of new wetland habitat, which would attract birds and wildlife enthusiasts, and the creation of an extremely wide beach on which recreational activities like windsurfing and sunbathing could take place. As the beach at Tywyn is currently dramatically lowered and narrow, with poor visual amenity (see Figure 8.2), it is likely that the creation of a larger beach would attract more tourists to the area. Evidence from the Dutch sand engine project indicates that tourists visit the sand engine as a feature of interest, as well as for a beach holiday; there are now several restaurants, a surf school, kite surf hire, and 40 beach houses to rent on or near the sand engine (Strandhuisjes Kijkduin 2017). A sand engine would provide protection from erosion to Aberdyfi dunes and golf course, which is an important tourist attraction.

Floodplain reconnection could have significant impacts on agricultural productivity on the affected land. Extensive pastoral agriculture can often still be undertaken on wet ground, and floodplain reconnection means that the land would only be flooded for short periods, and more during the winter than summer. Some farmers would have the majority of their land in the floodplain reconnection scheme if all of the low-lying land was included, so they would have to find places to store their livestock during the winter or during freak flood events, which could be costly. The threat of flooding and its impact on farming practices is also likely to become more severe in the coming decades due to climate change.

Many rivers, including the Dysynni, act as property boundaries. If channelisation is reversed and the river allowed to migrate laterally across the floodplain, it may result in the loss of property on one side of the river, and an increase in land on the other bank due to accretion, leading to property disputes. Furthermore, the re-establishment of land as floodplain may cause it to lose value, for which landowners may expect compensation (Zhu *et al.* 2007). Much of the research on the loss of land value and agricultural profits focuses on arable agriculture, which can be significantly affected by flooding (Remo *et al.* 2017). Pastoral agriculture can still take place on floodplains, just less intensively (*ibid*.), so agricultural profits in the Dysynni valley may be less affected.

Floodplain reconnection can create more space for outdoor recreation and tourist industries (Sparks and Braden 2007). This diversifies local livelihoods, leading to a more robust local economy (Ebert *et al.* 2009).

Criterion: Socio-cultural sustainability

The IS alternative scored higher than SMP2 for all socio-cultural sustainability parameters other than 'Impact on current way of life' (Attribute: public perception) and 'Impact of the finished project on the historic character of the Dysynni landscape as a whole' (Attribute: Impact on the historic landscape).

Attribute: Public perception

In maintaining the defensive line along the stretches of coastline with important infrastructure, business and properties, the SMP2 scenario would maintain the current ways of life for most people in the study area. The only people directly affected would be those associated with Aberdyfi Golf Club, and any landowners affected by MR schemes in the Dysynni estuary and at Penllyn. Grazing could still be undertaken on the saltmarsh and in periodically flooded areas, so this would not impact the farming practices too significantly.

Hard defences and other HTL tools can have high public support, due to the reassurance they provide for homeowners and businesses (de la Vega-Leinert and Nicholls 2008). Research in New Jersey indicated that some beach users prefer the presence of groyne structures as they act as wind breaks, sun-traps, and provide an enclosed area for children's play, and because they are a familiar part of some beaches (Williams *et al.* 2005). Other studies have shown a negative public perception of hard defences; on Wisemans Bridge beach in South Pembrokeshire, which is backed by a sea-wall, most visitors indicated that they would have been willing to pay a small amount to use an alternative method of coastal defence due to the impact that the seawall had on scenic quality (Blakemore *et al.* 2008). There is also an issue of health and safety; the way that groynes interact with longshore currents can cause rip currents to form around a groyne field. On Boscombe beach, Bournemouth, strong offshore-directed rip currents were detected on the updrift side of the groynes due to the deflection of the longshore current, which can cause a bathing hazard (Scott *et al.* 2016). There are even several accounts in recent years of people being caught by strong rip tides on Tywyn beach and requiring rescuing, with two deaths occurring as a result (Misstear 2015; ITV 2016; Dailyin 2018; Evans 2018; Jones 2018). Hard defences along Tywyn frontage are currently and will continue to cause beach lowering, resulting in a narrow beach with little space for recreation.

Although some new wetland habitat could attract environmental tourists, a MR scheme at Aberdyfi dunes would eventually threaten the existence of Aberdyfi Golf Club through erosion and flooding. Public acceptance of MR schemes is often mixed; for the Brancaster MR scheme, only around half of the locals supported the MR project (Myatt *et al.* 2003). A survey of UK participants indicated that 76% of stakeholders and members of the British public did not consider MR as a good method for flood risk reduction or cost saving (Esteves 2014). This is due to a range of reasons, including the perception that defence maintenance would be cheaper or more effective, and a lack of trust of organisations carrying out MR projects (Myatt *et al.* 2003; Roca and Villares 2012; Nordstrom *et al.* 2015).

The sand engine element of the IS scheme would not impact the way of life of local people, other than providing additional space for recreation, which would have a positive socio-cultural impact, as it increases opportunity to take part in outdoor activities (Stive *et al.* 2013).

If a large area of floodplain is being reconnected, it could lead to the displacement of people who live there (Guida *et al.* 2014). This could have negative social consequences such as loss of communities. This is less of an issue in small floodplains such as the Dysynni, in which very few people live in areas that would be affected. However, a floodplain reconnection scheme could have a negative impact on the lowland farmers who rely on the affected land for their livestock. As well as an economic issue, farming practices form an important aspect of local cultural identity. Having to change farming practices, diversify, or change livelihoods would have a negative social impact on the local farmers, regardless of whether subsidies are provided (Lobley *et al.* 2005). The new habitat created would increase the space available for activities such as bird-watching and walking.

Attribute: Impact on the historic landscape

The MR scheme at Penllyn in the SMP2 policy plan would require the partial or total removal of the embankment there, on which several Military LCFs are located. The retreat of the shoreline along the Penllyn frontage and Aberdyfi dunes would also lead to further erosion of the line of pillboxes that characterise the Military LCA. Excavation and 3D digital recording could be used to preserve the archaeological information held within these features, but this would not prevent the loss of historic character to the LCAs, or improve the accessibility of any surviving remains after the MR project. The pillboxes in particular are a very visible and striking element of the coastal landscape, and the defensive Military LCA that they create as a unit would be markedly damaged if some of the pillboxes were destroyed.

Aberdyfi beach is characterised by a wide sandy beach with high dunes. A loss of beach and dune area due to a MR scheme there would significantly impact the Wetland and Beach LCA. The wide, sandy beach at Aberdyfi can be seen from several vantage points in the study area, so a loss of this LCA would have an impact on the wider historic character of the valley. However, as Penllyn is already relatively rough ground, the development of saltmarsh in a MR scheme would not have a significant impact on the historic character of the local area. It would return the area to its former use, indicated by the lake visible on the Tithe map of the area (Figure 5.11; The National Library of Wales 2019), and the placename (Penllyn means 'head of the lake' or 'top of the lake' in Welsh). A MR project in the Dysynni estuary may not impact the Wetland and Beach LCA of Broadwater itself, but could impact the wider historic character of the estuary area and lowlands. This includes the Regular Field Systems and Regular Drained Land LCAs, which are characterised by uniform, grid-patterned drainage ditches and field boundaries, and are a result of the land reclamation schemes several centuries ago (Smith 2005).

Hard defence construction causes direct erosion and damage to the beach, while current beach lowering at Tywyn due to the hard defences threatens features preserved in the intertidal zone, such as the peat cuttings and submerged forest, and causes a direct loss of the Wetland and Beach LCA. However, as hard defences have existed along much of the coastline for over a century, the historic character of the Dysynni landscape as a whole would not be dramatically altered by the maintenance or extension of the structures. The defences protect the Historic and Modern Settlement LCAs from flooding and erosion (although these LCAs are not considered vulnerable to climate change). They also protect several caravan parks, which are important for the Recreation and Tourism LCA in the study area.

Like the MR scheme in the Dysynni estuary, the floodplain reconnection scheme in the IS scenario would have a considerable impact on the Regular Fieldsystems and Regular Drained Land LCAs. The regular pattern of drainage ditches and field boundaries that covers the flat valley bottom is a significant element of the historic character of the Dysynni valley, and one that links strongly to the current and historic economies. Although flooding may not be a regular occurrence, the drainage ditches would need to be blocked and some field boundaries removed to facilitate the natural function of the floodplain, which would have an impact on the historic character of the lowlands of the landscape. De-channelisation of a stretch of river would give the lowlands of the river valley a more natural character, but erase some of the recent historic features and character of the landscape. It could increase the risk of flooding at the Peniarth and Ynysymaengwyn estates, both of which have important historic features within their grounds. Cropmarks identified in the lowlands would become less accessible, and subsurface features may become waterlogged. This may increase the potential for the *in situ* preservation of archaeological remains, as waterlogging can provide anoxic conditions which reduce organic degradation (Douterelo *et al.* 2010). However, Gearey and Chapman (2006) warn that, even if an area is becomes waterlogged, any previous drainage may already have damaged archaeological remains. Furthermore, the introduction of water from a different source, which would occur during overbank flows, could change the pH, oxygen level, or salinity of the current burial environment (Holden *et al.* 2009). If *in situ* preservation was attempted in these areas, a regular monitoring system would be required to record changes and adjust the preservation approach if necessary (see Malim *et al.* 2015).

A sand engine project would not have much negative impact on vulnerable LCAs, and would increase the area and protection of the Wetland and Beach LCA. It would create a wider and higher beach along the whole coastline, with greater visual amenity, which would be more akin to what the beach may have been like prior to the beach lowering over the past few centuries. Evidence for a wider, higher beach than at present comes from the name 'Tywyn', which means 'beach', 'seashore', or 'sand-dune' in Welsh. Moreover, the development of Tywyn into a major sea-side resort in the late 19th century indicates that the beach may have had greater visual amenity at the time. As a sand engine approach would only affect the beach itself, there would be little impact on the overall historic character of the Dysynni valley. The historic character of the beach itself would be significantly altered. As well as an aesthetic change, an increase in beach volume could bury some of the features on the foreshore such as pillboxes, fish traps and peat cuttings. This would afford the features additional protection from erosion, but it would reduce their accessibility to the public and would alter the historic character of the shoreline. In terms of positive impacts, it would provide additional protection to other features that characterise the Military LCA, such as the rifle range and shooting butts at Penllyn, and the pillboxes along Aberdyfi beach.

Criterion: Environmental sustainability

The SMP2 policy plan scored lower on every environmental sustainability parameter than the IS alternative, other than the 'Is the project a net source or net sink of carbon emissions?' parameter (Attribute: Impact on carbon emissions), for which both scored 50. This is because the data on whether saltmarsh and reconnected floodplain act as carbon sources or sinks is conflicting.

Attribute: Ecological impact

The hard defences required for the SMP2 scenario are predicted to have a mainly negative environmental impact. Hard defences cause beach erosion, reducing the available area for intertidal habitats, which is evidenced by the beach lowering in front of the sea-wall at Tywyn (see Figure 8.2). The construction or maintenance of these defences can damage both marine and intertidal ecosystems due to heavy machinery and scour. Required maintenance of defence structures causes periodic disturbance to ecosystems on and around the structure (Airoldi *et al.* 2005; Firth *et al.* 2013b; Sherrard *et al.* 2016). Regular disruption can cause an ecosystem to stay in the early stages of succession, rather than maturing into a climax community (Airoldi *et al.* 2005; Firth *et al.* 2014).

Of the potential positive impacts, there is some potential for artificial reef habitat to be created on hard defences, as discussed in 8.4.1. This could increase biodiversity, however when hard defences are constructed in areas that are exclusively sandy coastlines, they can act as 'stepping stones' for hard substrate species to expand their range into previously inaccessible areas (Airoldi *et al.* 2005;

Firth *et al.* 2014). This could facilitate the spread of invasive species which require rocky habitat for colonisation (Firth *et al.* 2013b). Airoldi *et al.* (2005) warns that this could increase the gene flow within a species, thus reducing local adaptation and evolution, and also increase the potential spread of disease within a species. As the Dysynni valley includes sections of shingle beach and rocky cliff as well as sandy beach, and has had hard defence structures installed for several centuries, it is unlikely that the SMP2 policy plan would facilitate further invasive species colonisation in this way.

MR is generally thought to be an ecologically-friendly coastal management approach. The expansion of intertidal or wetland habitat at both Penllyn and in the Dysynni estuary would provide more space for birds and fish nurseries, among other things. However, the MR at Aberdyfi dunes would cause a loss of coastal dune habitat, which is a BAP priority habitat (JNCC 2008). Saltmarsh can provide nutrient cycling, and increase the storage of sediment and pollutants, so MR at Broadwater could improve water quality in the estuary (Tinch and Ledoux 2006; Roca and Villares 2012). The area encompassing Broadwater, Morfa Gwyllt, and the river and banks between Broadwater and Pont Dysynni, is a designated SSSI due to the importance of the wetland for bird species. A MR project in the area could expand the area of important habitat. Saltmarsh establishment is not always successful; at Brancaster marsh in Norfolk, five years after a MR project was completed, large areas of the site were still unvegetated and the areas of vegetation had a very different community structure to natural reference marshes (Mossman *et al.* 2012). This difference can be caused by different soil redox potentials between natural and created marshes, seed availability, soil compaction, and sediment or organic matter input (Morgan and Short 2002; Wolters *et al.* 2005a; Mossman *et al.* 2012). MR schemes may not necessarily provide all of the environmental benefits of a natural saltmarsh habitat.

The ecological impact of the IS option is more positive overall than the SMP2 option. Floodplain reconnection would allow the small areas of wetland in the valley to expand slightly, and floodplain meadows or floodplain wetlands may form. This would have ecological benefits such as providing habitat for migratory birds, pollinators, and wild flowers, and invertebrates, wading birds and fish nurseries respectively (Opperman *et al.* 2009; Paillex *et al.* 2009; Guida *et al.* 2014; Rothero *et al.* 2016). Floodplain reconnection can also improve biogeochemical fluxes and river water quality due to an increase in overbank deposition of sediment (Volk *et al.* 2004; Johnstonova 2009; Paillex *et al.* 2009; Ledford and Lautz 2015). Research in the Danube showed improved water quality and access for both drinking water and irrigation, and a reduction in eutrophication following a floodplain reconnection project (Ebert *et al.* 2009). The River Dysynni has poor water quality in places (Campaign for the Protection of Welsh Fisheries 2009; NRW 2016b) and reconnecting the floodplain would address this as nutrients and sediments are deposited on floodplains during overbank flows (Johnstonova 2009).

A sand engine could provide new habitat for fish, birds and intertidal species, for instance through creating shallow lagoons (Mulder and Tonnon 2011; Stive *et al.* 2013; De Schipper *et al.* 2016; New Civil Engineer 2017). Seals have been observed visiting the lagoon area created in the Dutch sand engine (Ecoshape 2017). The addition of a large amount of sand in the sediment cell would stimulate dune growth in Aberdyfi dunes. However, the deposition of sediment in beach nourishment schemes can smother existing intertidal ecosystems, which can take several years to recover (Wooldridge 2015). The long lifespan of a sand engine project compared to a traditional beach nourishment scheme means that there would be several decades between sediment depositions, allowing the intertidal ecosystems to recover. The use of natural processes to distribute sediment along the shoreline reduces the ecological impact of sand engine projects compared to traditional beach nourishment, which uses heavy vehicles such as tractors (Stive *et al.* 2013). A sand engine project would also reduce the need for the piecemeal nourishment of Aberdyfi dunes with sediment from Aberdyfi harbour, which impacts beach ecosystems much more frequently (Earlie *et al.* 2012b, c).

Attribute: Sustainability of sourced materials

In the most recent defence project at Tywyn, the wooden groynes were constructed from recycled timber in order to improve the environmental impact of the scheme. The timber was sourced from Scotland which, although better than being imported from abroad, caused more transport emissions than if it were sourced more locally. Some groynes in the study area, the detached breakwater, and a stretch of revetments, are all built from granite which was quarried, although the source of the granite is not known. Quarrying significantly impacts local habitats, and the transport of such large quantities of rock will have resulted in significant transport emissions. The sea-wall structure is made of cement, the manufacture of which contributes around 7% of global CO_2 emissions. Therefore, the environmental impact of the hard defences required for the SMP2 option would have a wider footprint than the study area alone. The MR project would not require many additional materials, as any landward embankments could be constructed from local material.

Similar to MR, floodplain reconnection would not require any significant materials, as any additional levees required could be made from the material from the embankments that are removed. Dredging is currently undertaken in Aberdyfi harbour, the sediment from which could be used for a sand engine project. A sand engine requires an immense volume of sediment to be sourced, and it is important that the sediment used is a similar size to that on the beach already. If a sufficient amount cannot be sourced locally, the sediment must be transported a significant distance, which could increase the transport emissions associated with the project. Dredging can damage benthic ecosystems, and can cause changes to the oxygen gradient, salinity, hydrodynamic patterns and the amount of particle suspension (Van Dalfsen and Arninkhof 2009). This can impact the abundance of food for fish, birds and mammals, thus having a wider ecological impact (*ibid*.). Removing the amount of sediment required from one place could also have hydrodynamic impacts such as the creation of a trench in the sea floor (Van Dalfsen and Arninkhof 2009).

Attribute: Impact on carbon emissions

The hard defences, once constructed, will not act as either a carbon sink or source. There is the potential for saltmarsh developed in the MR scheme to create a carbon sink (Roca and Villares 2012). This is dependent on a range of factors such as the rate of saltmarsh succession and the rate of sediment deposition, and so may not occur (*ibid*.).

Overbank deposition and the development of floodplain wetland habitats can increase carbon sequestration (Tilman *et al.* 2006), so the floodplain reconnection project in the IS scenario could create a carbon sink. As with the MR project, this is dependent on the frequency of wet/dry cycles, which can reduce the capacity of soils to store carbon. The presence of a sand engine would not have any impact on carbon emissions.

Criterion: Functionality

As with the other criteria, the IS alternative scored higher than the SMP2 policy plan for almost all parameters. However, the SMP2 policy scored higher for the ‘Impact on coastal flash-flood risk’ parameter, and both alternatives scored 65 for ‘Impact on inland flash-flood risk’ (Attribute: Impact on flood risk). Overall, the SMP2 alternative scored higher for the ‘Impact on flood risk’ attribute. The lower overall score for the SMP2 was due to long-term issues such as displaced erosion, maintenance, and policy lock-in. A detailed justification of the scores for each attribute is provided in this section.

Attribute: Impact on flood risk

The sea walls at Tywyn and Aberdyfi provide a barrier protecting the towns from storm surges, although extreme sea level scenarios can lead to over-topping of defences (McDougall and Boyd 2009; Guida *et al.* 2016). In the long term, hard defences will need to be updated and heightened at significant cost in order to maintain the same standard of protection against flooding, as sea-level rise will cause more frequent high-water levels (Guida *et al.* 2016).

MR at Penllyn could reduce the risk of overtopping in areas protected by sea walls, as the expanded saltmarsh would allow space for the tidal and wave energy to dissipate. The MR scheme in the estuary would reduce the risk of fluvial flooding further upstream, as the MR area allows flood waters to dissipate. Evidence from the MR project at Orplands, in the Blackwater Estuary, indicated that the created saltmarsh lessened the impact of storm tides and reduced the potential impact of floods elsewhere in the estuary (Tinch and Ledoux 2006).

As some areas near Penllyn and behind the Aberdyfi dunes are below MHWS already, sea-level rise will result in a much greater risk of flooding beyond the MR area, unless higher embankments were built in front of the railway line. MR in the Dysynni estuary could, in the long term, result in the permanent inundation of some areas of land that were previously farmed, as well as Tywyn Sewage Works, which is located very close to Broadwater and the coast. At some point it may become unsustainable to protect the sewage works from inundation on all sides, so it would require relocating under the SMP2 policy plan. There would also need to be cooperation with landowners in order to prevent them carrying out private defensive works on their land, which would undermine a MR project.

Another issue is that the groynes and sea wall at Tywyn act as a barrier to sediment transportation along the Dysynni coastline, reducing the available sediment at Penllyn and the Aberdyfi dunes. A sufficient sediment input is important for MR schemes to generate accretion on the developing saltmarsh (Wolters *et al.* 2005b). Without adequate sediment supply, the coastline may retreat or turn into intertidal flats following the breaching or removal of defences (Wolters *et al.* 2005b; Hanley *et al.* 2014).

In the IS option, floodplain reconnection would provide inland flood risk benefits. There is robust evidence for the effectiveness of floodplain reconnection projects; the Sinderland Brook project in Cheshire managed to reduce the flood-risk to a neighbouring housing development from 1-in-35 years to 1-in-75 years (Environment Agency 2010). Floodplain reconnection of the Long Eau and Great Eau in Lincolnshire also reduced flood risk in the towns of Great Carlton and Manby from 1-in-20 years to 1-in-50 years (*ibid*.). Floodplain reconnection allows the river to diffuse its energy over the floodplain during periods of high discharge, rather than constraining the river and causing overtopping in the 'wrong' areas (Environment Agency 2010). Re-meandering would lengthen the river, which would provide more area for the water, thus delaying the time it takes to reach peak discharge (*ibid*). The deposition of sediment overbank means that the floodplain would be able to accrete, raising the level of the lowlands slightly. This makes the land less susceptible to sea-level rise (Johnstonova 2009). Reconnection of the floodplain would lead, in the long term, to a more naturally functioning estuary system, in which the floodplain and a widened channel would reduce the impact of sea-level rise on the tidal prism (Holleman and Stacey 2014). In the Dysynni valley, under the present management scenario, maintaining the current level of protection would require the defences to be raised and a pumping system installed in the DLLD as sea level rises (Earlie *et al.* 2012b). This would become increasingly unsustainable into the future as sea-level rise continues (*ibid*.). Floodplain reconnection would allow the floodplain to be periodically flooded, and sediment deposition would cause the land to warp up, thus becoming less susceptible to sea-level rise (*ibid*.).

If a sand engine project was undertaken on the Dysynni coastline, the initial sand deposition would occur on the beach and foreshore in front of Tywyn. The net drift of sediment on this coastline is divided, with a net drift from the southern end of Tywyn towards the Dyfi estuary, and a net drift from the northern end of Tywyn towards the Dysynni estuary and beyond towards Llwyngwril (see Figure 8.11) (Earlie *et al.* 2012c,d). This is corroborated by Figure 8.2, in the location of areas of shoreline retreat (along the Tywyn frontage) compared to areas of shoreline accretion (along the Tonfanau and Aberdyfi Dunes frontages) at the MLW mark. A sand engine here would provide sediment to protect the Penllyn and Aberdyfi frontage, the shingle bar at Morfa Gwyllt, and the railway line north of Tonfanau. Initial monitoring of the Dutch sand engine project indicated that 6km of the adjacent coastline benefitted from accretion in the first year following the sand engines creation, which attenuates wave energy and reduces the risk of flooding and overtopping (Luijendijk *et al.* 2017). The greater width and height of the beach along the Dysynni coastline in a sand engine project would reduce the risk of overtopping defences, as the higher beach would attenuate some of the incoming wave energy. Any dune growth at Aberdyfi would also reduce the risk of high-water levels overtopping the dunes and damaging the golf course (Van Dalfsen and Arninkhof 2009). In the long term, the sand engine would gradually diminish, and the coastline would return to an equilibrium state, so there would be no long-term impact on flood risk.

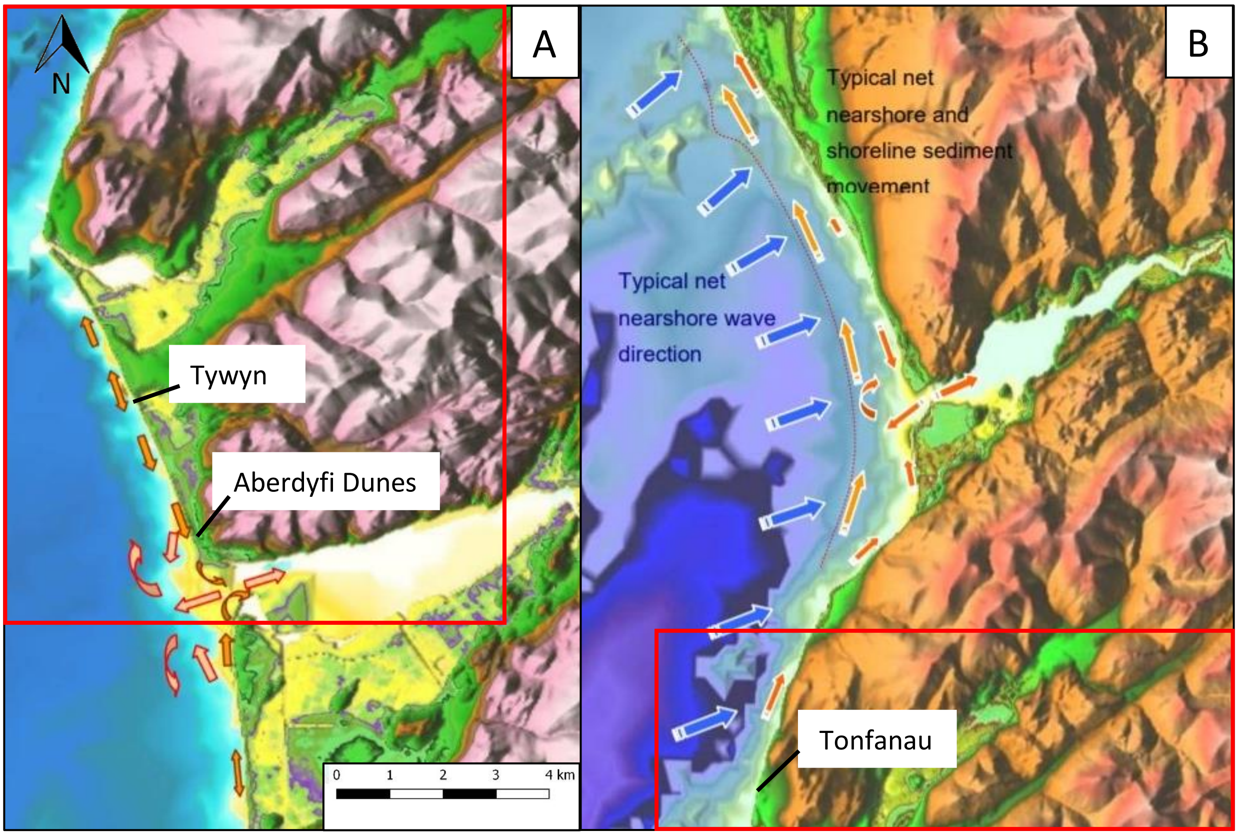


Figure 8.11. *Direction of longshore sediment movement along the shoreline of the study area in PDZ 10 (A) and PDZ 11(B). The Dysynni study area is demarcated in red on each map. Source: Earlie et al 2012c, d.*

Attribute: Impact on coastal erosion

A main aim of the Hold the Line approach along several stretches of the Dysynni coastline is to prevent coastline retreat due to erosion. However, defence structures can reflect the wave energy back onto the beach, leading to erosion of the beach itself (Griggs 2005). Tywyn beach has reduced in elevation by around 3m in the last century (YGC 2011). This has also been recorded at seawall-backed Slaughden beach in Suffolk, which is much narrower and steeper than other unprotected beaches in the vicinity (Pontee *et al.* 2004). Dornbusch *et al.* (2007) argue that it is not just the presence, but also the construction, of sea walls and similar defences that result in long-term increases in erosion, due to compression and disruption from heavy machinery. The presence of groynes has also been linked with accelerated coastal retreat in downdrift areas, in this case Penllyn and the Aberdyfi dunes (Earlie *et al.* 2012b). Following groyne construction on Lady Robinsons Beach, Botany Bay, New South Wales, a downdrift area that used to accrete began to erode (Frost 2011). Furthermore, on the coast of Suffolk, the rate of accretion on Dunwich beach was lower after groynes were constructed updrift at Kessingland (Pontee *et al.* 2004). This indicates that groynes disrupt longshore sediment transport and displace erosion, rather than preventing it completely.

Under the SMP2 policy option, displaced coastal erosion from groynes, combined with the MR approach along the Penllyn and Aberdyfi dune frontage, would likely result in an increased rate of erosion of the dune system and Penllyn saltmarsh. Furthermore, the reduction in sediment supply caused by hard defences could prevent the MR project at Penllyn from accreting sufficiently to form a functioning saltmarsh habitat that would be able to keep up with sea-level rise.

The IS alternative would likely have a positive impact on coastal erosion. A sand engine project would widen the beach and therefore reduce the amount of erosion occurring at the base of cliffs and defensive structures, thus reducing the risk of undercutting and failure. Although the initial deposition of the sand engine would likely occur in front of Tywyn, coastal processes would redistribute the sand to both north and south, providing additional protection to Tonfanau, Rola, Penllyn and the Aberdyfi dunes. This approach does not cause sediment starvation elsewhere by preventing longshore drift, unlike seawalls and groynes (Bide 2014).

Attribute: Flexibility

Areas of the SMP2 for which HTL methods are proposed could experience policy lock-in, as defined in 8.1. For instance, the presence of sea walls would allow business and property development to continue in the coastal zone, as it is assumed that the defence structures would remain indefinitely. This would increase the value of the property and infrastructure that is being protected, and would worsen the potential cost of coastal flooding. Coastal managers would be obliged to keep maintaining and raising coastal defences to protect the new property, even at a much greater cost than would have originally been feasible. Furthermore, the decommissioning of defensive structures is expensive. MR projects would not necessarily cause policy lock-in, as if coastal embankments are breached for the project then they could also be repaired. If the defence were fully removed, or if mudflats developed instead of saltmarsh during the MR project, it would be more difficult to reverse the project and reclaim the land.

Floodplain reconnection would be relatively easy to reverse, as unblocking the drainage channels and rebuilding riverbank levees would be unlikely to cost more than the original project. Re-channelising the re-meandered stretch of river would be more costly. The cost of reversing a floodplain reconnection scheme would become more difficult and expensive over time, as areas of wetland are established and flooding occurs more frequently. A sand engine project would not cause policy lock-in, as it has a relatively short lifespan. Over time, the sand deposited would be redistributed along the coastline by wind and wave action, so the coastline would return to an equilibrium state and there would be no left-over structures to be renewed or removed.

Attribute: Longevity

In the SMP2 policy plan, the existing or future hard defences would have to be replaced periodically, around every 15-25 years (groynes) to 50-100 years (sea walls). The structures would require more frequent maintenance due to erosion, undercutting and storm damage. Beach erosion could also worsen with sea-level rise, which would put increasing pressure on the hard defences and make them more likely to fail. Sea-level rise would increase the potential for flood defences to fail, as the standard of protection they provide decreases. In contrast, a MR scheme could have a long (potentially indefinite) lifespan if there was adequate sediment supply to allow the saltmarsh to accrete in line with sea-level rise. If sediment supply were insufficient at Penllyn and Aberdyfi dunes due to the hard defences updrift, the MR area could be inundated relatively quickly, or erode and require more defences to be built to protect the railway line. The likelihood of failure at MR schemes would be lower than hard defences, providing there was adequate sediment supply and that a functioning saltmarsh habitat develops, as a saltmarsh would attenuate wave energy and provide an area across which flood waters could disperse. This wave attenuation would reduce the pressure on hard defences nearby, and on the defences at the back of the marsh.

Like the MR scheme, floodplain reconnection would be potentially indefinite, as it would allow the river to function as a more natural system. It would require very little management or maintenance, although new embankments could be required around some properties or on the edge of the floodplain if sea-level rise causes larger floods. In terms of failure, there is the potential that high water levels and high river discharge would cause a freak flood event that could overtop the new dykes at the edge of the floodplain. However, this would be less likely to happen than if the river remained channelised and the same event occurred.

The lifespan of a sand engine project would depend on the coastal processes that redistribute the material along the coastline. As there have only been two previous sand engine projects, it is difficult to estimate the lifespan of one on the Dysynni coastline. The Dutch sand engine was originally projected to have a lifespan of 20 years, but it is redistributing less quickly than expected, and may last longer than anticipated (Buitenkamp 2016). This is still a shorter lifespan than most hard defences or MR projects. The likelihood of failure of a sand engine is difficult to estimate, as there are only two known projects and both are relatively recent. There is not yet any evidence of failure in other projects, and the wider and higher beach that would be created in the study area would reduce the likelihood of failure of the existing defences, as it would reduce undercutting and attenuate wave energy.

8.8 Evaluation of the multi-attribute value theory methods

This discussion focuses on the MAVT methodology utilised in this research and its suitability for the assessment of the sustainability of coastal management approaches, based on the results for the Dysynni coastline. First the benefits of the hierarchical structure are discussed, followed by the efficacy of MAVT for addressing sustainability. Next, the scoring system is discussed, followed by the use of weighting parameters or attributes. The importance of involving stakeholders or expert opinion is then considered, including how the omission of consultation from this project may affect the Dysynni coastline results. Finally, the way that the MAVT method could be used within decision-making, and the stage at which it would be used, is explored.

8.8.1 Hierarchical structure

The MAVT is structured in a hierarchical manner, so the overall scores are comprised of the scores of different criteria, which in turn are the composites of the scores from various attributes. This compares to other sustainability assessment methods, such as Analytical Hierarchy Process, which generate the overall score as a function of the individual parameters (e.g. Cinelli *et al.* 2014). Generating scores for each attribute and criteria, as well as an overall score, allows alternatives to be compared in terms of their economic sustainability, functionality, or ecological impact, for example, as well as for overall sustainability. The separation of criteria thus allows for more transparency as it is clear where a strong score in one area is compensating for a weaker score in another. It also reveals the specific areas of weakness for certain alternatives, which could be used to inform changes in the chosen alternative in the design stage.

8.8.2 Sustainability

MAVT has been criticised as a sustainability assessment method due to the compensatory rule, in which high scores for some criteria can balance out bad scores for other criteria. This could allow the compensation of poor environmental scores (indicating significant negative environmental impact) with high economic scores, resulting in substitutions between natural and man-made capital (Van Herwijnen 2006) and leading to MAVT assessments supporting weak sustainability. It implies that a lower score in a crucial parameter or attribute, such as the impact on flood risk, can be compensated for by higher scores in parameters that may not be as crucial for the successful functioning of a management approach, such as the maintenance cost. This can be seen in the Functionality criterion of this MAVT assessment, in which the IS alternative scored highest overall, despite having a lower score for the 'Impact on flood risk' attribute, as it scored highly for parameters such as 'Maintenance required' and 'Flexibility'. It is important to remember that, although all attributes are given equal weighting within each criterion, one of the main reasons that coastal management approaches are required is to reduce flood risk. Therefore, the importance of the flood protection that they provide may outweigh other parameters. This is not accounted for in the scoring system used here, unless it is weighted (see below). However, by dividing the MAVT into separate criteria, and maintaining transparency in the results through the hierarchical structure, any compensation between attributes or parameters remains evident.

Within the IS option there were two separate MAVT assessments: a floodplain reconnection project and a sand engine project, which were combined into a single score. This may have resulted in some compensation, which is referred to as intrinsic compensation. For instance, the sand engine scored only 25 for the Initial Cost parameter, whereas the floodplain reconnection scored 75. The overall score was 50, indicating a neutral score, which implies that the overall cost of the IS alternative would be similar to that of the recent defensive scheme in Tywyn. Combining the scores of these approaches before undertaking the MAVT assessment was necessary to compare the overall IS alternative with the SMP2 alternative, however it creates intrinsic compensations or substitutions within the IS alternative scores. This is also the case for the SMP2 alternative, as the individual scores for MR projects would be different to those for the HTL projects. This difference is obscured as only one numerical score is generated for each parameter. To account for this, separate scores could be given for different types of project within each alternative for each parameter.

8.8.3 Scoring system

The scoring system used in this MAVT, allowing for both positive and negative scores, as well as a 'neutral' or no impact score, was beneficial as it allowed the scores to represent the fact that not all impacts on the study area may be negative. Applying the same scoring system to each parameter, attribute and criterion made the process simple, and makes the results clearer to understand. In contrast, Ferretti *et al.* (2014) scored all attributes from 0-1, but divided each attribute's scores differently. For instance, the Conservation Level attribute scores were divided thus: 0 = bad, 0.33 = discrete, 0.67 = good, 1= very good, whereas the Flexibility of the Building attribute scores were divided into 0=discrete, 0.5 = good, 1 = very good. This makes the results more difficult to understand for people using the data, and makes the methodology more difficult to follow for decision-makers.

Generating a numerical score allows the alternatives to be compared with new alternatives in the future. This contrasts with the Analytical Hierarchy Process method, which makes pairwise comparisons between the alternatives for each criterion, and expresses these comparisons as ratios (Cinelli *et al.* 2014). This prevents a third alternative being directly compared with the original two alternatives, without having to undertake the whole assessment again. With the MAVT approach, a third alternative could be assessed using this framework after the initial assessment, and directly compared with other alternatives that were previously subject to this assessment. This allows new information or potential management approaches to be included in the assessment at a later date.

8.8.4 Weighting parameters

None of the parameters, attributes or criteria were weighted above any other in this MAVT methodology, as the potential weightings given to different attributes are dependent on the specific context of the alternatives being compared. For projects located in ecologically important rural areas, the 'Ecological impact' attribute would be given greater weight than 'Public perception'. In contrast, if applied to a project in a densely populated urban area, attributes such as 'Public perception', 'Impact on flood risk', and 'Impact on local business' may be weighted more highly than others.

In the current study area, having unweighted attributes means that the 'Impact on flood risk' attribute is afforded the same value as 'Impact on carbon emissions' attribute. Both are important, however the purpose of undertaking coastal management on the Dysynni coastline is largely to control flood risk. Therefore, it is likely that the 'Impact on flood risk' attribute would be considered more important than some others. Evidently, weighting is something that should be decided for the individual MAVT assessment based on the specific context and project objectives. MAVT has the advantage of being a dynamic management tool, as the scores can be adjusted and weightings applied in subsequent iterations.

8.8.5 Inclusion of stakeholders and consultation of experts

Although a range of information and case studies were reviewed for each alternative, the more detailed aspects of the MAVT such as the initial cost, were based on broad estimates. These estimates were based on the cost of other projects and assumptions about the size of projects, for instance the area that would be involved in a MR or floodplain reconnection scheme. The estimated costs would be different if a smaller area were involved than assumed in this assessment. To remedy this, the inclusion of economic experts and local decision-makers in the assessment would reduce the reliance on guesswork and make the predicted costs would be more reliable.

The impact of each option on local business was based on assumptions, such as an expected increase in tourism if the beach area increased, or that the local council would employ local businesses for hard defence construction. In order to gain a better idea of the potential impact of each alternative on the local economy and industry, it would be advisable to look at the local economy in greater detail, for instance the percentage based on primary industries compared to the tourist industry, and the percentage reliant on the areas potentially affected by each management option. This would require the consultation of economic experts, and may benefit from the use of an economic model, so that the scores for the 'Impact on local business' parameters reflect the specific context of the Dysynni coastline and valley.

Another finding of the research and MAVT assessment was that determining whether an alternative would be a carbon source or sink depends on too many factors (such as the frequency of wetting and drying, the temperature, and the rate of vegetation development) to assess it just based on similar projects. Accurately scoring this attribute would require modelling of the specific environment under each alternative to assess the rate of carbon sequestration or emission. Such modelling would require expert consultation and the use of sophisticated terrestrial carbon cycle models. Another attribute that would require modelling to score accurately is the 'Impact on coastal erosion' attribute. The choice of coastal management alternative could impact rates of beach and cliff erosion both in the immediate vicinity of the project and further along the coastline. The score given for the alternatives in this MAVT for this attribute was based on theoretical research and review of case studies. To generate a score that is meaningful and accurate for the study area, a coastal erosion model would be useful to assess the impact of each alternative. This is also the case for the 'Likelihood of failure' parameter

The requirement for more detailed information and models highlights the importance of understanding the local context, project objectives and management priorities for scoring and weighting attributes, and therefore indicates the value of consulting and including stakeholders, experts and decision-makers in the MAVT process. Assessing public perception and how a project might alter current ways of life cannot be accurately determined without public consultation. If this MAVT method were to be used for the Dysynni coastline or another area, it should involve significant stakeholder and public consultation throughout the process.

8.8.6 Use within decision making

This MAVT assessment has indicated the value of this methodology for directly comparing two or more alternatives based on a range of potentially conflicting objectives. The clear hierarchical structure allows the weaknesses in each alternative to be easily identified, allowing potential project designs to be altered accordingly. This MAVT assessment method could be undertaken at the very start of a planning/design process to initially determine the overall method of coastal management that should be used, as demonstrated here (for instance, by comparing two different approaches). It could also be used further along in the planning/design process to compare two or more similar projects in order to fine-tune the most sustainable approach. A MAVT carried out later in the planning process could include more detail than the initial MAVT, for instance on how much land would be included in the floodplain reconnection or MR projects, how much sand would be used in the sand engine project, or more accurate costings for hard defences.

8.8.7 Summary

Undertaking this MAVT assessment demonstrated the simplicity of the methods, which would be easy to introduce to decision-makers with little training required. The results indicated that this approach provides a helpful and clear way to compare between two (or more) alternatives with conflicting objectives. Compiling the parameter scores into attributes, and then into criteria, makes it clear which areas are the strengths or weaknesses of each approach, rather than just compiling all parameters into a single overall score. This reveals where compensation is occurring, for instance where a strong score for one parameter is compensating for the weak score of another parameter within the same attribute.

If this MAVT method were to be applied in reality, more detailed plans of the alternatives would be required, and a crucial addition would be public, stakeholder and expert consultation (see above). All MAVT literature reviewed either involved stakeholder/expert consultation (e.g. Giove *et al.* 2010; Bottero *et al.* 2014; Ferretti *et al.* 2014), or stated the importance of including decision-makers and expert opinion (e.g. Brandão Cavalcanti *et al.* 2017). Including a range of opinions and expertise would create a more reliable and robust score and analysis. As mentioned in the Results section, the use of models such as economic models, coastal erosion models and terrestrial carbon cycle models to assess the potential impacts of each alternative would allow the scores to be more reliable and based on the specific context of the project. Furthermore, public acceptance of coastal management projects is often greater if there is increased public participation. The weighting of attributes is another element of the methodology that was unexplored in this example, but which may be a valuable addition, as it would allow the decision-makers at each location to determine the priorities based on the project's context, as well as aiming for an overall sustainable option.

8.9 Conclusion

Chapter 8 addressed Research Aim 3: *establish a way to identify the most appropriate approach(es) for sustainably managing the coastal historic landscape in the face of climate change.* The MAVT sustainability assessment method developed and established in this chapter forms the final part of the Landscape Vulnerability Framework that is being created throughout this study. MAVT, a type of multi-criteria decision analysis, was chosen as the most suitable method for several reasons, including its inclusion of both qualitative and quantitative data, its ability to involve conflicting objectives, and the ability to break the criteria down into thematic groups. The division of criteria into the three pillars of sustainability, and including functionality, was important for maintaining transparency about how each option scored. Several other sustainability assessment approaches attempt to create a single score, for instance cost-benefit analysis. This equating of ecological, social and economic factors (and discussing all factors in terms of their economic value) erases the intrinsic value of nature, land-use practices and tradition. In many studies (e.g. Gren *et al.* 1995; Schwartz *et al.* 2006; Kettunen and ten Brink 2006), ecological benefits of coastal and flood-risk management projects are discussed in terms of the economic benefit or loss to ecosystems. Research by Roca and Villares (2012) indicates that, despite the offer of subsidies and the economic benefit of wetland creation, local people do not necessarily consider this an equal trade for the loss of agricultural land. This highlights the fact that people place values on land that cannot necessarily fit into economic measures, and that the intrinsic value of land or land-use practices may be greater than anticipated by economic appraisals (*ibid*.). Using MAVT allows the intrinsic environmental and socio-cultural factors to be considered alongside, but separate to, economic valuation.

In order to test the MAVT methodology on the Dysynni valley, two different coastal and flood-risk management scenarios were created which could be compared in the MAVT. One option, the SMP2 policy option, was based on the current policy plan for the study area as defined by the West of Wales Shoreline Management Plan 2 (see Guthrie and Clipsham 2011; Earlie and Brunner 2012; Earlie *et al*. 2012a,b,c,d). The second option was an Innovative Sustainable (IS) alternative, based on two techniques that may be more environmentally friendly, but are less commonly used.

The results of this MAVT assessment in terms of the Dysynni valley are discussed in depth in 8.8.1, but the most important conclusions from this chapter can be drawn from the evaluation of the MAVT methodology. A crucial finding from undertaking the MAVT was the importance of stakeholder and expert involvement in several stages of the process. Attributes such as public perception require consultation of local stakeholders to score correctly, as there are a multitude of factors that influence them and the reaction to management tools can be context specific. Other attributes, such as economic estimates of the initial or maintenance costs of projects were based on cost data from similar projects. The wide range of potential costs found indicated that numerous conditions affect both the initial and ongoing cost of any management project. Consultation of economic experts would be essential to accurately score this kind of attribute., as well as for predicting the ecological impacts and benefits of different options. Although there was not the time or budget to undertake stakeholder and expert consultation when applying the MAVT to the Dysynni valley, this methodology testing was important for informing the way that it should be applied to other landscapes when used in practice.

Using a landscape-scale VI to inform the creation and completion of this MAVT influenced both the methods and results. Planning processes such as Environmental Impact Assessments consider elements of landscape character. However, defining both the historic landscape character (through HLC) and its vulnerability (through a VI) provides greater clarification of the object of study and the ways in which it may be vulnerable to change. This facilitates the application of the MAVT as the meaning of historic landscape character and the vulnerability of different types of character is clearly defined and explained. It also acknowledges the impact that large coastal and flood-risk management projects can have on the visual, socio-cultural and historic character of rural and urban spaces. If the VI focussed only on archaeological features, the MAVT could only reliably consider the impact of different management approaches to these features, rather than to the landscape as a whole.

In terms of its use in decision-making, MAVT can be used at any point in the policy process, both generally as a method to narrow down potential options at the start of a process, and as a more detailed way to refine management tools. It can be used more than once, and applied several times to a single option, to determine the level of improvement after adjustments have been made. The weighting of each attribute can be adjusted following stakeholder or expert consultation, or depending on the landscape that it is being applied to. These factors make MAVT a flexible tool, which allows the Landscape Vulnerability Framework to be applicable to other landscapes with different threats, environmental settings and economies.

Chapter 9
Conclusions

9.1 Introduction

This research set out to develop a Landscape Vulnerability Framework, which would establish the vulnerability of the coastal historic landscape to climate change, and assess the sustainability of options for managing these changes. This overall research goal was developed in response to several factors: the increasing threat of the impacts of climate change on cultural heritage; the relative lack of research into the impact of climate change on material cultural heritage compared to other disciplines; the focus of archaeology vulnerability studies on discrete sites at the expense of the historic landscape; the disjointed way in which the vulnerability and management of the archaeological resource is currently undertaken in different areas; and the need to prioritise the archaeological resource for protection, due to the limited budgets of archaeological organisations and public bodies.

Several of these factors were identified initially in 2015 through my undergraduate research on the direct and indirect impacts of climate change on British coastal archaeology (Cook 2015). During this initial research, there was a notable lack of material explicitly discussing the consequences of future climate change for archaeology, both in academic and grey literature. This indicated the vast potential for research into this topic and the pressing need for research to inform future heritage management policies.

The concluding chapter of this study first provides a summary of the overall research. Next, it assesses the extent to which each of the research objectives were achieved. Subsequently, there is a discussion of the implications of this research, including ways in which it could influence archaeological management and policy. Finally, suggestions for future research are explored in relation to any questions or knowledge gaps that have been identified in this thesis.

9.2 Thesis Summary

This study began by outlining a range of potential impacts of climate change on archaeology (Chapter 2), although this did not constitute an exhaustive list of effects. Chapter 2 established the context of the study and highlighted the importance of research into this threat. Chapter 3 defined the conceptual framework that underpinned this research, including the focus on the concept of sustainability, the explicit acknowledgement of the scalar framework of this research, and the concept of the historic landscape. As well as to transfer the focus of vulnerability research from sites to landscapes, the historic landscape concept and HLC methods were used to render the methods and results of this research 'value-free'. One of the underlying principles of HLC is that it is value-free, and therefore does not assign any weight or significance to any LCA over any other (Fairclough 2006a; Fairclough and Herring 2016). This allows the output of the HLC to be versatile in its use. In contrast, the prioritisation of archaeological sites or features for management is often based (either wholly or partly) on their 'value' (e.g. Drury and McPherson 2008; Cassar 2009; Dawson 2010; Dawson 2013). This is problematic as different stakeholders may place greater value on different sites, or determine 'value' by different criteria. For instance, some stakeholders may consider the oldest remains as the most valuable, as they are the furthest removed from current society and there are no historic records to enhance our knowledge of ancient periods. In contrast, others may value more modern remains, such as those from the First and Second World Wars, as they have a tangible link to modern politics, culture and living people. Finally, the value of different types of archaeological feature for academic research is difficult to determine, as there are many research questions and techniques that have not yet been conceived. For this thesis, prioritisation of archaeology for management and protection was determined by the level of vulnerability, as informed by Daly (2013).

Acknowledging the scalar framework of this research at the start and throughout was important, as it explicitly recognised the interconnectivity of different spatial levels within the landscape, and how each level can influence others. It was important to include the concept of sustainability as it informs management approaches in the environmental and social sectors, and therefore is an important consideration if archaeological management is to be included within mainstream climate change adaptation reports. Interestingly, no literature on archaeological preservation could be found that mentioned any potential environmental or ecological impacts of archaeological management techniques, or any secondary benefits. Furthermore, methods for maintenance of submerged sites discussed by some authors (e.g. Bruno *et al.* 2013) include chiselling off organisms like bivalves from archaeological remains. Allowing organisms to live on submerged artefacts can cause considerable damage. However, the ecological damage of these techniques, or the potential habitat impacts of excavation and site management, must be considered if archaeological management and protection is to become part of mainstream climate change adaptation or coastal management.

During the development of the Landscape Vulnerability Framework, methods were tested on a case study, the Dysynni valley in Wales. This area was chosen for several reasons, such as the low-lying valley floor susceptible to flooding, and the range of archaeological time periods represented in the known archaeological resource. It was also a practical choice, as there are fieldwork and geophysical survey projects ongoing in the study area by the University of Sheffield Department of Archaeology.

This provided access to remote sensing data for the valley floor, which was considered at risk of future environmental change.

A range of sources were used to analyse the study area, including geophysical survey, archive research and aerial photography (Chapter 5). The data collected were then used to inform a HLC of the Dysynni valley (Chapter 6). This HLC created the object of research for the vulnerability assessment, namely the LCAs. Chapter 7 included a literature review of vulnerability assessment studies in archaeology, identified several limitations with the most common approaches, and used this to inform the development of a landscape-scale VI. The data-collection techniques were piloted on a few sites in the Fenlands, and then the whole VI was tested on the Dysynni valley HLC.

Once the threat to the historic landscape and the vulnerability of different LCAs was identified, the information was utilised in Chapter 8 to inform sustainable management approaches. Literature reviews of what sustainable coastal and flood risk management entails, and different tools that could be used in the study area, identified an Innovative Sustainable coastal management option. This was compared to the current approach to coastal management in the Dysynni valley, the SMP2 policy plan, using a MAVT assessment tool. The outcomes of this study are discussed in greater detail in relation to the research aims and objectives in the following section.

9.3 Achievement of Research Objectives

The research aims and objectives that informed the approach taken in this thesis are outlined in section 1.4. The following section discusses the research findings in relation to each of the aims and objectives, and determines the extent to which the objectives and aims were met.

9.3.1 Research Aim 1: identify a method of analysing and characterising the archaeological resource on a landscape level.

Objective 1a: Collect information on the known archaeological resource in the Dysynni valley
Several sources of existing archaeological data were available for study, including archaeological reports and DBAs for construction projects in the Dysynni valley (see Smith 2004a, 2005; Blackburn 2011; Knight 2011; Frost 2012; Roseveare 2012; Wessex Archaeology 2012, 2014; Smith 2013; Cooke 2014; Meek 2015). Section 4.4 synthesised the data available in these studies, providing an overview of the archaeological record from the Mesolithic period onwards. Geographically, the DBAs included in these reports focussed on areas of 1-2km around their study site (see Figure 9.1), although they also mentioned sites of high importance in the wider landscape. As shown in Figure 9.1, these studies were predominantly located in or near low-lying urban areas and near the coast, as these are the areas most popular for development. The main source of data that the archaeological reports

cited were the HER and NMRW databases, and some included information from archives in NLW and the County Record Office, Dolgellau.

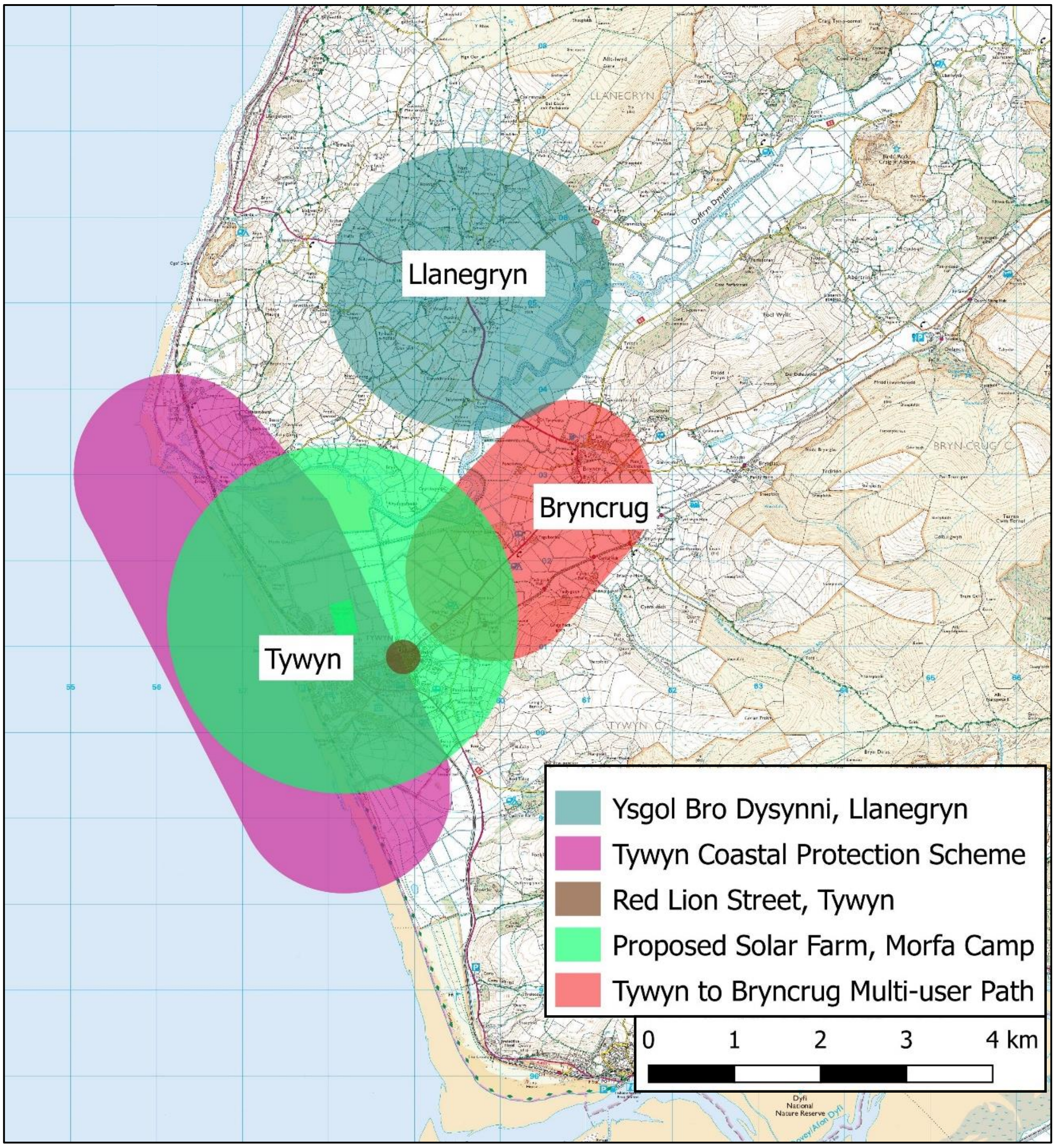


Figure 9.1. *Location and extent of the various desk-based assessments carried out in the Dysynni valley for different development projects. Crown copyright and database right 2019 Ordnance Survey 100025252*

To supplement the information found in the archaeological reports, the HER information for the whole study area was requested from Gwynedd Archaeological Trust and Dyfyd Archaeological Trust, and the NMRW records for the study area were requested from RCAHMW (section 5.2.1 and

5.2.2). Having access to the raw point data for the HER and NMRW records meant that the data could be analysed in GIS rather than just recording the information stated in the DBAs. This allowed identification and removal of any duplicated points, compilation of the records into a single database, and addition of new data such as elevation. The distribution of HER and NMRW records in the Dysynni valley was more concentrated in sloped and upland areas, with relatively little coverage on the valley floor.

Archive research provided a plentiful source of information (see section 5.2.2). The National Archives held several maps and documents relating to land-use and management during the 20th century, which provided a useful back-drop for understanding the current issues, such as flooding and waterlogging, faced by land-owners in the Dysynni valley (see Table 5.3). The archives in NLW held older maps of the study area, including those displaying land divisions, and 19th-century plans for new proposed train lines and viaducts (Table 5.4). These detailed plans for a new railway line across the Dyfi estuary were drawn up in 1865, the same year that the Talyllyn railway opened, which carried slate from Abergynolwyn to the standard-gauge railway at Tywyn. These sources indicate the importance of the study area during the industrial period for quarrying and trade with other regions, and the rapid development of the railway, as the railway line through Tywyn was only built in 1863 (Quick 2012).

Objective 1b: Use aerial photography and geophysical surveys to enrich the archaeological record of the Dysynni valley

Additional archaeological research was required in the Dysynni valley to supplement the existing database and archive records, and ensure that the landscape characterisation would be based on as much information as possible. Excavation was not used as a method of archaeological research, as the focus of the study is on the historic landscape and its character, which are broader themes than can be addressed by excavating single features. Instead, aerial photography was used as a way to analyse large swathes of the study area and identify any cropmarks that may indicate historic or prehistoric land-use. Features identified as cropmarks in aerial photographs stretched from the coastline to near Castell y Bere, 12km inland, but were mainly located in low-lying areas along the valley floor. This finding indicates that the distribution of HER and NMRW records is a result of more archaeological survey and superior preservation in upland areas, rather than a lack of human activity in the lowlands in the past. The different level of preservation may be due to both environmental factors, such as increased flooding on the valley floor, and land-use factors, such as less intensive farming practices and greater public access to land in the upland areas.

The large number of previously-unknown cropmarks identified indicates a knowledge gap in the study area regarding land-use prior to the 18th and 19th century drainage schemes. It is not currently clear how long the lowlands of the Dysynni valley were uncultivable wetland, or whether they may have been occupied at some point previously.

Geophysical surveys were used in some areas to deepen knowledge about the cropmarks and test adjacent areas where cropmarks were not visible. In the fields surveyed, the majority of cropmarks identified were revealed as subterranean features by magnetometry and/or resistivity. In some places, additional features were revealed that had not been visible as cropmarks in the aerial photographs. The various shapes of the cropmarks and geophysical features in close proximity to one another, including circular, square, linear and curvilinear, with several instances of features intersecting, suggests that these areas were used throughout different periods in history and hold rich archaeological information spanning several time periods from at least the Bronze Age to the early medieval period. Again, this indicates that there is the potential for further archaeological research into the Dysynni lowlands.

Objective 1c: Use Historic Landscape Characterisation to characterise the historic landscape of the Dysynni valley.

A review of HLC theory and methods provided a basis for applying HLC to the study area, and helped to identify the approach that would be most suitable (section 6.3). Although HLC had already been carried out in the Dysynni valley by GAT (see section 6.2), the method of characterisation used in Welsh HLC projects is much more specific, and each polygon is defined as a unique LCA. Research into English methods, such as those used in the Cornwall HLC (see Herring 1998), indicated that the thematic approach used, in which areas of the same LCA can be spread across the landscape, was more appropriate for the purposes of the thesis as a whole. The decision was made to allow the LCA polygons to overlap in the HLC, as in many areas the landscape displays features of more than one period or more than one character type. Allowing overlap between LCAs meant that the HLC represents the multiplicity of land-use over time, and does not exclude one type of character in favour of any other in any area.

The research undertaken to satisfy research objectives 1a and 1b fed into the HLC, as the information gained from archaeological databases, archive research, aerial photographs, and geophysical surveys informed the creation and location of different LCAs. When applied to the Dysynni valley, the HLC revealed the distribution of different types of current and historic land-use. The results indicated that the upland and sloped areas of the valley are dominated by older features, such as those related to post-medieval extractive industries and farming, prehistoric activity, and pockets of ancient woodland. In contrast, the valley floor is mainly characterised by more modern features such as regular field systems and drainage systems, and mobile home and caravan parks, while Maritime Industry, Wetland and Beach and Military Character areas are located along the coastline. The cropmark features identified in the lowlands for objective 1b meant that some areas of the valley floor could also be characterised as having ancient character.

HLC is used to display the distribution of human activity and historic land-use decisions across a landscape. However, the distribution of different LCAs into defined geographical areas can also indicate the influence that the environment, geology and topography has had on human action and land-use decisions in the study area throughout history, as can be seen in the Dysynni valley (Figure 5.13).

The historic landscape is complex and multi-layered, and so critics of HLC may consider it a reductive process that over-simplifies a nuanced and dynamic system (Landscapes 2006; A Howard 2019, pers. comm. 25 April). However, HLC is not designed to replace in-depth archaeological study, but rather changes the scale of analysis by creating another framework within which more detailed research can be targeted. Herring (2009) states that HLC classifies cultural heritage in the landscape in the same way that ecological complexity is simplified using classifications such as community, biotope and habitat, and the way that defined time periods are applied to archaeological remains. HLC sorts and contains complex information in the same way, and in doing so it allows geographically larger patterns and trends to be studied and identified *as well as* more detailed studies (Herring 2009). Therefore, HLC is not mutually exclusive with any other type of archaeological research. Furthermore, landscape features that may not be included in archaeological research, such as hedgerows and field-boundaries, transport routes, and modern features, are all incorporated within HLC. Arguably, HLC is therefore more inclusive and acknowledges more complexity and time-depth in the historic landscape than other archaeological approaches.

Summary of Research Aim 1

The purpose of Research Aim 1 was to define the observational scale of this vulnerability study as the historic landscape as a continuity, rather than taking a discrete site focus. In order to achieve this, objective 1a and 1b provided a detailed understanding of the recorded and visible archaeological resource of the study area. This was essential for informing the LCA-type definition, as well as for undertaking the HLC. For objective 1c, the in-depth exploration of HLC as a landscape characterisation method, the different possible methodologies, and its various uses, allowed the most suitable approach for the Dysynni valley and the Landscape Vulnerability Framework to be identified. The methods chosen could easily be applied to another historic landscape, although the

LCA-types used may require some alteration. This is a simple process, and the definition of LCA-types unique to the study area is common across most HLC projects reviewed. One of the main aims was to have enough LCA-types to indicate trends and patterns of land-use and represent some of the complexity of the study area, while having few enough to make it clear and understandable, and feasible for use in a vulnerability assessment (Research Aim 2).

9.3.2 Research Aim 2: *develop a landscape-level archaeology vulnerability assessment methodology*

Objective 2a: Determine the potential climatic changes in the Dysynni valley in the 21st century based on the results of a variety of climate models

An initial literature review of available climate model results, for instance from the UKCP18 project IPCC AR5 projections, gave an insight into the plurality of potential future climatic and weather conditions (see Figure 2.2). An online user interface run by the Met Office provided UKCP18 projections at a higher spatial resolution for some variables, such as change in air temperature, humidity, cloud cover, precipitation rate, and wind speed (Met Office 2018). The terrestrial variable data is available as raw data, maps, plume plots, probability density functions and joint probability plots, although maps and plume plots were used for analysing data for this thesis (See Figures 6.2-6.5).

Although there is variation in the results of different climate models and for different scenarios, most projections for the study area and for western Britain follow the same general trends. Temperature rise is projected across all seasons, although the increase in average and daily maximum temperature will be greater in the summer than winter. Rainfall, an important variable for impacts such as drought, flooding and inland erosion, is projected to increase in the winter and decrease during the summer, although the rain that does fall will be in more intense, high magnitude events. This greatly increases the risk of flash-flooding and erosion, as drier soils are more vulnerable to intense rainfall events (Rothwell *et al.* 2005). Finally, both mean sea level and high water levels are projected to increase. As well as meeting objective 2a, the findings of this research were used to inform the VI developed as part of objective 2b.

Objective 2b: Develop a vulnerability index for measuring and quantifying the vulnerability of historic landscapes, informed by the strengths and limitations of other archaeology vulnerability assessments

The literature on vulnerability indices in archaeology revealed several trends that are followed across the majority of approaches, namely a focus on 'sites' as the object of study. This does not align with the overall conceptual framework of this research, as outlined in Chapter 3, as it does not consider the historic landscape or different spatial scales of the archaeological resource. To address this, the VI methodology developed in Chapter 6 used the HLC LCAs the focal level. Another trend identified was a lack of recognition of the change to the threat to archaeology in the near future as a result of climate change. The majority of studies only considered past and current environmental conditions, rendering the results out-of-date in the near future. This highlighted the importance of a VI not only for the historic landscape, but also for addressing the changing threat to the archaeological resource. The climate change projections collated in section 7.3 were therefore used for establishing variables in the landscape-scale VI.

The vulnerability indices studied used various different scoring methods, so a range of approaches informed the final VI methodology developed for objective 2b, including two separate equations for different spatial levels (influenced by Reeder-Myers 2015). This allowed the influence of individual features on the overall historic landscape character to be considered, while keeping LCAs as the focal level.

Objective 2c: Test the methodology developed in 2b by applying the vulnerability assessment to the Historic Landscape Characterisation output for the Dysynni valley (objective 1c), to identify any weaknesses in the methodology developed

A logistical and technological test carried out in the Fenlands was undertaken to identify any methodological or technological issues that could affect data collection in the Dysynni valley. The main implication from this test was that HER and NMRW location data is inaccurate, a critical consideration when allotting the amount of time to locate sites during the fieldwork.

The main fieldwork for Stage 1 of the VI, which ground-truthed the HER and NMRW data in the study area, allowed the inclusion of additional features into the VI. This made the results more accurate and reliable. Following the application of Stage 2 of the VI to the Dysynni valley, the overall results indicate that LCAs in low-lying and coastal areas are most at risk from the impacts of climate change. However, the best way to classify and display the results was difficult to establish. A review of other VI studies revealed that a wide range of different methods can be used to classify results, the choice of which has an impact on the way the results may be perceived and used. This highlighted the importance of transparency when visually displaying VI results, for instance on a map.

Summary of Research Aim 2

The development of a historic landscape-focussed vulnerability index was the most important element of the Landscape Vulnerability Framework in this study in that it is a unique and novel contribution to the field of archaeological vulnerability. A similar approach did not exist before, as all other studies using this type of vulnerability assessment were focussing on sites independently. The VI created to satisfy Research Aim 2 can be applied to any coastal landscape as part of the Landscape

Vulnerability Framework, as evidenced by its application to the Dysynni valley. The methodology would also be suitable for applying to an inland landscape, as was trialled in the logistical and technological test, if some of the variables (e.g. Proximity to eroding shoreline) were removed or changed.

9.3.3 Research Aim 3: *establish a way to identify the most appropriate approach(es) for sustainably managing the coastal historic landscape in the face of climate change*

Objective 3a: Identify, through literature research, a sustainability assessment approach that could be used in the Landscape Vulnerability Framework

A literature review identified many methods that are used to assess the sustainability of different types of systems and processes. Some of these methods translate all factors (economic, environmental, social) into the same metric to be compared, for instance ecological footprint analysis measures the land area that would be required to create a product or process and deal with the outputs. Similarly, cost-benefit analysis translates all impacts and outcomes of a project into monetary terms, so that the net benefits can be easily calculated. A limitation of both these approaches is that they assume that ecological, social and cultural values can be easily measured and quantified in economic or land-area terms. This neglects the intangible, immeasurable value associated with some elements of the historic or natural landscape. This type of approach can also only support weak sustainability, as it allows one type of value or capital (e.g. cultural) to be substituted for another type of capital (e.g. economic), as though they were interchangeable. This type of approach was not considered suitable for the Landscape Vulnerability Framework as the concepts that underpin it, such as sustainability and the historic landscape, are based on the idea that all cultural and natural elements of the landscape are valuable, and have intangible value that cannot be easily quantified alongside economics.

Another requirement for the Landscape Vulnerability Framework sustainability assessment was the recognition that there would be several conflicting objectives that would have to be included and compared for each alternative. MCDA approaches were therefore considered most suitable as they can combine various qualitative and quantitative criteria and several objectives, and can be easily altered to suit specific contexts (Giove *et al.* 2010). This is particularly useful for the Landscape Vulnerability Framework, the purpose of which is to be applicable to any landscape, and therefore any context. Of the MCDA approaches reviewed, the MAVT approach was considered the most suitable, as it normalises criteria scores onto a common scale for easy comparison, and is most suitable when there are defined alternatives to be evaluated based on conflicting objectives (Dutta and Hussain 2009; Ferretti *et al.* 2014). MAVT sustainability assessments do not require the substitution or translation of natural or cultural values into economic metrics. Furthermore, to avoid the trap of weak sustainability, the MAVT methodology chosen for this thesis was based on that by Giove *et al.* (2010), which divided variables into different categories (environmental, economic, socio-cultural). This meant that there was transparency around the scores for different categories, so alternatives could be compared on their environmental or socio-cultural sustainability, as well as on the overall score.

Objective 3b: Review the current coastal and flood-risk management approaches in the Dysynni valley, and research innovative sustainable alternatives

In order to develop alternatives that could be compared in the MAVT sustainability assessment, it was necessary to establish the current coastal and flood-risk management policy in the study area, as defined in the SMP2 documents (section 8.3; Guthrie and Clipsham 2011; Earlie and Brunner 2012; Earlie *et al.* 2012a,b,c,d). A review of existing defence structures and the most recent coastal defence scheme also determined the types of defence in use, and the costs that are currently acceptable on the Dysynni coastline.

To test the suitability of the MAVT methodology for the comparison of different management options, an 'Innovative Sustainable' (IS) alternative to the SMP2 policy plan was developed. A literature review of sustainable coastal and flood-risk management theory and methods identified two alternative tools, floodplain reconnection and a sand engine, which could feasibly be employed in the study area (section 8.4). These were combined to form the IS alternative that covered both coastal and estuarine areas, as the SMP2 policy plan does.

Objective 3c: Test the suitability of the sustainability assessment methodology (objective 3a) by applying it to the output generated in Research Aim 2 and comparing the current management policy in the Dysynni valley with potential alternatives identified in Objective 3b.

The two options identified for managing the Dysynni valley (SMP2 and IS alternatives) were compared using the MAVT sustainability assessment established in section 8.2, with reference to the LCA vulnerability scores for the study area (see section 7.5). The scoring system was easy to understand, and allowed for both negative and positive impacts to be included. The categorisation of variables into different criteria (economic, environmental, socio-cultural and functionality) meant that the results were displayed clearly, and the strengths and weaknesses of each option were evident, as well as the overall score. Transparency is important in policy decision-making, so an approach like this that clearly breaks down each constituent score, would provide explanation and clarity for stakeholders.

A significant amount of literature research was required to undertake the MAVT assessment, for instance into the costing and environmental impact based on similar projects. The difficulty in finding sufficient information for some attributes highlighted the need for expert and stakeholder consultation if this Landscape Vulnerability Framework is applied to other landscapes and used to inform management decision-making. Consultation would increase the time required and cost of using this Landscape Vulnerability Framework, however parameters such as 'Impact on carbon emissions' or 'Impact on local economy' require specific models and expert understanding to be reliable. Furthermore, it is impossible for an external researcher or even a heritage 'professional' to fully understand the local cultural significance of certain elements of the landscape, so local consultation would also be advised.

Summary of Research Aim 3

The purpose of Research Aim 3 was to make the Landscape Vulnerability Framework into a useful tool that could directly inform policy and decision-making, and specifically incorporate sustainability in its outputs, rather than just identifying vulnerability. Choosing MAVT as the sustainability assessment approach allowed both qualitative and quantitative information to be included, and removed the need for substitution or translation of one type of value for another. It is a flexible tool within the framework, so the parameters and variables used for the Dysynni valley could be altered should the context of another landscape require it.

9.3.4 Overall Research Question: *How can the vulnerability of cultural heritage to future climate change be assessed and managed at a landscape scale?*.

In answer to the research question posed for this thesis, the outputs of the three research aims discussed here are combined to create a Landscape Vulnerability Framework, which provides a methodology for assessing and addressing the vulnerability of historic landscapes to climate change. The three-part framework, as visualised in Figure 9.2, first characterises the historic landscape based on available archaeological, historical and cartographic data. The second part provides a vulnerability assessment method that considers the vulnerability of LCAs defined in the first part, rather than discrete sites. Finally, the third part assesses management alternatives using a sustainability assessment that takes into account the historic landscape and the vulnerability identified in the second part. This framework can therefore be used to inform the decision-making process for historic landscapes from the initial conceptualisation of a landscape as a continuous, dynamic artefact, through to the development and selection of management alternatives.

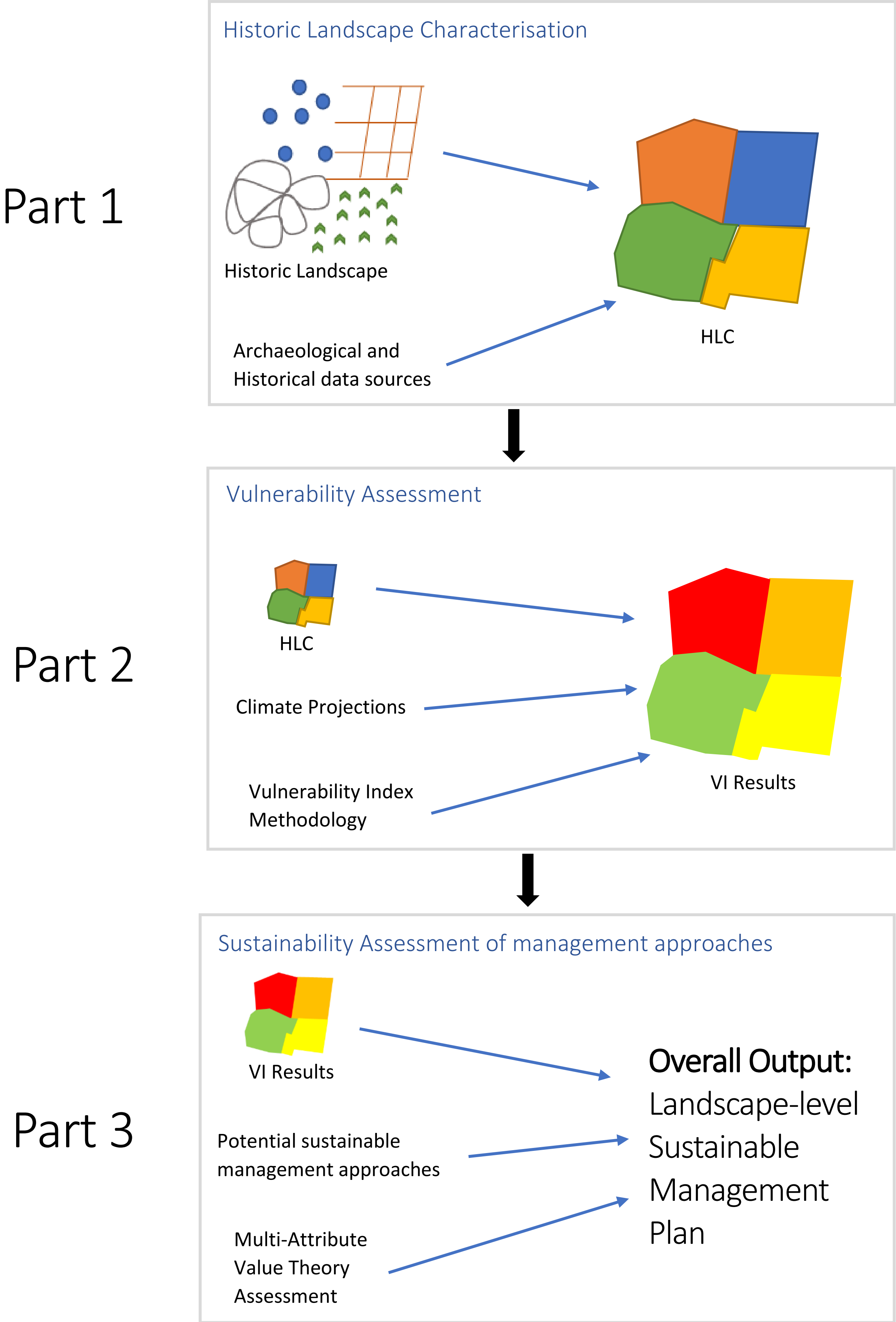


Figure 9.2. *Visualisation of the three-part framework created in this research*

9.4 Implications of Research Findings

9.4.1 Research output

Within this research, a three-step Landscape Vulnerability Framework was developed and applied to a case study, to address the limitations of current archaeological vulnerability assessments and site-based heritage management. Each step of the framework was designed to be flexible and adaptable to different landscape conditions, to facilitate its application to other landscapes. Firstly, characterisation using HLC can be informed by a range of different historical, archaeological and cartographic data sources, so can be undertaken in different landscapes in which different types of survey have been undertaken. Secondly, the variables used in the two-stage VI were general and could be applied to any other coastal landscape. This would allow comparison of historic landscape vulnerability between landscapes. For use in an inland landscape, the VI variables could easily be changed or adjusted based on the most important climate change impacts in that context. Finally, the MAVT methodology adapted for this framework uses variables and parameters that are universal and applicable to any management approaches for coastal and inland landscapes. It could also be easily adjusted to include additional variables or parameters if they were deemed contextually important. Applying the Landscape Vulnerability Framework to the Dysynni valley generated examples of the results from each step, to illustrate how the output of each step would be used to inform the subsequent step.

9.4.2 Research contribution to the field

Typically, research into (and management of) archaeological vulnerability to climate change and other environmental processes has taken a site-focussed perspective (Fitzpatrick *et al.* 2006; Westley *et al.* 2011; Chadwick-Moore 2014; Van Rensslelaer 2014; Reeder-Myers 2015). This is partly due to the prevalence of site-based and list-based management and legislation, such as Listed Buildings, HER, NMR, Scheduled Ancient Monuments, and even World Heritage Sites (King 2006). Characterisation of historic landscapes exists in various forms in the UK, and Fairclough (2006b) stated that HLC should be used as a management tool with sustainability in mind. However, Fairclough (2006b) only mentions the use of characterisation for management in terms of development risk, rather than environmental and climatic changes.

A unique example of landscape characterisation methods being used in relation to climate change is by Natural Resources Wales (Berry *et al.* 2019). This report identified the impacts of climate change on broad landscape types as defined in the LANDMAP Visual and Sensory dataset. LANDMAP is a resource of landscape characteristics, which contains five spatial datasets: Geological Landscape, Landscape Habitats, Visual and Sensory, Historic Landscape, and Cultural Landscape. The Visual and

Sensory dataset characterises the physical attributes of the landscape as it is perceived through our senses, primarily visually (Lle 2019). Therefore, while taking a landscape-level perspective, Berry *et al.* (2019) focus on the impacts of climate change to the visual landscape, rather than considering historical, cultural, spiritual meaning or character in the landscape. Their research is also at a larger spatial extent; the landscapes classified are whole counties, and the character areas (here defined as Landscape Types) cover several thousand to hundreds of thousands of hectares. This makes it more difficult to understand the subtle and unique historic character of different areas of a landscape, and how climate change may differently affect areas in close proximity. In contrast, HLC allows various sources (including stakeholder consultation) to come together to inform the output, and therefore may include elements that would not be considered if only visual elements of the landscape were assessed. Finally, the report by Berry *et al.* (2019) explores only the potential level of impact of climate change on different character areas, and includes no consideration of how the impact data could or should be used, other than to say it could inform policy. In contrast, the Landscape Vulnerability Framework in this study explicitly included a methodology for incorporating landscape-level vulnerability data into policy decision-making (see Chapter 7). The study by Berry *et al.* (2019) does, however, highlight the increasing recognition that landscape is a resource in itself, rather than just a canvas upon which natural and cultural resources are placed.

Prior to this research, there had been little consideration of historic character and historic landscape in archaeological vulnerability studies relating to climate change (although some studies have addressed the potential impact of development on historic character (see Lambrick *et al.* 2013).This study represents a conceptual and methodological bridge between cultural heritage/archaeology vulnerability studies, and the increasingly landscape-focussed approach of natural and environmental heritage organisations (e.g. Berry *et al.* 2019). The techniques and approaches taken throughout were still informed by archaeological approaches, as the object of the study (namely archaeology and cultural heritage) has different characteristics that influence its vulnerability compared to the natural landscape. However, the conceptual framework of this research rejected the typical list-based approach to heritage management (see King 2006), and instead made the object of the study spatially continuous areas defined by their historic character. It also structured the object of study within a hierarchical framework that acknowledged the interaction and interdependence between and within spatial levels, rather than treating different features or areas as discrete. This addressed the scale mismatch identified in Chapter 6, between the scale of the impacts of climate change and mainstream management of those impacts on the one hand, and the scale of archaeological vulnerability assessments on the other.

The pursuit of landscape-level assessment and management in this thesis is not intended to suggest that the study and management of archaeological sites, monuments and historic buildings is less important or valuable than taking a landscape perspective. Much archaeological and scientific data crucial for understanding past societies can be found at the site level, and monuments can hold as much cultural significance as historic landscapes (Fairclough 2006a). A Landscape Vulnerability Framework can be used alongside, rather than instead of, site-focussed research.

9.4.3 Implications for policy and practice:

Landscape Vulnerability Framework as a transferable tool

Applying the Landscape Vulnerability Framework to the Dysynni valley throughout this study enabled the development of the framework into a tool that could feasibly be applied to other landscapes. It also identified limitations, or ways in which the framework could be more robust, for instance through stakeholder and expert consultation during the sustainability assessment. Testing out the methods therefore informs future applications of the framework, which will be able to avoid the weaknesses identified.

Changing the observational scale of heritage management

In developing a methodology to assess the vulnerability of archaeology on a broader (landscape) scale, this research aims to shift the focus of archaeological vulnerability research and management towards the wider impact on cultural heritage and historic landscape, rather than looking only at sites out of context. This Landscape Vulnerability Framework allows consideration of a broader perspective on cultural heritage management, to identify the key areas of importance to local heritage (Landorf 2009). In terms of policy implications, the information generated from this type of approach is useful for informing a holistic approach to heritage management. This is because it considers the cultural heritage of the landscape as predominantly informed by the character of the historic landscape, and both the tangible and intangible heritage features within it, rather than just the archaeological sites. Protecting only the known or most 'valuable' archaeological features in a landscape ignores the historicity of the landscape itself, and the liminal spaces between sites.

Integrating heritage management with other landscape-scale management

With an increasing threat to coastal archaeology from the impacts of climate change across Britain (and indeed worldwide), it is unlikely that heritage organisations have the resources or budget to protect all archaeological sites at risk. Moreover, historic landscapes occupy the same geographical space as natural, socio-cultural and economic landscapes. Employing a patch-matrix approach to vulnerability allows the outcomes to be compared and integrated with other landscape-scale assessments, such as those relating to ecology, habitat management, geology, land use, and environmental designations. This is useful as the main focus of climate change impact and adaptation reports are social, economic and ecological systems, while archaeology and heritage get little mention (e.g. IPCC 2014a, b; ASC 2016; Defra 2018). The Landscape Vulnerability Framework developed in this study could allow archaeology and heritage to be more easily integrated into mainstream climate change adaptation policy plans

Practical application of the Landscape Vulnerability Framework

As the Landscape Vulnerability Framework is transferable and applicable to other landscapes, public sector organisations such as Cadw and Historic England could utilise it as a tool for creating regional or nationwide historic landscape vulnerability maps. It could also be applied to the coastal landscape at each SMP Policy Development Zone during the next round of SMP policy development, in order to test the sustainability of different coastal and flood-risk management alternatives with regards to the historic landscape.

9.5 Suggestions for Future Research

A number of potential future directions have emerged from the methodology and findings of this thesis, some of which are explored in this section.

9.5.1 Inclusion of stakeholder and expert consultation

A main limitation identified in the MAVT sustainability assessment, the third step of the Landscape Vulnerability Framework, was that expert and stakeholder consultation would be a necessary addition to the assessment process. In particular, it was not possible to determine economic appraisals, carbon fluxes, and local cultural values placed on LCAs through literature research alone. Engaging stakeholders, experts and locals during the MAVT assessment would make the results more reliable and context-specific, and therefore improve the usability of the MAVT results.

The MAVT section of the Landscape Vulnerability Framework could therefore be altered to formally incorporate one or more consultation and participation methods, such as focus groups, participatory budgeting, opinion-polls, online questionnaires, and citizens' juries (Andersson 2011). The levels of public participation developed by Arnstein (1969) range from Manipulation and Therapy (non-participation) through Consultation (tokenism) to Partnership, Delegated power, and Citizen control (Citizen power) (see Figure 9.3). In order for the Landscape Vulnerability Framework to maintain sustainability as a core value, participation must support social sustainability through empowerment, inclusion and social learning (Geczi 2007; Garmendia and Stagl 2010). Public participation in development and policy design has been shown to increase the level of acceptance (e.g. Anderson *et al.* 2012).

HLC can also be carried out using public participation and consultation, as characterisation is essentially determining how the landscape appears and is perceived by those within it (Dalglish and Leslie 2016). Incorporating public perceptions and oral histories about the landscape from local people could make the resulting HLC more unique and culturally meaningful for those living and working within it (Historic England 2019). Future research could incorporate public participation methods within both Part 1 and Part 3 of the Landscape Vulnerability Framework.

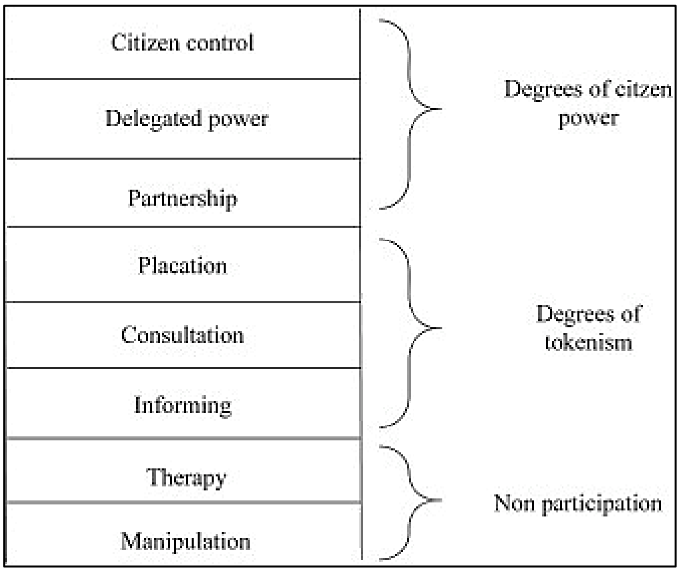


Figure 9.3. A Ladder of Citizen Participation, developed by Arnstein (1969)

9.5.2 Determine the transferability of the Landscape Vulnerability Framework

The Landscape Vulnerability Framework was designed specifically to be transferable across different landscapes, however it was only trialled in one study area. Applying the framework to a different coastal landscape within the UK would help determine how useful and useable it could be to UK heritage management policy. Additionally, research applying the framework to a landscape in a different environmental, economic and/or cultural context, such as in a developing country, an urban landscape, or a permafrost environment would test how easily adaptable it really is to different conditions.

9.5.3 Adapt the Landscape Vulnerability Framework for different types of landscape

As an extension of 9.5.2, different versions of the Landscape Vulnerability Framework could be developed for very different landscapes (for instance urban landscapes, desert/arid landscapes). This could involve including different variables in the VI depending on what the most significant threats to the historic landscape are in different areas. The MAVT assessment could also be altered to include different parameters, or weight some parameters over others, based on the economic and environmental context of the landscape. Developing slightly different versions of the Landscape Vulnerability Framework would mean that it would not need adapting each time it was applied to a landscape with a different context. As a result, the adapted Landscape Vulnerability Framework results could still be compared between landscapes, which would be more difficult if it were slightly changed for each iteration by the different practitioners that were carrying it out.

9.5.4 Consideration of the environmental impact of archaeological conservation

Although not directly related to the Landscape Vulnerability Framework, this research highlighted a significant knowledge gap in archaeology, namely the ecological and environmental impact of archaeological conservation and management; no literature on this subject could be found. In literature on coastal and maritime archaeological management techniques, methods for maintenance of submerged sites discussed by some authors (e.g. Bruno *et al.* 2013) include chiselling off organisms like bivalves from archaeological remains. Within this article there was no acknowledgement of the potential negative ecological impacts that this could have, for instance whether the species may be endangered, or the effect that it could have on the wider ecosystem and food chain. There was also no available literature that recognised the potential impacts of archaeological excavations on terrestrial habitats and ecosystems, such as disrupting ground nesting birds or small mammal burrows. Reburial, and the introduction of new materials such as sand and geo-textiles into subterranean environments (e.g. Perez Mejia 2014; Stewart 2013), could have dramatic impacts on soil ecosystems and nutrient flows.

Archaeology has been very active in encouraging social sustainability through participation (for instance through community archaeology). Furthermore, there have been significant efforts by organisations such as English Heritage/Historic England and National Trust to make historic buildings more energy efficient to reduce their carbon footprint (National Trust 2015b; Hermann 2017; Historic England 2018). However, archaeology seems oblivious to the physical impact that it can have on the natural world (see section 8.2). Future research should address the environmental and ecological impact of archaeological practice, in order to improve the sustainability of archaeology as an industry.

9.6 Conclusion

The Landscape Vulnerability Framework developed in this research is a useful tool for informing proactive coastal heritage and landscape decision-making for a future affected by climate change.

Although the potential impacts of climate change on the archaeological resource are beginning to be explored, there remains a disconnect between addressing the risks to archaeological sites and the mainstream approaches to climate change adaptation. The framework developed here goes some way towards addressing this disconnect, by altering the observational scale of archaeological vulnerability assessment and management so that it can be more easily integrated with, and compared to, landscape-scale approaches in other disciplines.

The methodologies developed for each part of the framework were informed by extensive research into common approaches, limitations, and knowledge gaps in the corresponding subject areas. Using a case study to trial and exemplify the chosen methodologies provided an exemplar for informing future applications of the framework, and allowed limitations to be identified. As a framework rather than a prescriptive model, future users are able to fit the methods to suit the context of their study area and available resources, for instance by using different types of data sources during the characterisation process, or altering some of the sustainability assessment parameters to account for specific local ecological conditions. The aim of this study was to create a framework that is flexible rather than restrictive in its approach, so that it is applicable to a range of landscapes. Public, expert and stakeholder participation was identified as a key limitation of the methods as demonstrated in the Dysynni valley case study. The research strongly indicates that, when applying this framework, heritage and landscape managers should include participation within both the HLC and MAVT processes, in order to generate more inclusive, robust, and accurate results.

Climate change will affect every aspect of the human and natural world, including economies, agricultural ecosystems, and flooding regimes. We have an obligation to reduce our carbon emissions in order to mitigate the most extreme potential damage, however the warming trends for the next century at least have already been set in motion (NASA 2014). The expensive and life-altering impacts on systems mentioned above are often given priority for research, management and adaptation, at the expense of less 'vital' resources. The archaeological record is finite, non-renewable, and essential for our understanding of the present and future, as well as the past. However, there are great challenges to calculating and addressing the threat of climate change to archaeology, such as undiscovered archaeological resources, unknown preservation environments, and intangible or unquantifiable heritage values. Widening the scope of climate change vulnerability assessments and management allows the intangible cultural elements of the landscape to be acknowledged, such as senses of place, traditional economies and lifeways, and the connection between communities and their natural environs. Importantly, developing a method that can be integrated with climate impact and adaptation plans from other sectors can allow archaeological management to become complementary with ecological, environmental and social management.

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Appendix 1: Study area background and Landscape Analysis

Table Ap1.1: *Archaeological records and features mentioned in Chapter 4, in order of mention*

Name	**Identifier**	**Type**	**Form**	**Description from source**	**Source**	**Location (x,y)**
Mesolithic (10,000 BC – 4,000 BC)						
Flint Pick	PRN 30899	Findspot	Find only	A flint pick from an unspecified location in Borth Bog.	HER	260000, 292000
Flint Flakes	PRN 30907	Findspot	Find only	Many flints retrieved by a local fieldworker (R Evans) and reported to staff at the RCAHMW. There are no details of the circumstances of recovery, nor any accurate location details of the findspot(s). NAP 2004. Toby Driver in his list of finds from the submerged forest not on the SMR, mentions 'Many flints' found on the foreshore at Borth-Ynys Las by Richard Evans.	HER	260000, 292000
Antler Tool	PRN 30894	Findspot	Finds	Findspot for a composite tool of antler, an axe or edge blade or sleeve for a flint blade or pick. Found on beach between Borth and Ynys-las. GW. 1995.	HER	260000, 292000
Neolithic (4,000 BC – 2,600 BC)						
Hearth, Ynyslas Beach	NPRN 506498	Hearth	Buried Features	The hearth was discovered amongst peat deposits at Ynyslas and consisted primarily of charcoal and fire-cracked stones.	NMRW	260450, 292850

				Samples taken from the hearth were sieved for food debris, but no remains were identified. The scientific dating of the associated peats suggested a date of approximately 4,000 BP.		
Two Neolithic Stone Axes, Findspot, Celmi Farm, nr Tywyn	PRN 4808	Findspot	Find only	Neolithic stone axe found in September 1871 'in putting down a wall fence close to the house at Celmi.	HER	259700, 304700
Bronze Age (2,600 BC – 800 BC)						
Waun Fach Stone	NPRN 302715	Standing Stone	Structure	Standing stone at Waun fach; 5ft 8ins high; on gently rising ground. The standing stone is 1.8m high, 0.8m wide and 0.6m thick, and packing stones are clearly visible on the N side.	NMRW	259440, 304870
Clwt y Menhir Standing Stone	PRN 4938	Standing Stone	Structure	Standing stone 6 foot high in use as a gatepost on Cae'r Berllan farm. It formerly stood on a piece of open ground called Clwt y Maenhir. Visited July 1914.	HER	266220, 307970
Bronze Axes findspot, Cefn Crib	PRN 4328	Findspot	Find only	Two looped and one unlooped bronze axes found about 1916 'between Aberdovey and Machynlleth' [centred SN 6899]. The looped axes are dated to about 1000-800 BC. Now in Grosevnor Museum Chester Acc. No. CC/278.1916.	HER	268000, 299000

Bronze Looped Axe Findspot, Dysynni	PRN 2982	Findspot	Find Only	Bronze looped axe found in 1873 near Hen Siop (SH 601063) dated to C9th BC. Probable Irish type. In NMW.	HER	260100, 306300
Bronze Tool (Axe), Findpot, Coed y Graig	PRN 3910	Findspot	Find Only	Socketed axe, found in hoard with bronze palstave PRN 3908.	HER	264200, 307800
Bronze Spearhead, Findspot, Tywyn Seafront	PRN 4813	Findspot	Find Only	N/A	HER	257700, 300950
Bronze Spearhead, Findspot, Tywyn Seafront	PRN 4816	Findspot	Find Only	N/A	HER	257900, 300200
Craig yr Aderyn Cairn	NPRN 407753	Cairn; Enclosure	Structure	Large stone cairn constructed of scree; with central robber pit; which lies some 300m south-east of the prominent hillfort of Craig-yr-Aderyn and stands at an altitude of 258m.	NMRW	264700, 306570
Urn Burials Findspot, Pantyneudd	PRN 4805	Finds		Several Middle Bronze Age cremations were found c.1884 during removal of a hedge in the garden of Pantyneuadd; Tywyn. Each urn containing a cremation had a Pygmy Cup inverted at its mouth. (Bowen & Gresham; 1967)	HER	259380, 300570
Cremation Urn Findspot, Tywyn Seafront	PRN 4806			An overhanging rim urn with cremation found 'near Tywyn'; of Bronze Age date and now in the NMW. (Bowen & Gresham; 1967)	HER	258000, 300000
Iron Age (800 BC – AD 43)						
Tal y Garreg Hillfort:	NPRN 302649	Hillfort	Earthwork	Llechrwyd hillfort is a bow-shaped	NMRW	257235, 303165

Llechrwyd Hillfort				enclosure; about 130m north-east to south-west by up to 45m; occupying a prominent ridge-end position. On the south-east it rests on steep natural slopes.		
Tal y Garreg Hillfort	NPRN 301736	Hillfort	Earthwork	Tal-y-Gareg hillfort is an earthwork enclosure complex; of uncertain form and date; occupying a ridge-top position. A subcircular banked enclosure/feature about 22m in diameter is ditched on the south-west; where an additional bank and ditch cuts across it.	NMRW	257415, 303585
Craig yr Aderyn Hillfort	NPRN 302862	Hillfort	Earthwork	Craig yr Deryn - a promontory fort of two periods occupies a summit divided from the main massif by a 'col' 100ft lower. The earlier work consists of a right angle earthwork protecting the S and E sides and fading out where the ground becomes steep enough.	NMRW	264513, 306834
Roman (AD 43 – AD 410)						
Roman coin	Find no. 672	Findspot	Single coin	Found at Borth	Guest and Wells 2007	260900, 289500
Group of Roman coins	Find no. 1083	Findspot	Group	Five fourth century bronze coins found in 'beach material moved by a mechanical excavator' at Tywyn beach in 1988.	Guest and Wells 2007	257600, 300600
Group of Roman coins	Find no. 1033	Findspot	Group	Two Greek/Hellenistic	Guest and	261300, 296200

				coins found in the Aberdovey area.	Wells 2007	
Group of Roman coins	Find no. 1061	Findspot	Group	Four coins found in the packing of a medieval well during clearance works within Castell-y-bere castle in 1951. The coins may have been contained in a mortarium, fragments of which lay near by.	Guest and Wells 2007	266700, 308500
Hoard of Roman coins	Find no. 1077	Findspot	Hoard	An unspecified quantity of coins (five recorded) found on the site of Pennal fort, all known before 1693. 'Besides the coyne there was found there a little gold chayne and a huge brass pan'.	Guest and Wells 2007	270500, 300100
Hoard of Roman coins	Find no. 1062	Findspot	Hoard	Two (of 'some') coins found near Fynon Vawr well 'within a bow shot from the town' sometime before 1695.	Guest and Wells 2007	272600, 317560
Early medieval (AD 410 – AD 1066)						
Croes Faen stone	PRN 1738	Cross	Structure	The stone is a Scheduled Ancient Monument. It measures some 7ft 6in in height and is thicker in the middle than at the base. In 1914 it was noted to be broken at the top and to be leaning slightly. It was also suggested that the broken fragment may have had a cross incised upon it.	HER	259680, 301540
Pascentius stone	PRN 4799	Stone setting	Documentary	Rough pillar stone reported in Tywyn churchyard in the late C18th and now lost. Latin inscription	HER	258820, 300950

				(incomplete) in one line reading vertically upwards: PASCENT[I] C5th to early C6th.		
St. Cadfans Inscribed Stone; Tywyn Church	PRN 4798	Inscribed Stone	Structure	St. Cadfan's stone is a tall; quadrangular pillar stone fractured in two pieces, of C7th - C9th date. At the top of one of the faces is a linear latin cross, measuring some 36cm in height. Both sides of the stone are inscribed with a total of four inscriptions, which are the earliest known examples of written Welsh and the only early medieval inscriptions (other than names) in Old Welsh	HER	258820, 300950
Medieval (AD 1066 – AD 1540)						
Castell Cynfal, Bryn-Y-Castell Castle Mound	NPRN 302770	Motte	Earthwork	Castell Cynfal is an isolated motte identified with a castle destroyed in 1147 and probably established only a short time before. The castle mound is situated above a line of crags on the crest of an isolated ridge on the lower slopes of the mountains on the south side of the Dysynni vale. This is a circular ditched mound, 42m in diameter & 5.0m high. The rock-cut ditch is some 3.0m accross & 1.0m deep. The summit of the mound is dished,	NMRW	261497, 301609

				producing an enclosed area about 12.5-13.5m across defined by a 1.0m high bank.		
Castell y Bere	NPRN 93719	Castle	Ruins	Castell y Bere was established by Llywelyn ab Iorwerth in 1221 on land seized from his son; Gruffudd. It was intended to secure Llywelyn's lordship and protect the southern periphery of his territory.	NMRW	266769, 308547
Llanegryn Parish Church of St Egryn and St Mary	NPRN 43890	Church	Building	St Mary and St Egryn’s Church is a Grade I listed building, and consists of a continuous nave and chancel, separated by a rood screen with a loft above, and is situated within a polygonal churchyard, which was extended eastward in 1883. The first known documentary reference to the church at Llanegryn dates to 1254.	NMRW	259618, 305786
Talybont Castle Mound; Domen Ddreiniog	NPRN 302714	Motte	Earthwor k	Talybont Castle mound is a near circular mound identified as a medieval castle mount. Set at a former bridging point on the right bank of the Dysynni river, the mount may have been associated with a llys or princely court.	NMRW	259690, 303600
Post-medieval (AD 1540 – AD 1901)						

Ynysmaengwyn Estate	NPRN 54223	Countr y House	Building (no longer extant)	Ynysmaengwyn was a fine brick house rebuilt for the Corbett family from 1758, with some earlier 18th-century agricultural buildings being retained, the whole forming an exceptionally fine 'U'-plan group. The house, which had been left to the local authority, was neglected and demolished in 1964. The ballroom wing was demolished as late as 1989. For associated structures at Ynysymaengwyn, see NPRNs 41757, 54224, 54225, 28894, 28895 and 265175.	NMRW	259920, 302300
Dolau-Gwyn	NPRN 28341	Countr yside House	Building	Circa 1620, excellent Jacobean rubblestone, 2 storey and attic, central gabled porch wing. Gabled left wing with dormer, all stepped, interior plaster ceiling, original stair; 1 drawing room dated 1656 bearing armorial bearings above fire, kitchen heraldic device 1628.	NMRW	262320, 303470
Talyllyn Railway	NPRN 34946	Railwa y	Complex	Talyllyn Railway was opened in 1866 on a two foot three inch gauge and it was steam operated from the beginning. The railway runs seven and a quarter miles between Tywyn and Nant Gwernol, near Abergynolwyn.	NMRW	258550, 300450

Modern (AD 1901 – Present)						
Tywyn WW1 Practice Trenches	PRN 58673	Practice trenches	Buried Feature	A system of WW1 practice trenches; seen on 1940s RAF APs.	HER	258006, 300431
Rifle Range, Tywyn	PRN 7287	Firing Range	Structure	Red-brick, concrete and earth shooting butts, target range and shelter that form part of Tywyn camp.	HER	258650, 298780
Prisoner of War Camp, Tywyn	PRN 7879	Prisoner of War Camp	Documentary	Modern	HER	258500, 309000
Pillbox (Type FW3-23), Towyn	NPRN 270340	Pillbox	Building	Remains of pillbox affected by coastal erosion. This consists of two compartments, the seaward half is roofed; and there is a single embrasure in each face, 5m x 4m. (Dutton & Gwyn; 1996)	NMRW	258710, 298460
Pillbox (Type FW3-23), Towyn	NPRN 270341	Pillbox	Building	Remains of pillbox affected by coastal erosion.	NMRW	258860, 298460
Pillbox (Type FW3-23), Towyn	NPRN 270342	Pillbox	Building	Remains of pillbox affected by coastal erosion. Main chamber has open court yard area attached via which entry is obtained.	NMRW	259340, 296800
Pillbox (Type FW3-23), Towyn	NPRN 270343	Pillbox	Building	Remains of pillbox affected by coastal erosion. A pillbox, L-shaped in plan, and with a smaller open compartment to the rear. Iron rings are still visible. (Dutton & Gwyn; 1996)	NMRW	259000, 297760
Pillbox, Towyn	NPRN 270344	Pillbox	Building	Remains of pillbox affected by coastal erosion; almost totally covered by sand. Rectangular plan, 5m by 4m,	NMRW	259150, 297290

				entirely roofed except for access at the NE corner. (Dutton & Gwyn; 1996)		
Pillbox, Towyn	NPRN 270345	Pillbox	Building	Remains of pillbox affected by coastal erosion. Main chamber has entrance to the rear. There are 3 embrasures.	NMRW	2660100, 295700
Pillbox: (TYPE FW3-24), Fairbourne Anti-Invasion Defences	NPRN 270355	Pillbox	Building	Type 24 pillbox, of brick construction, double skinned, with bricked up entrance and embrasures. Ricochet wall has been removed as has front to walls to create opening for present use as a beach shelter. Internal height 2.12m, reinforced concrete roof 0.22m thick. Walls 440mm thick, of twin courses of brick, with 230mm concrete infill. The pillbox has been painted white.	NMRW	261100, 312130
Pillbox: (TYPE FW3-24), Fairbourne Anti-Invasion Defences	NPRN 270356	Pillbox	Building	Type 24 pillbox, of brick construction, double skinned. Internal anti-ricochet wall has been removed, exterior was painted white (probably not originally), but most of the paint now flaked and weathered.	NMRW	261140, 312530
PillboxL Mos Ee Aa Ynyslas	NPRN 408400	Pillbox	Ruin	An area of rubble including slabs of concrete which suggest the potential of another wartime installation (pillbox or observation	NMRW	260550, 292820

				post?) now demolished.		
Pillbox	NPRN 411783	Pillbox	Building	Intact pillbox sited on shifting sands of a dune; with door protected by blast wall at rear.	NMRW	259540, 296350
Pillbox: Northeast Of Morfa Raf Base, Tywyn	NPRN 421484	Pillbox	Documen tary	A unique pillbox type documented here.	NMRW	258336, 301483
Pillbox: YNYSLAS NATURE RESERVE FIRING RANGE	NPRN 506532	Pillbox	Ruin	RAF aerial photographs dating to 1959 show a pillbox in amongst the sand dunes. No remains are visible today except a few pieces of weathered bricks and concrete fragments. The concrete roof lies upside down a few metres away suggesting that the pillbox may have been blown up by the military after the end of the war.	NMRW	260770, 290950
Morfa Towyn Airfield, Morfa Raf Base, Tywyn	NPRN 309967	Airfield	Complex	The airfield opened on 8 September 1940 and consisted of a grass landing area; Nissen and Maycrete huts; and two Besonneau canvas hangars. Two Bellman hangars and two Blister hangars were later added with concrete aprons. Most of the wartime buildings have been demolished and only parts of the concrete aprons remain	NMRW	258000, 301300
Air Crash Site: UNNAMED AIRCRAFT, BORTH SANDS	NPRN 506393	Air Crash Site	Documen tary	Aerial photographs dating to 1 July 1940 (RAF Medenham series) show a twin-	NMRW	260522, 292977

				engined aircraft on the beach. The aircraft is tail closet to the sand dunes (facing towards the water) and two items of wreckage lie to the south between the aircraft and the tideline.		
Air Crash Site: SUPERMARINE SPITFIRE BL518	NPRN 515290	Air Crash Site	Wreck	The site of the impacts is uneven and heather-covered but fragments of wreckage have been reported; including a glycol header tank; a fragment of rudder bar and part of a Merlin engine plumbing. Without serial numbers, it is impossible to identify which remains are that of NPRN 515290, NPRN 515291, NPRN 515292	NMRW	267500, 303500
Air Crash Site: SUPERMARINE SPITFIRE VB BM573	NPRN 515291	Air Crash Site	Wreck	The site of the impacts is uneven and heather-covered but fragments of wreckage have been reported; including a glycol header tank; a fragment of rudder bar and part of a Merlin engine plumbing. Without serial numbers, it is impossible to identify which remains are that of NPRN 515290, NPRN 515291, NPRN 515292	NMRW	267500, 303500
Air Crash Site: SUPERMARINE SPITFIRE R7296	NPRN 515292	Air Crash Site	Wreck	The site of the impacts is uneven and heather-covered but fragments of wreckage have been	NMRW	267500, 303500

				reported; including a glycol header tank; a fragment of rudder bar and part of a Merlin engine plumbing. Without serial numbers; it is impossible to identify which remains are that of NPRN 515290, NPRN 515291, NPRN 515292		
Air Crash Site: VICKERS WELLINGTON IC R1068	NPRN 515293	Air Crash Site	Wreck	Small fragments of wreckage remain; mainly airframe and exploded cartridge cases. The remains of this aircraft are designated as a Protected Place under the Protection of Military Remains Act 1986.	NMRW	268800, 302500
Air Crash Site: VICKERS WELLINGTON X9666	NPRN 515306	Air Crash Site	Documen tary	This Wellington was assigned to 21 OTU and had just completed a bombing exercise near Aberdyfi. It was flying north across the Dyfi estuary and descending through a gap in the cloud. Unfortunately they descended slightly too late approaching the high ground. The aircraft banked sharply to port, but the port wing struck the ground, the fuselage broke in two and the aircraft caught fire. Two of the five crew members survived. Archaeological remains associated with the loss of this aircraft are not	NMRW	263200, 297700

				confirmed as present at this location, but may be in the vicinity.		
Air Crash Site: DE HAVILLAND TIGER MOTH II N6933	NPRN 515320	Air Crash Site	Documen tary	Event and Historical Information: On 7 May 1948, the Tiger Moth took off, but its engine cut out soon after and on approach to a forced landing it collided with the mountain slope which rises from the shore at Llwyngwril. The airman survived, but the aircraft was a write off. The engine was recovered and then the remains were set on fire. Archaeological remains associated with the loss of this aircraft are not confirmed as present at this location, but may be in the vicinity.	NMRW	259522, 310500
Air Crash Site: HAWKER HENLEY III L3297	NPRN 515444	Air Crash Site	Documen tary	Event and Historical Information: On 4 February 1943, the aircraft crashed on the shore 3 miles north of Towyn (?Tywyn). Archaeological remains associated with this loss are not confirmed as present at this location, as the aircraft was reported salvaged.	NMRW	256478, 305856
Air Crash Site: SUPERMARINE SPITFIRE VB BL317	NPRN 515476	Air Crash Site	Documen tary	Event and Historical Information: On 11 May 1942, the aircraft's engine cut out and it belly-landed on the beach	NMRW	255987, 304398

				at Tonfanau, 8 miles south of Barmouth. Archaeological remains associated with the loss of this aircraft are not confirmed as present at this location, but may be in the vicinity.		
Air Crash Site: HAWKER HENLEY I L3276	NPRN 515490	Air Crash Site	Documentary	Event and Historical Information: The pilot was trying to reach airfield with a failing engine. When he found he could not make it, he decided to land at the mouth of the Dysynni but lost control at the last minute. The aircraft lost power and control was lost on approach to a forced landing. The aircraft crashed into a river near Dysynni, Merioneth on 28 February 1945. The pilot's body was recovered and buried at Chester. Archaeological remains associated with the loss of this aircraft are not confirmed as present at this location, but may be in the vicinity	NMRW	258400, 302900
Air Crash Site: HAWKER HENLEY I L3386	NPRN 515491	Air Crash Site	Documentary	Event and Historical Information: The aircraft's engine lost power and it belly-landed 2 miles east-0northeast of Ynyslas on 4 January 1944. Archaeological remains associated	NMRW	264910, 295379

				with the loss of this aircraft are not confirmed as present at this location, but may be in the vicinity.		
Air Crash Site: MILES MARTINET I MS528	NPRN 515654	Air Crash Site	Documen tary	Event and Historical Information: The aircraft's engine lost power and bellylanded at Towyn on 17 June 1949. Archaeological remains associated with the loss of this aircraft are not confirmed as present at this location, but may be in the vicinity.	NMRW	258000, 301500

***Table Ap1.2**: Databases of archaeological sites and features provided by the Welsh heritage agencies, and the new database of compiled information*

Name	Source	Format	Information within it	Fields	Number of entries
NMRW_ RCAHMW	NMRW	Microsoft Access Database	Information on the sites recorded by the National Monuments Record of Wales in the study area	NPRN, Name, Broadclass, Type, Period, Form, Entry Date, Last Updated, KMSquare, X, Y, Community, Council, Old County, Long Text (description), URL	1625
GATHER 783_ Core	HER	Microsoft Excel Worksheet	Information on the sites recorded in the Historic Environment Record for the part of the study area located in Gwynedd	PRN, Site Name, Summary, Description, URL, Form, Period, Type, Broadclass, Condition, Evidence, Status Grade, Status Ref, Unitary Authority, Community, NGR, Map Sheet, Easting, Northing,	1074
HER_DAT	HER	Microsoft Excel Worksheet	Information on the sites recorded in the Historic Environment Record for the part of the study area located in Dyfed	PRN, NGR, Easting, Northing, Community. (information on the Name, Type, Period, Condition, Status, Evidence and Description were provided in an accompanying Gazeteer)	1076
New Database	**HER and NMRW**	**Microsoft Access Database**	**Compiled information from the three databases provided**	**ID, PRN/NPRN, Source (HER/NMRW), Name, Type, Form, Period, Council, Community, X-Coordinate, Y-Coordinate, Elevation Description**	**3271 (1529 following processing**

Table Ap1.3: *Changes made to the labelling system used in the new database to facilitate searches*

Original categories (FORM)	New category (FORM)
Buried Vessel Structure Wreck	Wreck
Fieldname Place name Placename Placename Evidence	Placename Evidence
Finds Find Find only	Finds
Ruined Building Building - Ruined	Building - Ruined
Ruin Ruins	Ruins
Sub-Surface Deposit Buried Features	Buried Features
Original Categories (TYPE)	**New category (TYPE)**
Shelter,Sheep Fold Building, Sheep Fold Sheepfold	Sheep Fold
Agricultural Building; Farmhouse Farmhouse Farmhouse	Farmhouse
Agricultural Building Farm Building	Farm Building
Farmstead Dwelling;Farmstead Dwelling, Farmstead	Farmstead
Finds Findspot	Findspot
Bank and Ditch Bank (earthwork); Ditch	Bank (earthwork); Ditch
Settlement Town Village Settlement, Town Settlement, Village	Settlement
Pillbox Pill Box Pillbox (TYPE FW3/23) Pillbox (TYPE FW3/24)	Pillbox
Spoil Tip Spoil Heap	Spoil Heap
Cow House Cow Shed Cowshed	Cow shed
Incised Stone	Inscribed Stone

Cross Incised Stone Inscribed Stone	
Deserted Settlement Deserted Rural Settlement	Deserted Settlement
Flood Defence Flood Defences	Flood Defences
Defended Enclosure; Hillfort Hillfort	Hillfort
Defended Enclosure; Fort Fort	Fort
School House School	School
Original Categories (PERIOD)	**New Category (PERIOD)**
Bronze Age,Medieval Bronze Age;medieval	Bronze Age, Medieval
Bronze Age;unknown Unknown;Bronze Age Unknown,Bronze Age	Bronze Age
Multiperiod MULTI-PERIOD	Multi-period
Medieval,Post-Medieval Medieval;Post-Medieval Post Medieval,Medieval	Medieval, Post-Medieval
Post Medieval Post-Medieval	Post-Medieval
Post-Medieval,Modern Post-Medieval/Modern Post-Medieval;Modern	Post-Medieval, Modern
20th Century 21st Century Modern Unknown;Modern	Modern
Prehistoric Mesolithic,Neolithic,Bronze Age	Prehistoric

Table Ap1.4: *Results of archive research in The National Archives*

Record no.	Reference no.	Date	Description	Map included?
1	MAF 77/258	02/12/1957	**Dysynni Valley Drainage District** This is an order from the Gwynedd River Board to alter the boundaries of the Dysynni Valley Drainage District and the 'Towyn' Drainage District, however it does not include a map to indicate where the original boundaries are, or where the proposed new boundaries would be.	no
Gwynedd River Board, 1957. *Dysynni Valley Drainage District* [document]. MAF – Agriculture, Fisheries and Food Departments. MAF 77/258. Kew: The National Archives				
2	MAF 77/257	14/07/1931 – 19/05/1950	**Dysynni Catchment Area: showing watershed and main river** Map that outlines the Dysynni Catchment Area, and indicates which channels and watercourses are part of the 'main river', and therefore under the jurisdiction of the local authority rather than the landowner (according to the Agriculture Act 1937 and the Land Drainage Act 1930). Another watercourse was included in the 'main river' on 28th September 1944, and a further 4 watercourses were included under the title of 'main river' on 19th May 1950.	Yes
Ministry of Agriculture and Fisheries, 1950. *Dysynni Catchment Area: showing watershed and main river* [map]. MAF – Agriculture, Fisheries and Food Departments. MAF 77/257. Kew: The National Archives				
3	MAF 112/100	1942-1952	**Dysynni Catchment Board land drainage proposals** This item was a collection of minutes from the meetings of the Dysynni Catchment Board and the Merioneth Rivers Catchment Board. Several letters within this item describe areas of land in the Peniarth estate being subject to flooding to the point that farming economy and activity was seriously affected. They mention the appointment of an engineer to improve the drainage scheme. There is also correspondence from 1948 between Colonel J Williams Wynne of Peniarth and Sgd C. H. Wake of the Dysynni Catchment Board, stating that the financial deficit of the Peniarth Estate was too great to maintain the drainage ditches on the land.	no

Merioneth Rivers Catchment Board, 1952. *Dysynni Catchment Board land drainage proposals* [meeting minutes]. MAF – Agriculture, Fisheries and Food Departments. MAF 112/100. Kew: The National Archives				
4	MAF 136/36	1942-1950	**River Dysynni Catchment Board variation of map of main river** This item includes a letter to the River Dysynni Catchment Board, dated to 1942, which stated that the Air Ministry was unhappy with the drainage conditions in some areas of the valley. Under the Agriculture Act 1937, grant-aid for land drainage could only cover up to 50% of the cost. Therefore, the writer of this letter suggested that the watercourses in question should be 'mained', i.e. included within the jurisdiction of the 'main river', then the cost of drainage would be funded as part of the main river, as under Section 55 of the Land Drainage Act 1930. – Therefore, the watercourses in these maps and in the map in item MAF 77/257 being included as pater of the main river was for the purpose of easing the financial burden of management and drainage from the landowners onto the local authority.	3 maps: The two maps from 1944, on a six-inch scale, are part of the same proposal and have watercourses near Morfa Barracks highlighted in blue, which are also proposed to become part of the 'main river'. A single map, Titled "River Dysynni Catchment Board – Map Showing Proposed Additions to "Main River", made by J. Olav Williams, Engineer to the Board Dros-y-Mor, Harlech, 7 Jan 1950, has 6 watercourses marked in green that were proposed to become part of the "Main River".

River Dysynni Catchment Board, 1950. *River Dysynni Catchment Board variation of map of main river* [file]. MAF – Agriculture, Fisheries and Food Departments. MAF 136/36. Kew: The National Archives				
5	RAIL 1033/389	1887	**O.S. Map (1 inch to 880 feet) of Aberdovey and rural areas of Ffridd Cerfn-isaf** This record only includes a map of Aberdovey and surrounding land and coastline. Superimposed on the map in red are the limits of the Aberdyfi Piermaster on the River Dyfi.	Yes
Cambrian Railway's Engineers Office, 1887. *O.S. Map (1 inch to 880 feet) of Aberdovey and rural areas of Ffridd Cerfn-isaf* [map]. RAIL. 1033/389. Kew: The National Archives				
6	MT 19/4, Folder 11	1835-1862	**Aberdyfi Harbour** This item contains letters and a map relating to Aberdyfi Harbour and the River Dysynni. Two notes (12/01/1860 and 14/01/1860) discusses the issue of ships depositing ballast and limestone in Aberdyfi Harbour, which can cause a hazard to other ships, cause additional sand to accumulate and reduce the depth of the harbor. Other letters (16/11/1862 and 05/12/1862) from the Aberystwyth & Welsh Coast Railway Company to the Admiralty discusses the plans of a proposed bridge over the River Dysynni, and that the Admiralty want the bridge to have a wide span so that, should the sand bar that currently covers most of the entrance to the river be scoured away, the bridge, would not impede the access of small vessels. At the time this was written, they say the bar had been impassable for 40 years	Yes, a 1835 map of Aberdyfi harbor with all buoys and passable water channels marked on.
Aberdyfi Harbour, c.1836-1862. [letters]. Ministries of Transport, MT 19/4. Kew: The National Archives				
7	BT 356/77	1890-1920	**Dysynni Valley Drainage District, Merionethshire** The only item in this record is a map indicating the boundaries of the Dysynni Valley Drainage District. The areas covered are only the very low-lying areas from the coast, up the river valley, to just past Craig-yr-Aderyn. The boundaries follow the 5m contour line up to Craig-yr Aderyn, and then extend to the end of the 10m contour line around 1km further up the valley.	Yes, one map depicting the boundaries of the Dysynni Valley Drainage District.

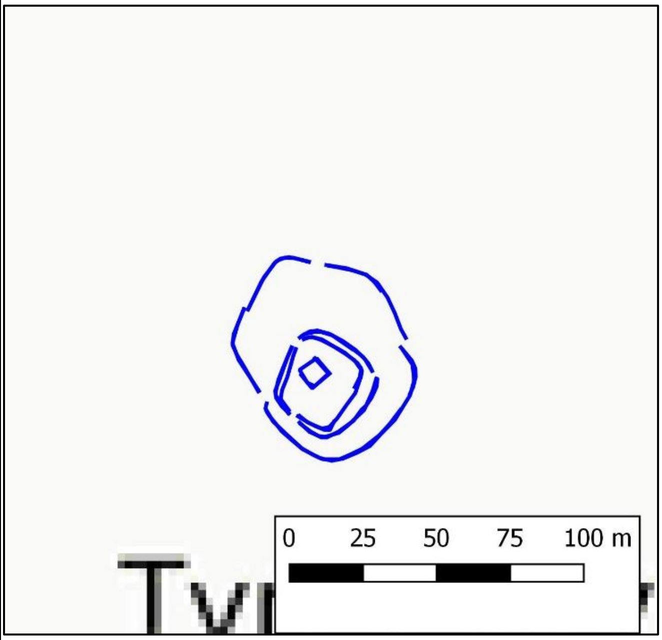
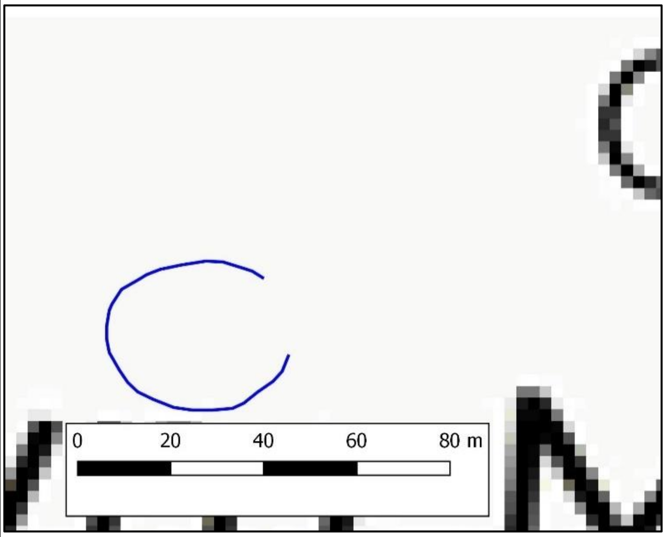
Dysynni Valley Drainage District, 1920. [map]. Board of Trade, BT 356/77. Kew: The National Archives				
8	CRES 49/4582	1931-1949	**Land Drainage Act 1930: Orders relating to Borth Drainage District and catchment areas of rivers Prysor, Dysynni, Tawe and Caermarthenshire rivers** This item includes letters between the Ministry of Agriculture and Fisheries, and the River Dysynni Catchment Board. The Catchment Board made an application to include some watercourses near Gwalia Road, which flow into the Dysynni, as part of the definition of the 'main river'. It says that the change in the extent of the watercourses classed as part of the 'main river' was for the purpose of Part II of the Land Drainage Act 1930. This relates to the lines added to the map in source MAF 77/257	No
Ministry of Agriculture and Fisheries, 1949. *Land Drainage Act 1930: Orders relating to Borth Drainage District and catchment areas of rivers Prysor, Dysynni, Tawe and Caermarthenshire rivers* [letters]. Crown Estate, CRES 49/4582. Kew: The National Archives				

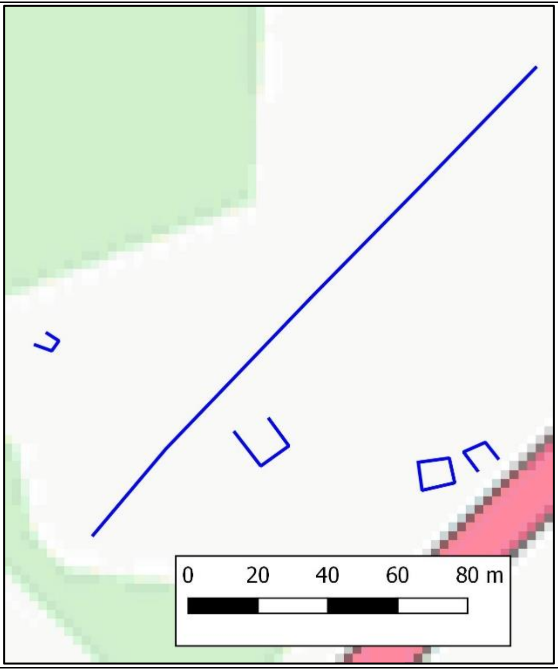
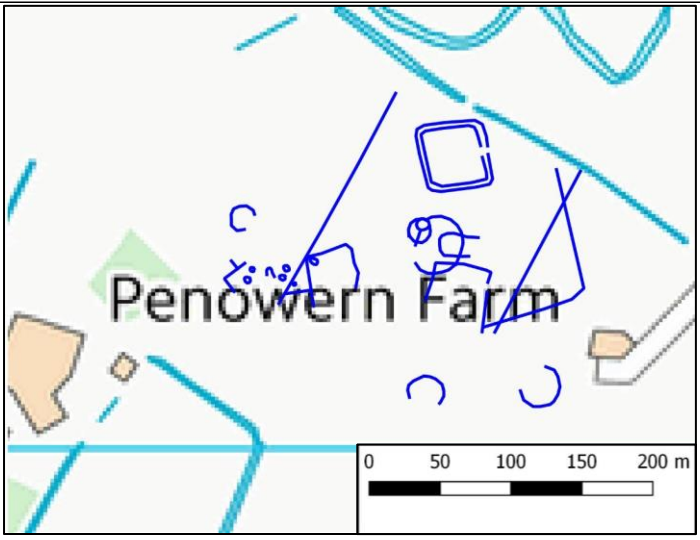
***Table Ap1.5**: Results of archive research in The National Library of Wales*

Record no.	Reference no.	Name	Date	Description
9	MS ESTATE MAPS Peniarth Map 21 139/6/6	Lands at Aber Dysynni, Towyn Parish	May 1833	A hand-drawn map, which is a copy of the plan on the grant from the Crown dated 24th May 1833. It indicates the lands belonging to The Reverend William Domville, to the south of Broadwater. The map does not recognize Broadwater as an estuary or a lagoon or part of the river, but instead just indicates a terrestrial area of 'Mudlands overflown by each tide'. The extended sand bar in front of the mouth of the Dysynni that exists today does not seem to be present on this map. It also indicates that the sluice running south from the point that the River Dysynni meets Broadwater already existed in the early 19th century.
Lands at Aber Dysynni, 1833. [map] MS ESTATE MAPS Peniarth Map 21 139/6/6. Aberystwyth: The National Library of Wales				
10	MAP Accession:MAP 7719	Aberdyfi harbor cartographic material	ca. 1880	Map of Aberdyfi harbour, some nearby buildings in block-plan and the route of the railway line (in red ink) between the harbour and Penhelyg, one mile to the east along the Dyfi River estuary.
Aberdyfi harbor cartographic material, c.1880. [map]. MAP Accession, MAP 7719. Aberystwyth: The National Library of Wales				
11	MAP RAILWAY PLANS BRN 1827 141/5/6	Aberystwith and Welsh Coast Railway: crossing of Aberdovey Estuary	1865	This item includes three figures: a) A plan of the Dyfi estuary including the trainline, a proposed second trainline crossing the Dyfi estuary at Pennelig/Penhelyg, and the line of a railway along the sand of the south side of the estuary from Ynyslas, connecting to a ferry line across the river to Aberdovey. b) A cross-section of the Dyfi estuary and northern approach to the proposed viaduct

				c) A cross-section of the estuary and northern approach with differing lengths of viaduct and embankment.
Aberyswith and Welsh Coast Railway, 1865. *Crossing of Aberdovey estuary* [cartographic material]. MAP RAILWAY PLANS BRN 1827 141/5/6. Aberystwyth: The National Library of Wales				
12	MAP MS.MAPS Vol. 93 028/7/10	Lands at Towyn in the parish of Towyn, in the country of Merioneth: belonging to John Edwards Esqr (Map 5)	ca. 1820	Plan showing field with field numbers and adjoining landowners and properties. Table included shows field names, acreages, land use and rent charges associated with each field. The map is too sparse and lacking in detail to be georeferenced onto a modern map.
Lands at Towyn, c.1820. *Lands at Towyn in the parish of Towyn, in the country of Merioneth: belonging to John Edwards Esqr* [maps]. MAP MS.MAPS Vol. 93 028/7/10. Aberystwyth: The National Library of Wales				
13	MAP (ATLAS Ab 1043)	Aberdovey in Welch Aber Dyfi in Meirioneth Shire [cartographic material] / by Lewis Morris; Nath'l. Hill Sc.	1748	One of 24 map plates, all drawn by Lewis Morris of sections of the Welsh Coastline. This one is Plate 16, a hand-drawn map of the Dyfi estuary, available to view online.
Morris, L., 1743. *Aberdovey in Welch Aber Dyfi in Meirioneth Shire* [map]. MAP ATLAS Ab 1043. Aberystwyth: The National Library of Wales				

***Table Ap1.6**: Description of cropmark features discovered prior to this research, for instance by RCAHMW. Vectorised cropmark features are displayed in blue. Crown copyright and database right 2019 Ordnance Survey 100025252*

Feature Number	Vectorised Features	Description
A		Defended enclosure measuring 52m x 40m, 1km south west of Castell y Bere. It comprises an outer enclosure with several entrances. In the southern end of the enclosure is a smaller double-ringed enclosure around 25m square, also including several gateways. A small square structure lies at the centre, 7m square. RCAHMW date this structure to the Iron Age or Roman period. NPRN: 423305 Source: Driver 2018; BDC_05_11
B		A single circular enclosure identified by Glyn Davies and Jonathan Brentnall, c.35m in diameter, located in Cwm Maethlon or Happy Valley. It is 280m northeast of a prehistoric tumulus or round barrow (NPRN 303602). The break in its eastern wall may be due to its intersection with a field boundary (not visualised on this map). NPRN: 424021 Source: Ryder 2019; BDC_03_01_02

C		Several cropmark features around 350m north-northeast of the findspot of the medieval Croes Faen cross (NPRN 302713). The long linear feature may be a modern feature such as a pipeline. The four square features, measuring 5-10m square, are thought to be early medieval square barrows. NPRN: 310263 Source: RCAHMW 2012a; AP_2006_2903
D		Cropmark complex identified by RCAHMW 300m west of Bryncrug. Several of the identified features overlap; the circular enclosure in the centre, c.30m in diameter, is intersected by a smaller circular enclosure, a curvilinear feature, and a rectilinear feature. This rectilinear feature may be associated with the 45m square, double-ditched enclosure to the north of the circular enclosure. The intersection of features and varying morphology indicates that these features resulted from different periods of occupation during the prehistoric and roman period. The linear features that cut across the complex may be the remains of later field boundaries. NPRN: 420685 Source: Driver 2014; AP_2006_2909

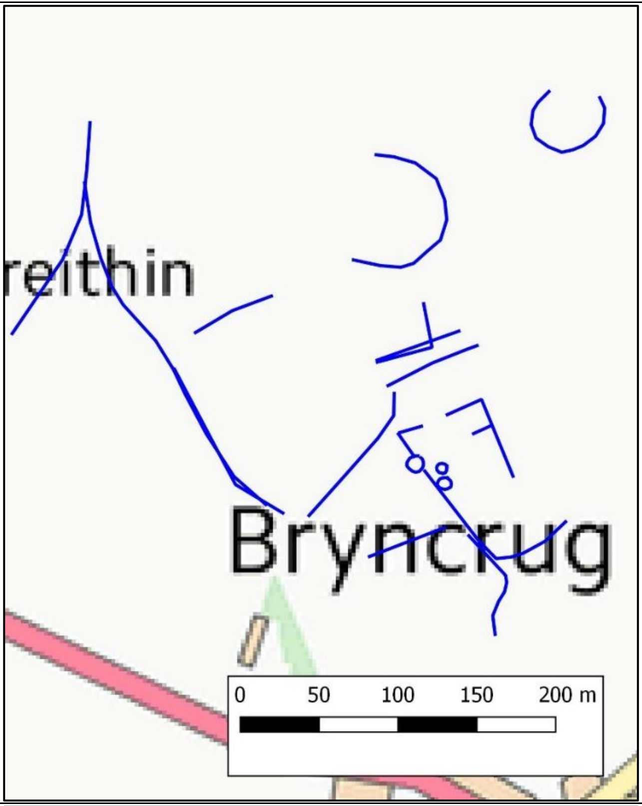
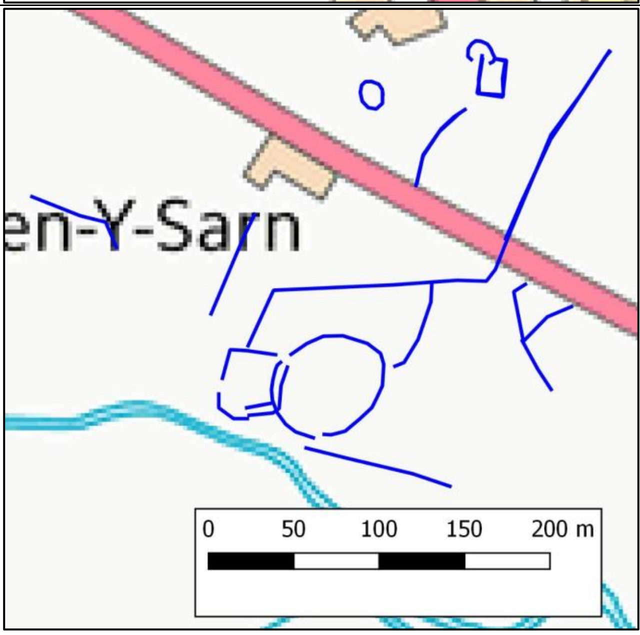
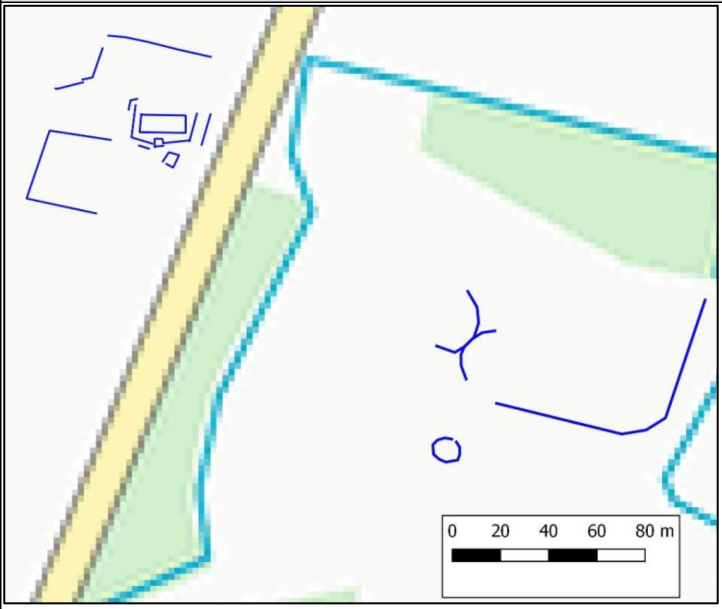
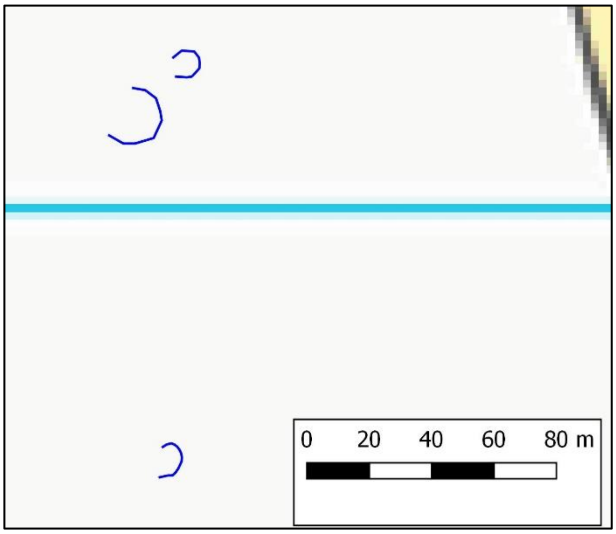
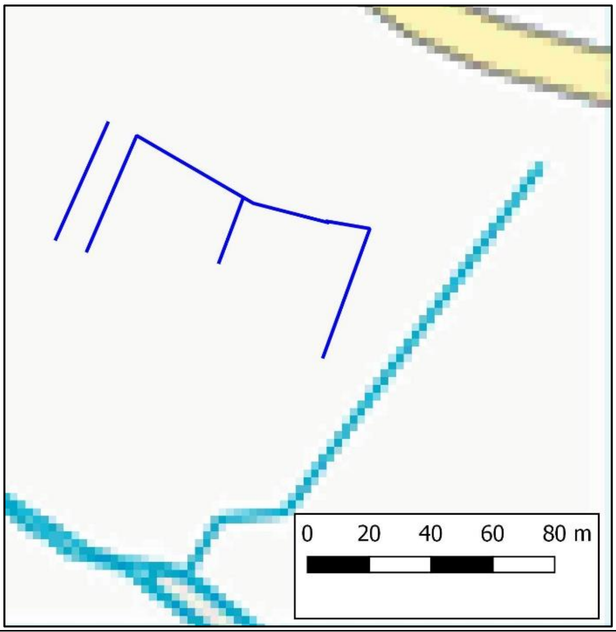
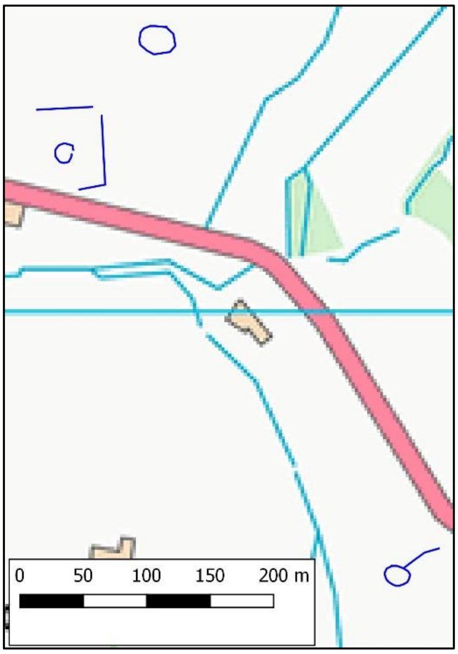
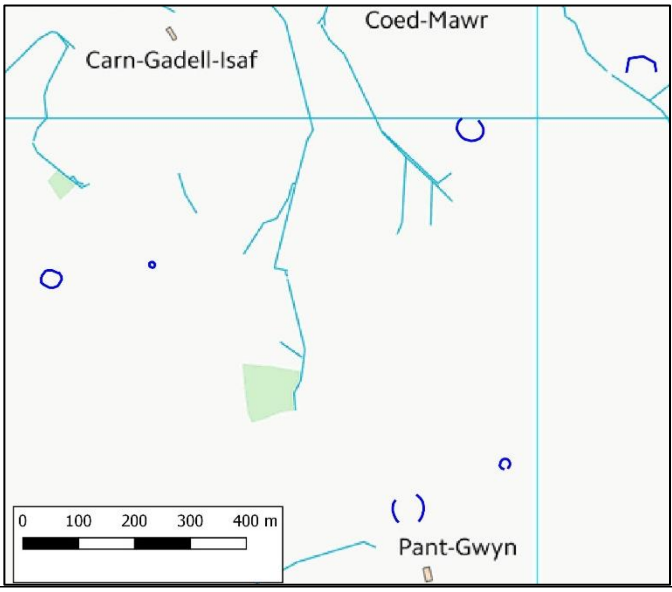
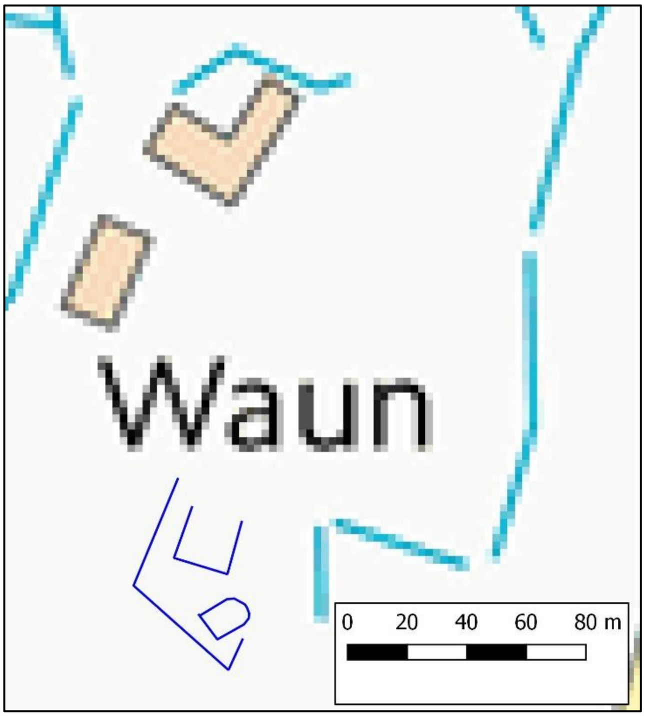
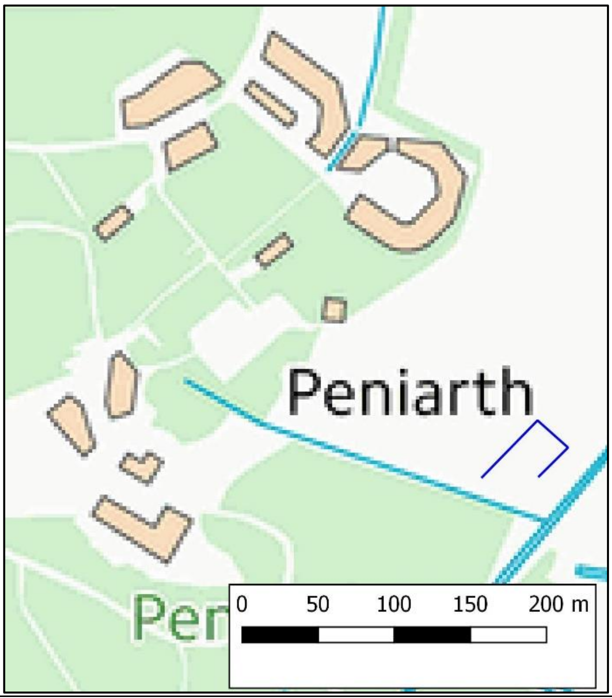
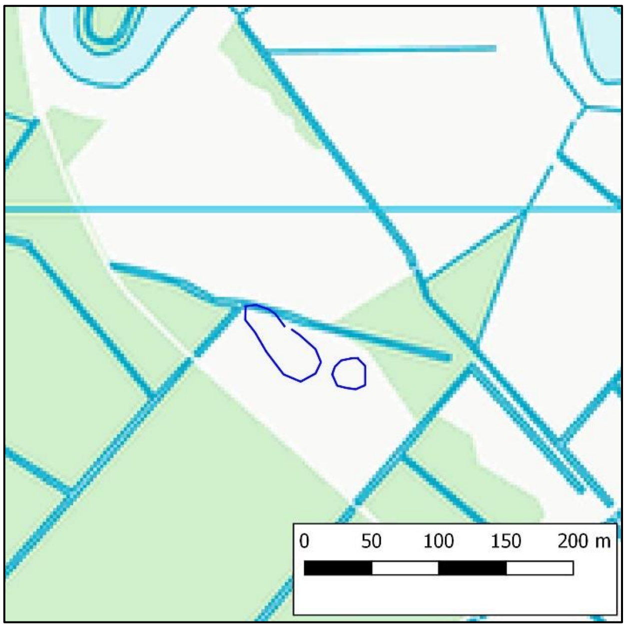
E		There is a complex array of cropmark features 200m northeast of Bryncrug, extending several hundred metres in each direction. The complex includes linear and rectilinear features, and circular enclosures of various sizes. The most prominent feature is the largest circular enclosure, 75m in diameter. The linear feature running towards the south-west connects with the linear feature in the northeast corner of the map in feature F NPRN: 406318 Source: Wiles 2007c; CUCAP_BUB_61, CUCAP_BUB_63_7775
F		Cropmark complex identified 450m northwest of Bryncrug, including a large circular enclosure 62m in diameter, intersected by a smaller subrectangular enclosure. RCAHMW estimate that this dates to the later prehistoric period. It is connected with a linear feature that extends 200m northwards, towards the features discussed in feature E. This could represent a trackway, boundary wall, or field boundary. Smaller circular and rectangular features to the north may be associated with the existing farm building indicated on the map. NPRN: 275900 Source: Wiles 2007a; CUCAP_BUB_64

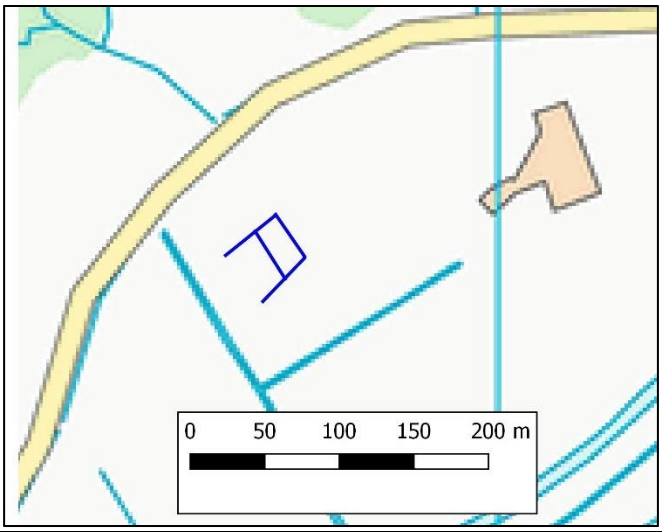
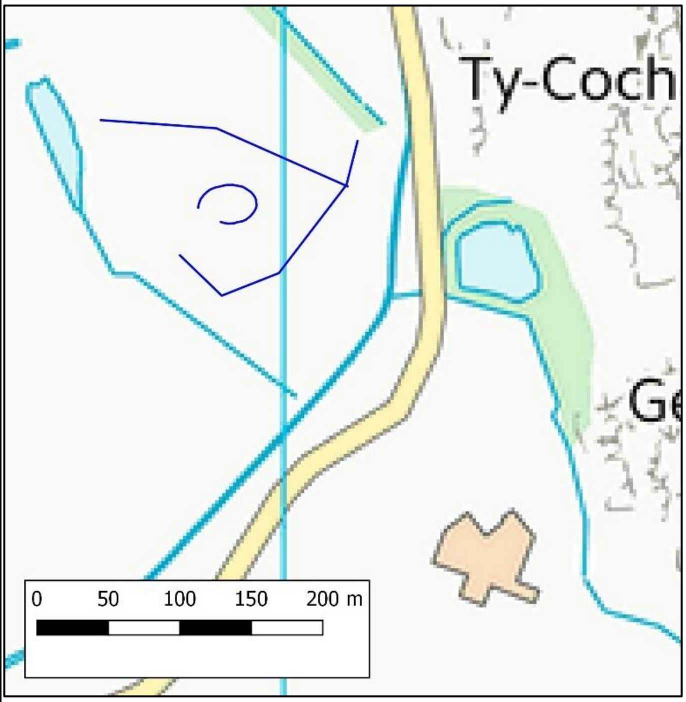
***Table Ap1.7**: Description of cropmark and geophysical features discovered during this research. Vectorised cropmark features are displayed in blue, and geophysical survey features are displayed in pink. Grey polygons indicate the location of geophysical surveys. Crown copyright and database right 2019 Ordnance Survey 100025252*

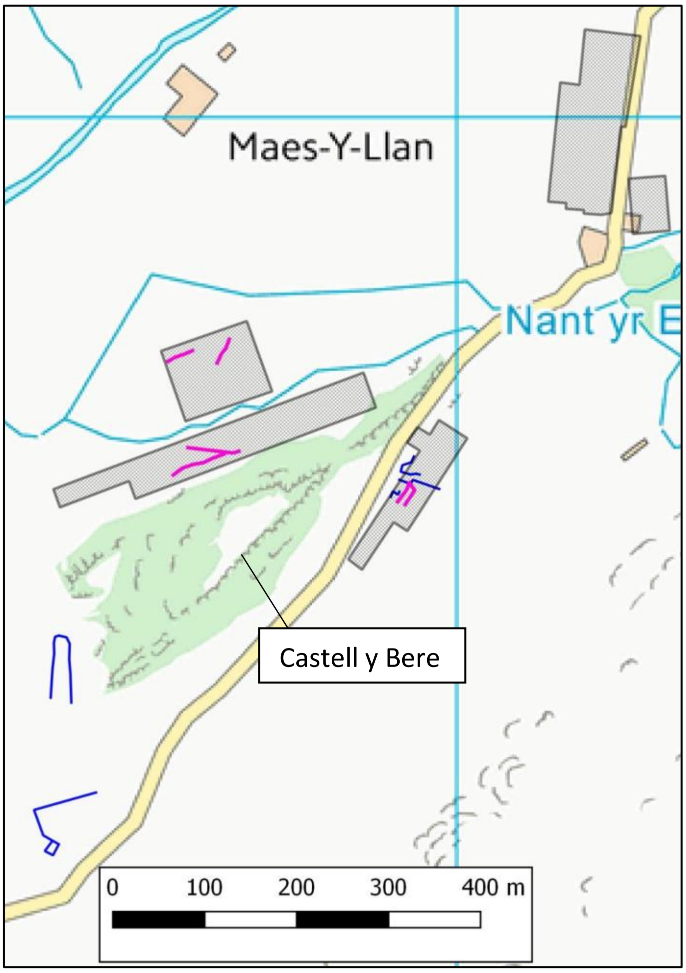
Feature Number	Vectorised Features	Description
1		Cropmark features c.600m north of Tonfanau station, either side of a road. The group of curvilinear and circular features to the east span 90m altogether. They may be related to the former military training camp that was situated here between 1938 and the 1980s (PRN 7281), although no extant above-ground features are visible in this area. The group of rectilinear and rectangular features to the west, each spanning around 30-40m, may also be related to the former military camp, although they could also be the remains of post-medieval or modern agricultural buildings. Source: Oblique_2003_5047_58 and Oblique_2003_5047_57
2		Three circular features identified 200m north of Tonfanau station, 8-18m in diameter. These may be related to the nearby modern military activity (see feature number 1) Source: Oblique_2003_5047_59

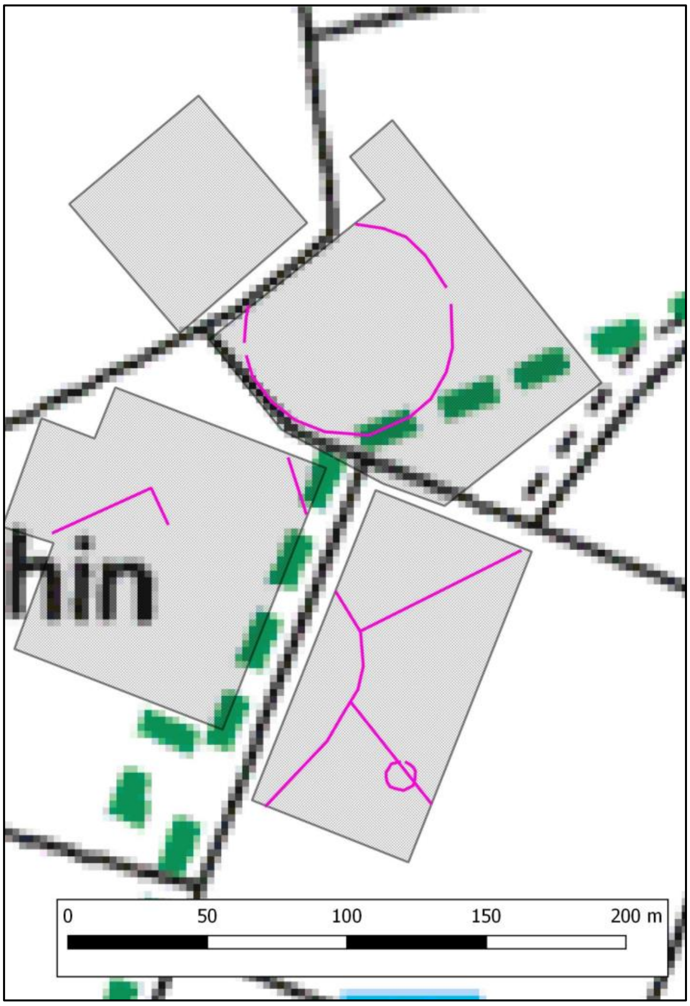
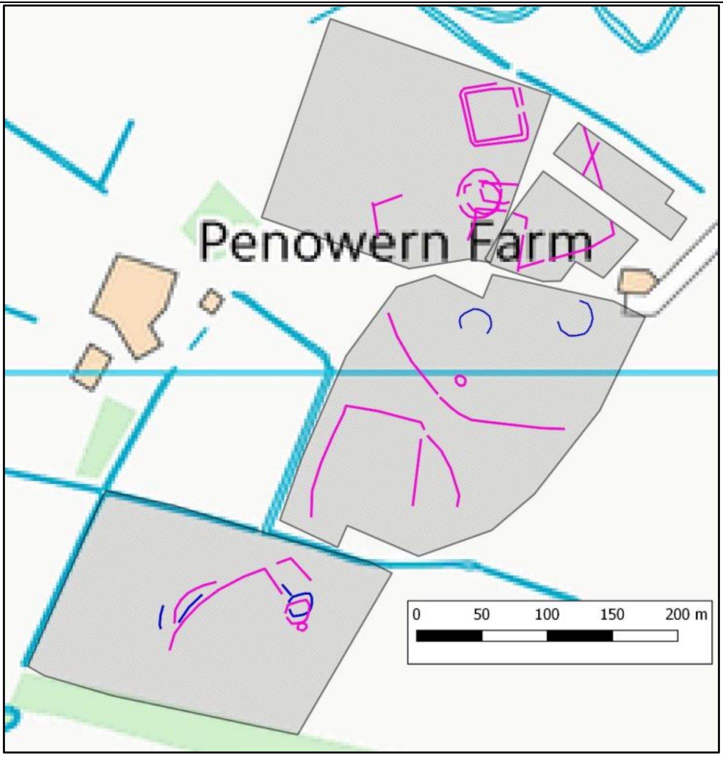
3		Rectilinear cropmark c.90m in length located 300m north east of Dysynni Bridge. Morphology indicates a two-roomed building with an additional external wall. Possibly the remains of the external walls of a post-medieval farmstead or agricultural buildings. Source: OS_71_323_888
4		Three circular cropmark features near Rhoslefain, 15-25m in diameter, with associated linear features. The most westerly feature has an east-facing entrance, and is surrounded by rectilinear features, may indicate a walled enclosure with a circular structure inside. Source: OS_71_323_728

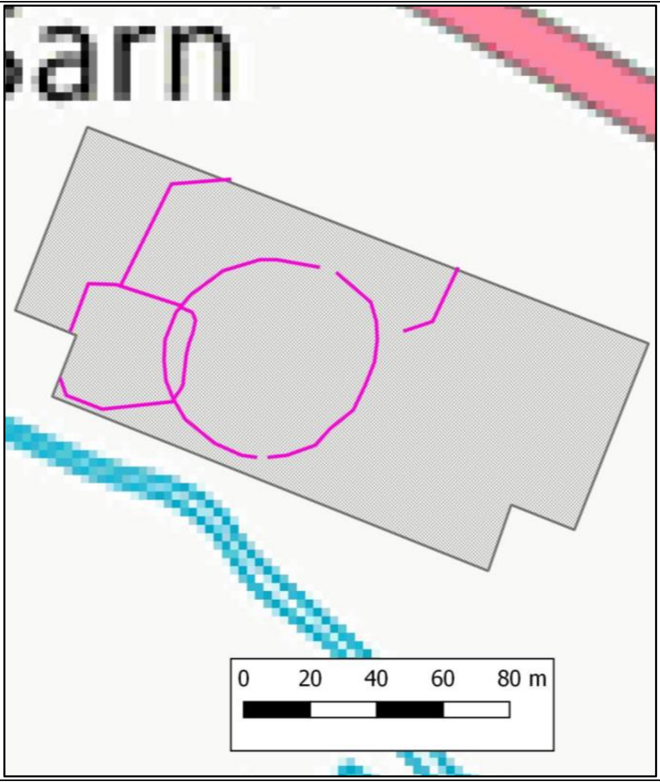
5		Six circular features near Llangelynin, spread across land above 100m aOD that slopes down towards the coast in the west. The features measure between 10m and 55m in diameter. Prehistoric features such as a burnt mound (PRN 60834) and the remains of a stone hut circle (PRN 4089) are located 80m and 500m north of this group of features, respectively. This indicates the presence of prehistoric activity in the immediate vicinity, suggesting that these features could be prehistoric in date. Source: OS_71_323_638 and OS_71_323_639
6		Rectilinear and rectangular cropmark features 900m north of Llanegryn. Proximity to extant agricultural and domestic buildings (also featured in image) suggests that these features may have been post-medieval farmstead buildings c.15m in length, with an external surrounding wall Source: OS_71_323_724

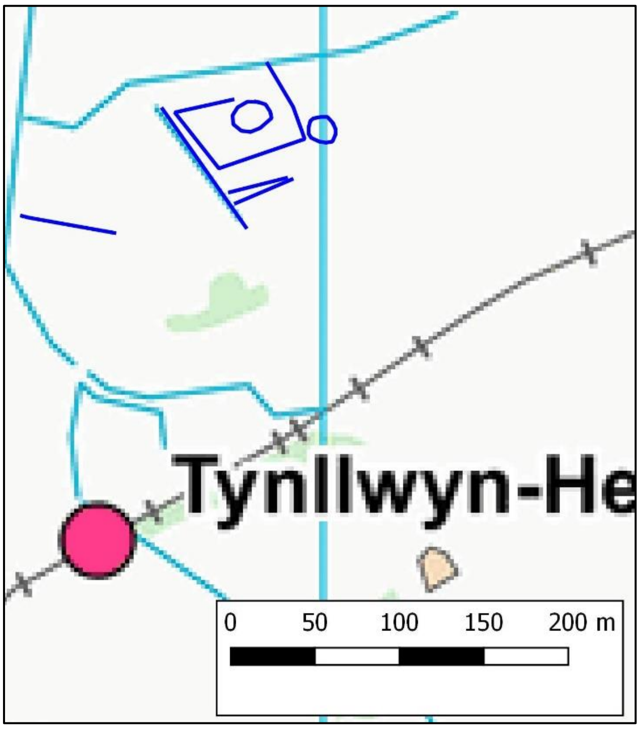
7		Single rectilinear cropmark feature, c.45m in length, identified 200m from the main buildings of the Peniarth estate. Peniath estate was established over 600 years ago, so the proximity of this cropmark to Peniarth suggests that it may be a feature associated with the earlier estate buildings Source: Oblique_935065_02
8		Circular and irregular oval cropmark features located near a post-medieval or modern drainage ditch. The oval feature is c.65m in length, and the circular feature is 23m in diameter. These features are just over 1km north of the prehistoric cropmark complex identified at Bryncrug (see Table Ap1.6 feature E), and so may date to the same period. However, they may also be the result of the construction of the drainage ditches nearby Source: RAF_1468_6011

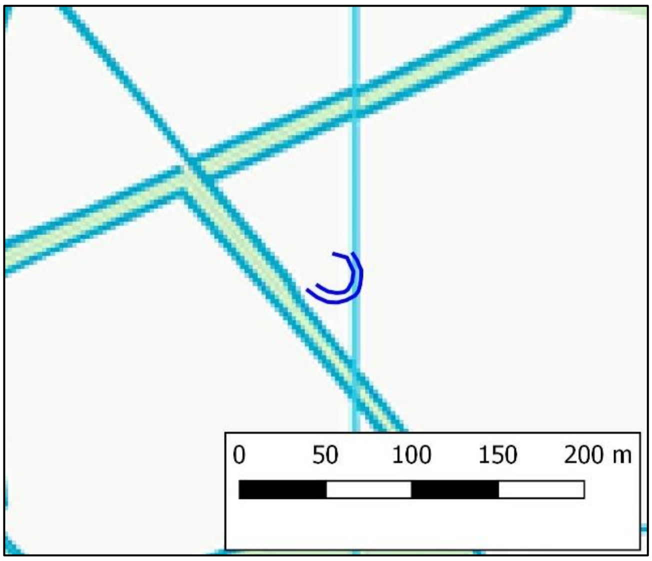
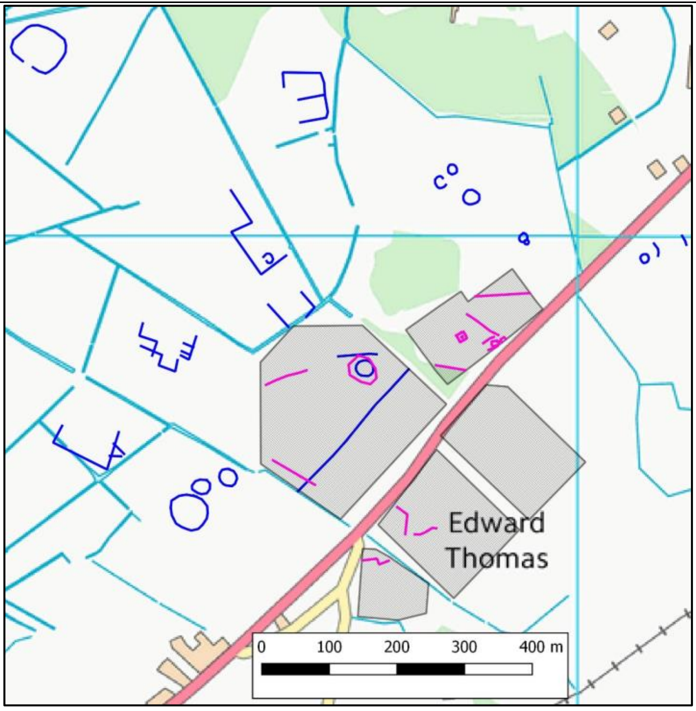
9		Cropmark feature identified 120m west of Glanywern farm buildings. The rectilinear feature measures 40m by 48m, and has a dividing wall. The shape, size and proximity to an existing farm suggests that this feature may be the remains of a post-medieval agricultural structure Source: RAF_1468_3012
10		This cropmark feature includes a circular enclosure c.30m in diameter with an opening to the south-west, and a surrounding rectilinear feature. It is located c.60m from the foot of Craig yr Aderyn, a promontory upon which there is an Iron Age hillfort (NPRN 302862), a Bronze Age cairn (NPRN 407753), and a post-medieval quarry (PRN 20561). This feature may therefore relate in period to one of the nearby known remains Source: Slide_89_CS_59

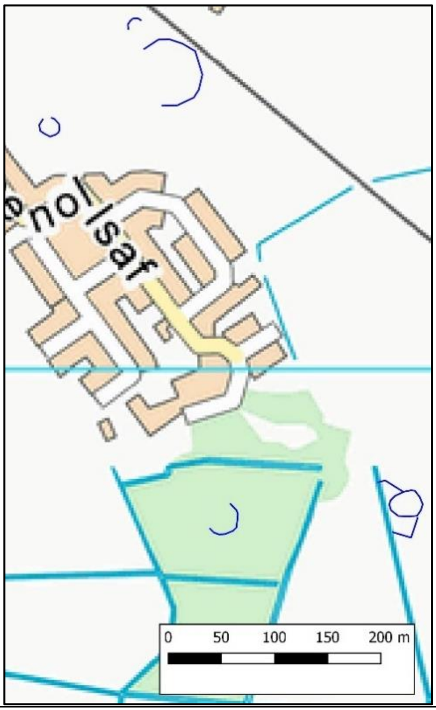
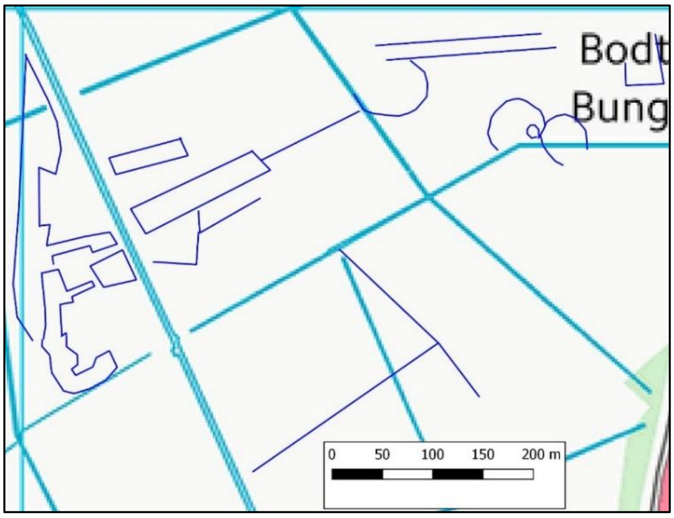
11		**Aerial photographs** Several rectilinear and curvilinear cropmark features were identified around Castell y Bere. These may be related to a medieval burgh reported to have been built near Castell y Bere (see Morris 1901). Source: Oblique_895008_17 and Oblique_995099 **Geophysical surveys:** Both gradiometry and resistivity surveys were undertaken to the north of Castell y Bere (see Figure 5.2D), but only a few short linear features were revealed.

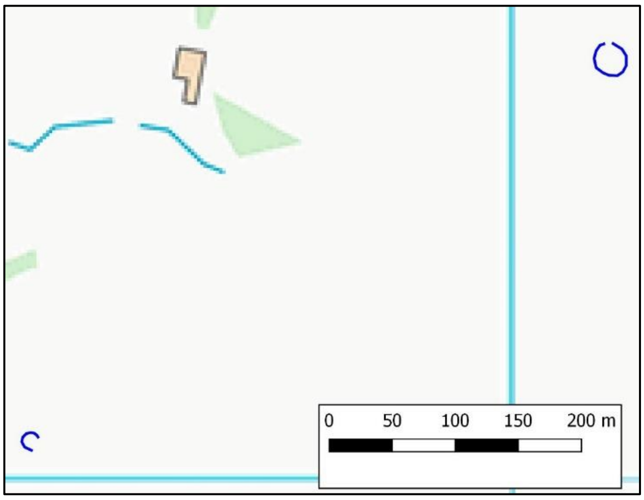
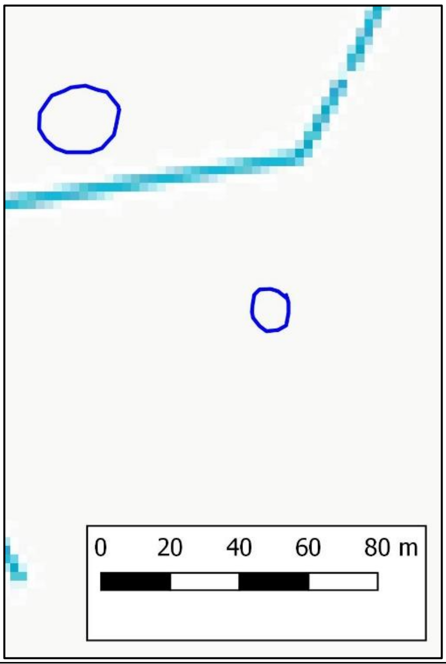
12		**Geophysical surveys** Magntometry undertaken at Gwyddelfynydd confirmed the presence of some of the cropmarks identified by RCAHMW (see Table Ap1.6 feature E). In particular, the large circular enclosure is around 75m in diameter, and displays at least two entrances. The curvilinear feature, which could represent field boundaries, runs close but does not appear to intersect the circular feature, indicating that they may have been contemporaneous. The smaller circular feature, 10m in diameter, may predate the possible field boundary, as the former is intersected by the latter. The other cropmarks in Table Ap1.6 feature E were not within the extent of the geophysical survey.
13		**Aerial Photographs** A circular cropmark 20m in diameter, with associated linear features was identified 300m south of the complex , and two circular features were identified in close proximity to the cropmark complex identified by RCAHMW (see Table 1.6 feature D). **Geophysical Survey** Geophysical surveys confirmed the presence of some of the cropmarks identified by RCAHMW west of Bryncrug, such as the intersecting circular, rectilinear and curvilinear features, and th double-ditched enclosure (see Table 1.6 feature D), as well as the small circular and associated linear feature identified to the south. In addition, magnetometry undertaken in fields south of the cropmark complex revealed a curvilinear feature with a small

		circular feature, and a possible rectilinear enclosure. These surveys did not reveal the circular cropmark features identified in aerial photographs Sources: AP_2006_2908, AP_2006_2909, AP_2006_2910
14		**Geophysical Survey** Gradiometer surveys confirmed the presence of the large circular enclosure identified northwest of Bryncryg (see Table 1.6 feature F). The circular enclosure has two entrances, to the south and northeast, and is intersected by a subrectangular feature. The associated linear features appear on the geophysical survey, but the size of the surveys did not allow for the full extent of the linear feature to be explored.

15		Three circular features located 200m from the Penowern cropmark complex (see Table Ap1.6 feature D). Each measures 20-30m in diameter. The density of remains in the cropmark complexes nearby indicate that these features may date to the same period of occupation likely prehistoric) Source: RAF_1468_2008
16		This group of features includes two circular enclosures 15-20m in diameter, surrounded by linear and rectilinear features. These are 1.3km southeast from the Gwyddelfynydd cropmark complex (see Table Ap1.6 feature E). One of the linear features lines up with a drainage ditch, and others are perpendicular, so these may be a more modern feature. The circular features and surrounding rectilinear enclosure could be contemporaneous, or the rectilinear structure could post-date the circular features. Source: RAF_1468_2011

17		This is a single cropmark feature consisting of a double-ringed circular enclosure 32m in diameter. This is located 250m northeast of the post-medieval Ynysmaengwyn estate (NPRN 28895), but may also predate this. Source: Oblique_935065_10 (next to Ynysmaengwyn)
18		**Aerial Photographs** Several cropmark features were identified near Croes Faen and in the fields surrounding the square barrow complex identified by the RCAHMW (see Table Ap1.6 feature C). Circular enclosures to the southwest and northeast of the map measure between 12m and 55m in diameter, and a larger curvilinear enclosure in the northwest corner of the map measures 73x62m and has a southwest entrance. The other features are rectangular or rectilinear, and all measure around 55x80m. Some or all of these features may be associated with the square barrow complex or the standing stone discovered at Croes Faen. **Geophysical surveys** Geophysical surveys confirmed the presence of subterranean square barrow features identified as cropmarks by RCAHMW. Further linear features and a circular enclosure 22m in diameter were revealed in geophysical surveys to the southwest of the square barrows. Additional surveys south of the main road only revealed a few small linear features. Source: Oblique_995093_51, Oblique_935065_14, OS_71_323_805, RAF_1468_2007, RAF_1450_3006,

		Oblique_AP_2006_2904
19		Five circular or curvilinear features, with diameters between 20m and 65m, were identified just south of Tywyn, and around 200m east of Penllyn farm. Tywyn was founded during the early medieval period, so these features could be associated with the early settlement here. Source: OS_73_323_734, RAF_1468_4004
20		Cropmark complex extending 700m by 400m including rectangular, rectilinear, and circular features, 1km south of Penllyn farm. This may be associated with the Second World War rifle range (NPRN 525491) 300m to the west, or the documented flour mill 500m to the south (NPRN 421390). Source: RAF_1450_4142

21		Two circular closures 800m southeast from the centre of Tywyn, located on sloping ground. These features are 15m and 25m in diameter, and may be related to the many post-medieval granite and slate quarry features within a few hundred metres (e.g. PRNs 20397; 20398; 20498). Alternatively, they may be associated with the prehistoric flint axe found 180m southwest of the smaller feature (PRN 4928) Source: RAF_1450_3069, RAF_1468_4004
22		Two circular features, 10m and 20m in diameter, 100m from Dysefin farm in the further inland stretches of the Dysynni valley floodplain. These are located only 300m southeast of the findspot of several Bronze Age axes (PRNs 2985; 3908; 3910) and 500m southeast of another likely-prehistoric circular structure in the uplands north of the Dysynni floodplain (PRN 5617), so may date to the prehistoric period. Source: RAF_58_2649_166_F21

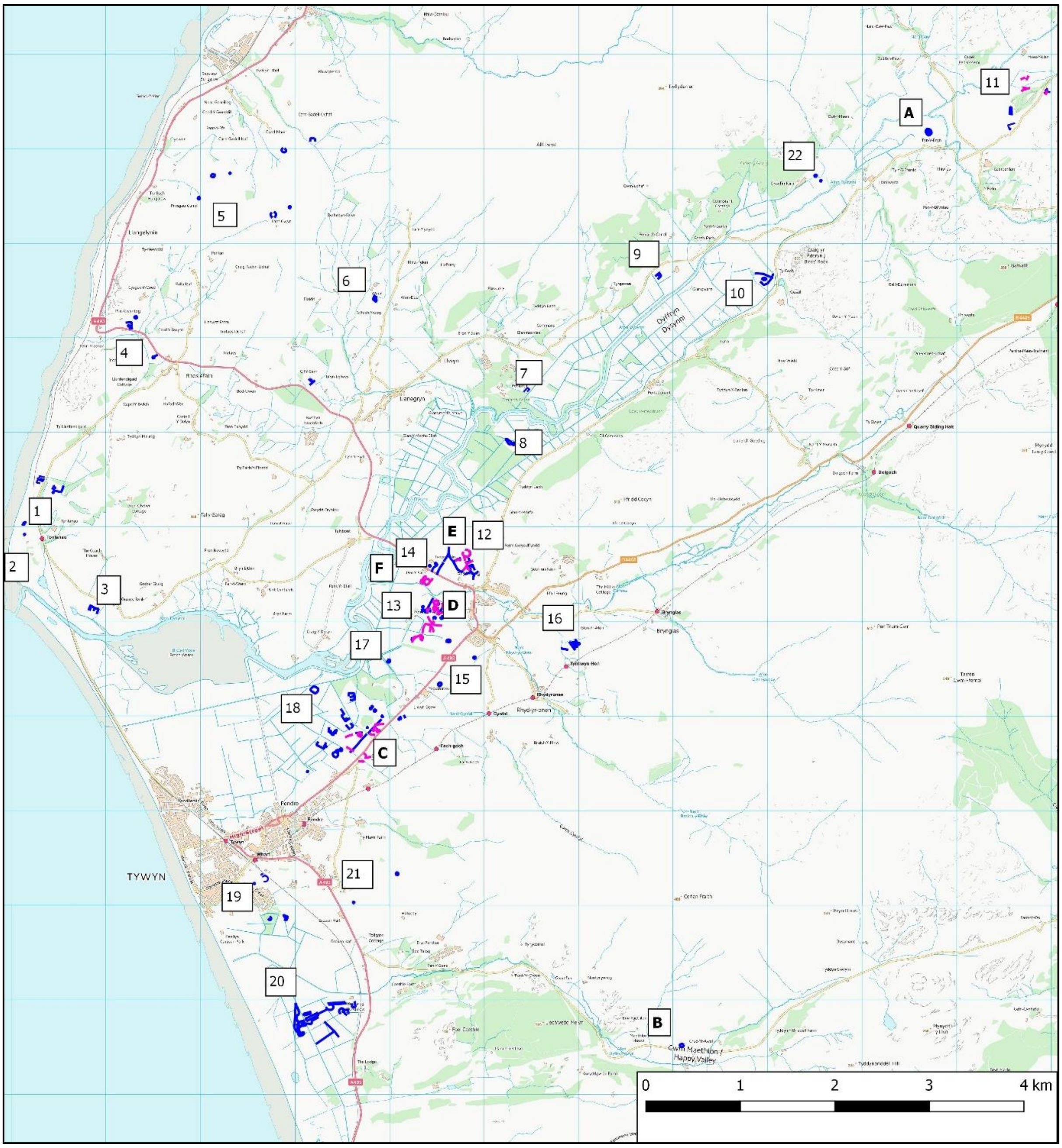


Figure Ap1.1. *Location of the cropmarks (dark blue) and geophysical features (pink) described in Tables Ap1.6 and Ap1.7. Crown copyright and database right 2019 Ordnance Survey 100025252*

Appendix 2: Historic Landscape Characterisation

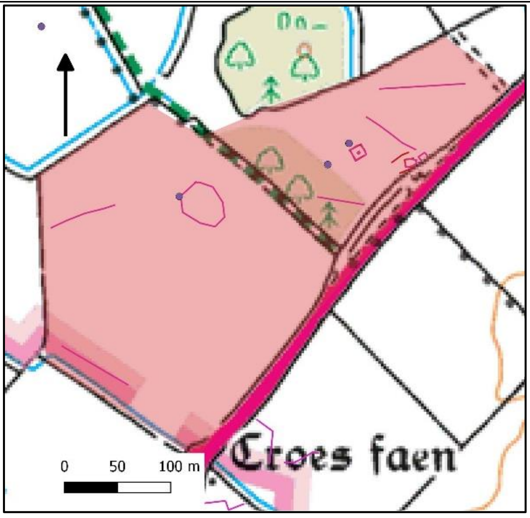
Table Ap2.1: Descriptions and examples of how each Landscape Character Area is defined

Figure Ap2.1-17: Separate LCAs displayed on maps of the Dysynni Valley

Table Ap2.1: *Descriptions and examples of how each Landscape Character Area is defined. Crown copyright and database right 2019 Ordnance Survey 100025252*

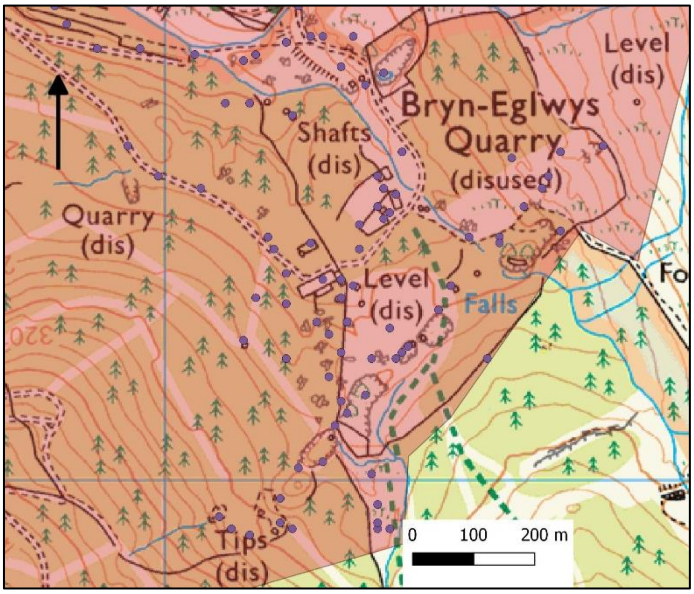
Ancient

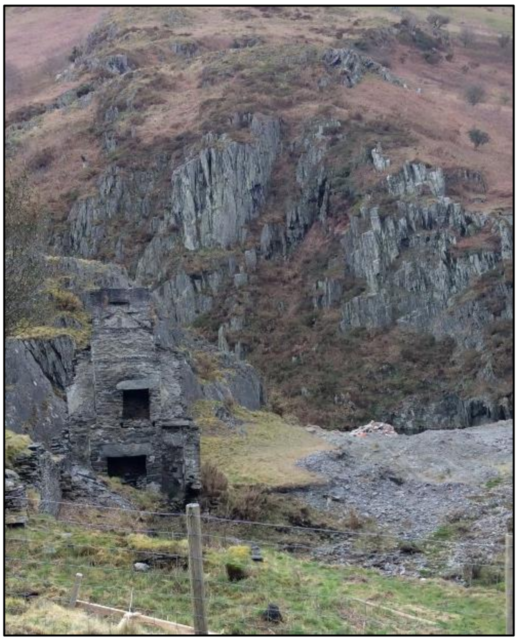
The Ancient LCA-type is defined by the presence of LCFs dating to the medieval period or earlier, such as Iron Age hillforts, medieval barrows, Bronze Age cairns, or prehistoric cropmarks.



Historic Industry

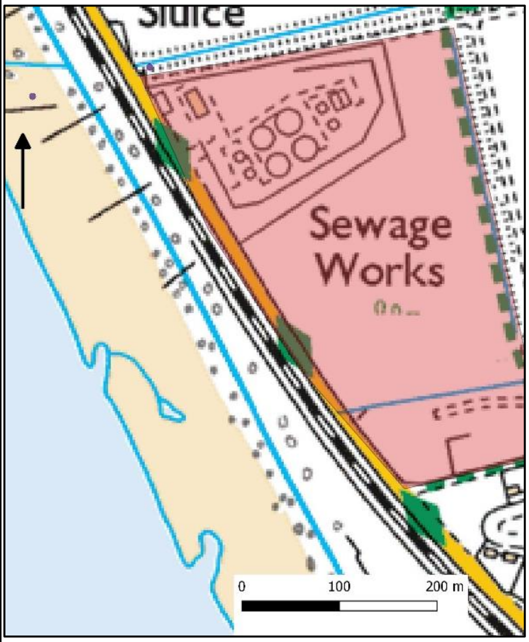
Although other HLC projects combine all industrial activity into one LCA type (e.g. Herring 2008), this project separates the industrial type into three different LCAs, due to their different visual character and origins. The Historic Industry type is defined by the LCFs that are the remnants of extractive industries from the post-medieval period, predominantly features associated with quarrying and mining (e.g. levels, shafts, spoil heaps, open quarries, and the Tallylyn railway).





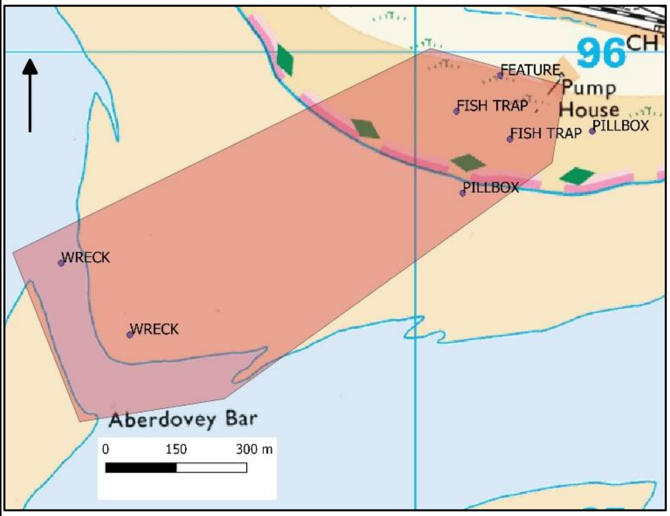
Modern Industry

Modern industrial activity in the study area is no longer based on extractive industries, but rather is confined to a sewage works near Broadwater and an industrial estate on the outskirts of Tywyn.



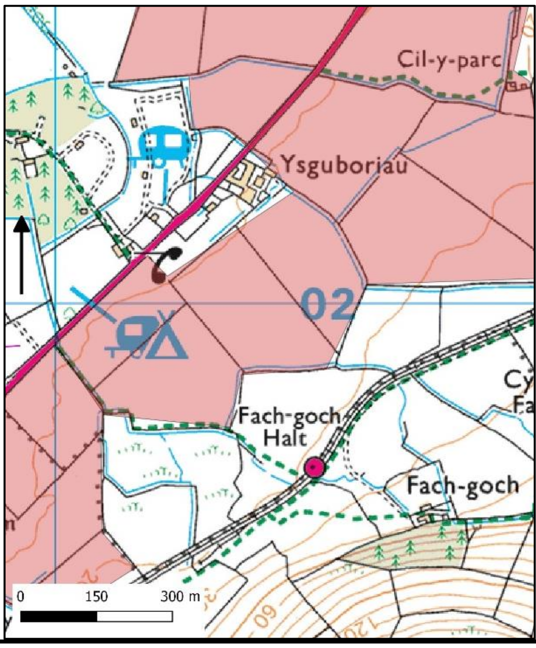
Maritime Industry

The maritime industry LCA is defined by areas with LCFs that are remnants of maritime industrial activity, such as fishing, shipbuilding and seafaring. This includes features like harbours, shipyards, jetties, shipwrecks, and medieval and post-medieval fish traps.



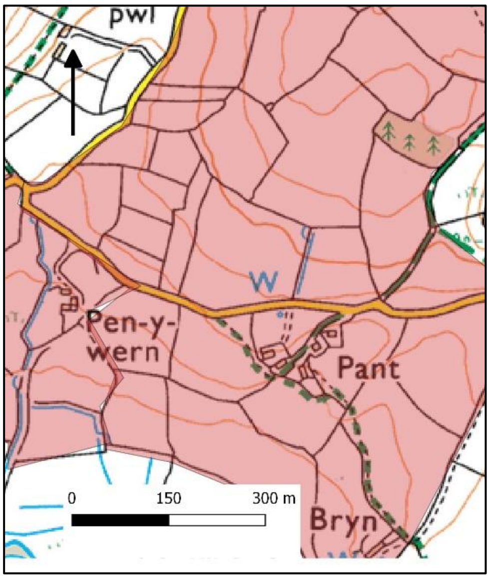
Regular Field Systems

Regular field systems are those that have straight, often parallel boundaries and right angles, and are indicative of a large-scale planned group of fields. These are characteristic of agricultural land established in the post-medieval and modern period



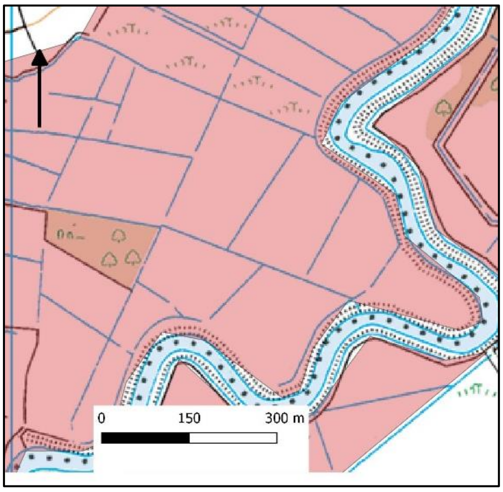
Irregular Field Systems

Irregular field systems are here defined as field systems with small fields, irregular angles, some curved boundaries, and no clear layout, indicative of the gradual establishment of individual fields over time, rather than a planned field system

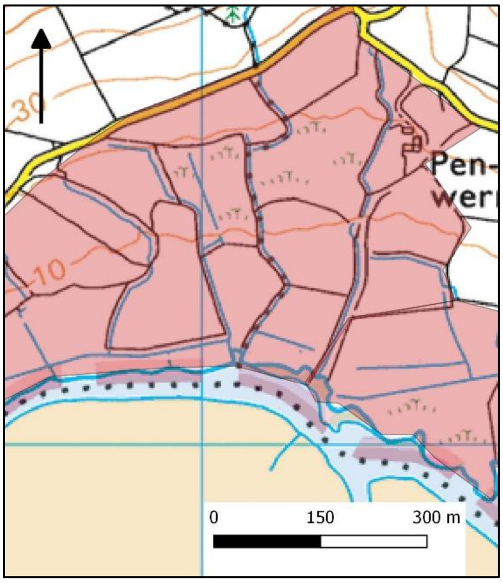


Regular Drained Land

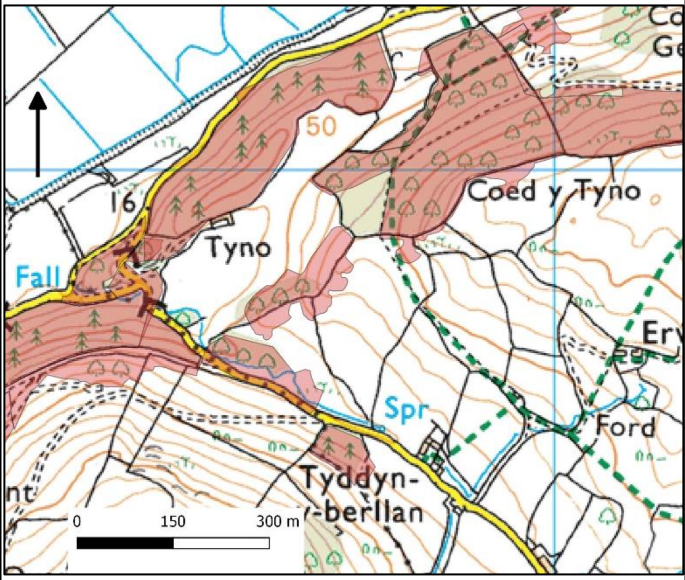
These areas were created by the land improvement projects that took place in 18^{th}-20^{th} century. This LCA is defined by areas of land with regular, perpendicular and right-angled drainage ditches, often serving as field boundaries

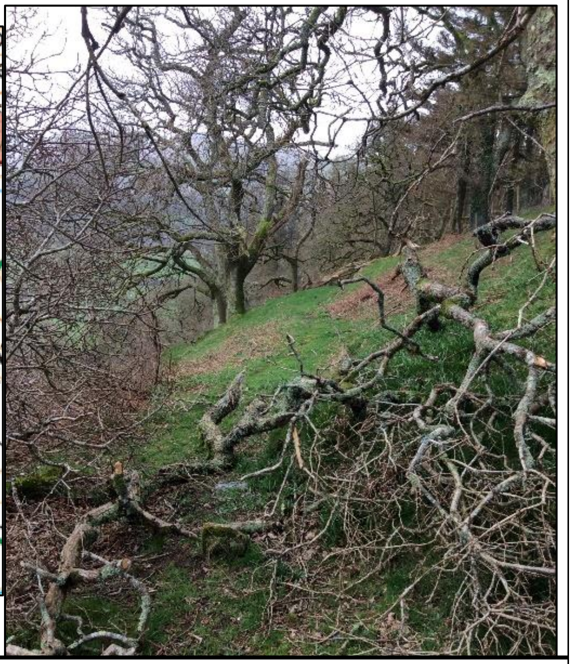


Irregular Drained Land
This is characterised by areas of land with irregular drainage ditches, often serving as (or following) field boundaries of irregular field systems. Unlike the regular drainage ditches, these do not have straight, parallel sides or regular angles. Often on slightly more hilly areas than Regular Drained Land

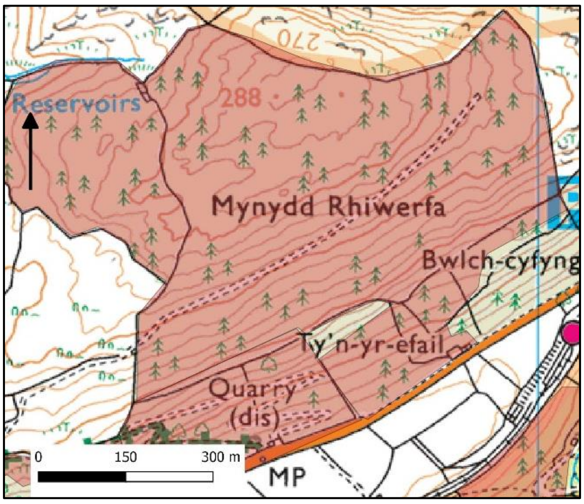


Ancient Woodland
Areas of wood that appear to originate from before AD1600 based on their name, location, nature of surrounding enclosure, and the presence of indicator species, have been classified as ancient woodland (*ibid*.).

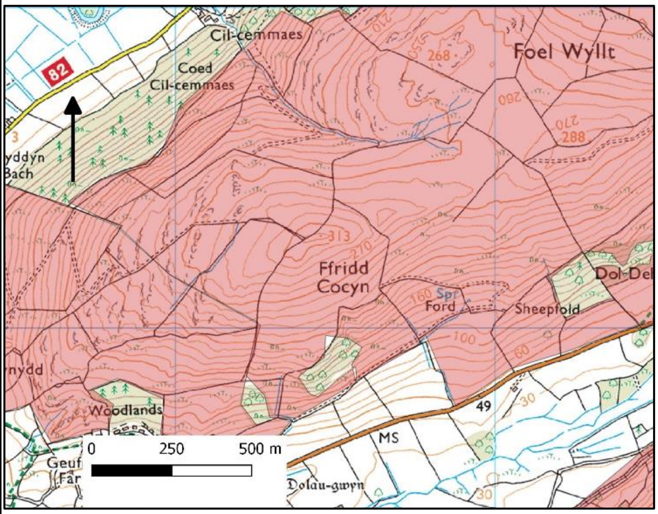




Modern Woodland
Areas of Modern Woodland LCA were identified as areas of woodland on the OS basemap that were not included in the Ancient Woodland inventory. While ancient woodland consisted mainly of deciduous species, the areas of modern woodland are predominantly coniferous plantations

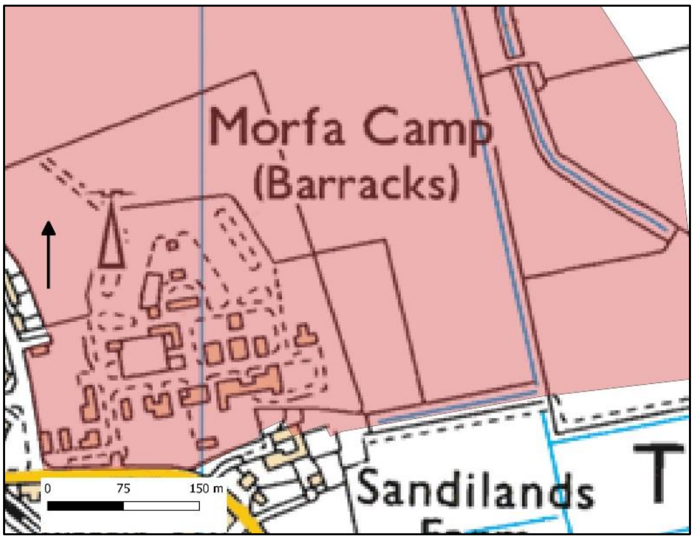


Rough Pasture
The Rough Pasture LCA type is characterised by scrub, bracken, heath or rough grassland, and is located in areas of high elevation and/or high relief as indicated by the contour lines in the OS basemap. It also includes areas of scree, rocky outcrops and loose rock. In terms of the LCFs, post-medieval agricultural remains such as sheep folds, clearance cairns and farmsteads characterise rough pasture areas



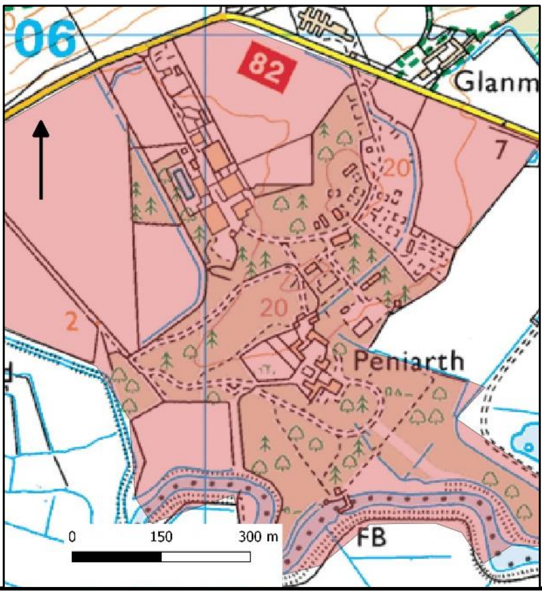
Military

The Military LCA type refers to areas that maintain a character influenced by military activity, predominantly from the Second World War. The LCFs that characterise the Military LCA include practice trenches, rifle ranges, an RAF airfield, pillboxes, camps, and several air crash sites.



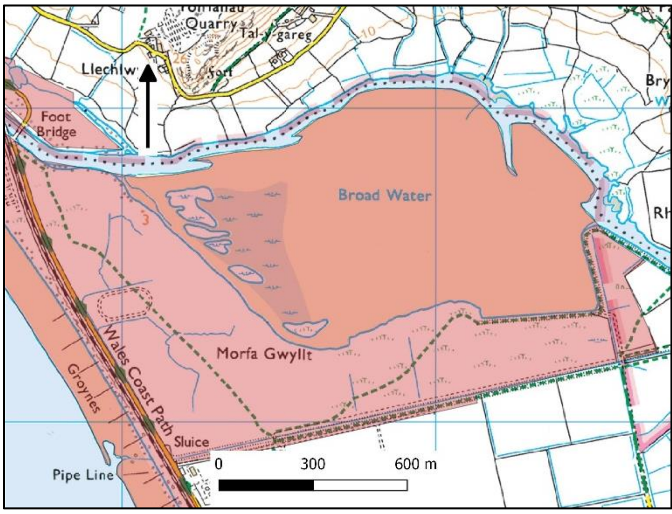
Ornamental

The Ornamental LCA is areas or park, garden or estate that has been deliberately designed, for instance the lands, gardens or deer park of a country estate. The LCFs that characterise the Ornamental LCA are those associated with the previous estate, for instance outbuildings, boat houses, cottages, and mansions



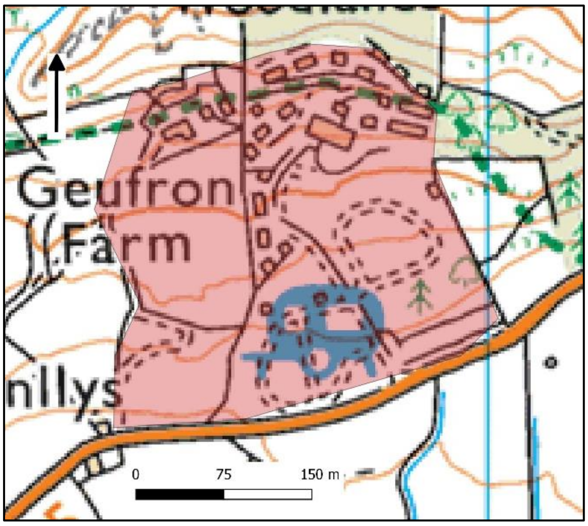
Wetland and Beach

This LCA includes the land and intertidal zone by the coastline and water courses that is comprised of sand, shingle, marsh, reeds or saltings.



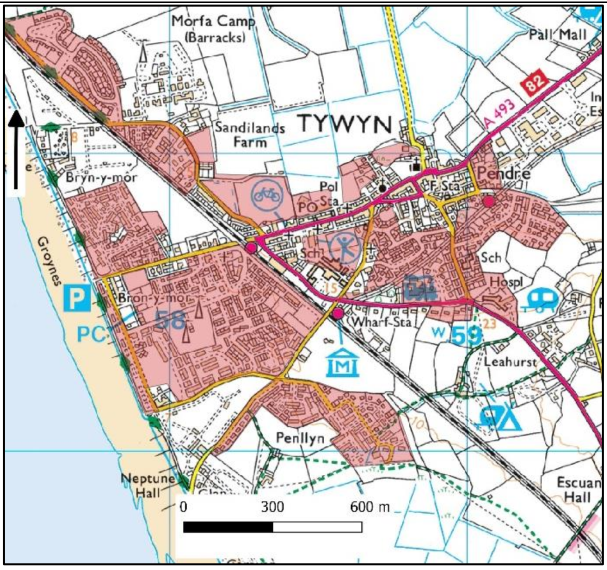
Tourism and Recreation

The Recreation and Tourism LCA is characterised by LCFs that are for tourists and leisure activities, such as camp sites, caravan and mobile home parks, golf courses, and theme parks. These are often on the borders of settlements or along the coast.



Modern Settlement

The Modern Settlement LCA type is defined as areas of settlement that are present on the modern OS basemap that were not present on the 1853-1904 1:2,500 County Series 1st Edition map.



Historic Settlement

The areas of Historic Settlement LCA in the Dysynni valley were defined as the large and small settlements included on the 1853-1904 1:2,500 County Series 1st Edition map. This included clusters of farms and farm buildings, but not single farmsteads


Market Hall
Presbyterian Chapel
(English)
1875
·881
College Green
Church St.
National Street
School
Vicarage
1923
1·418
1917
1922
2·318
1924
1·855
TOWYN
0
50
100 m

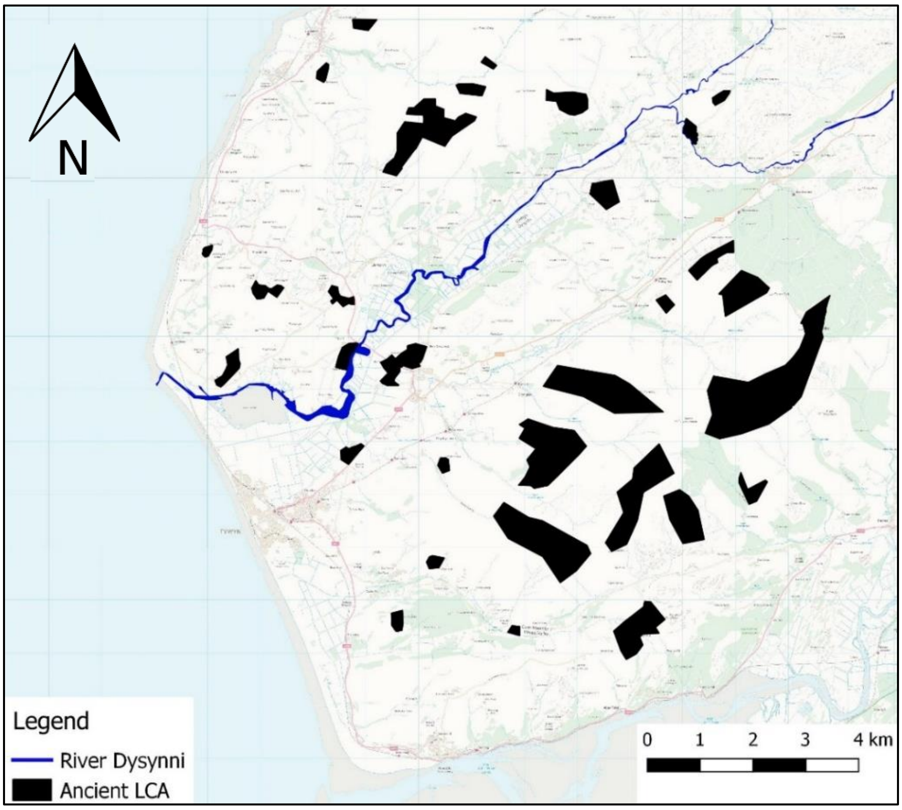


Figure Ap2.1. *Map to indicate the areas of the Dysynni valley characterised as Ancient LCA. Crown copyright and database right 2019 Ordnance Survey 100025252*

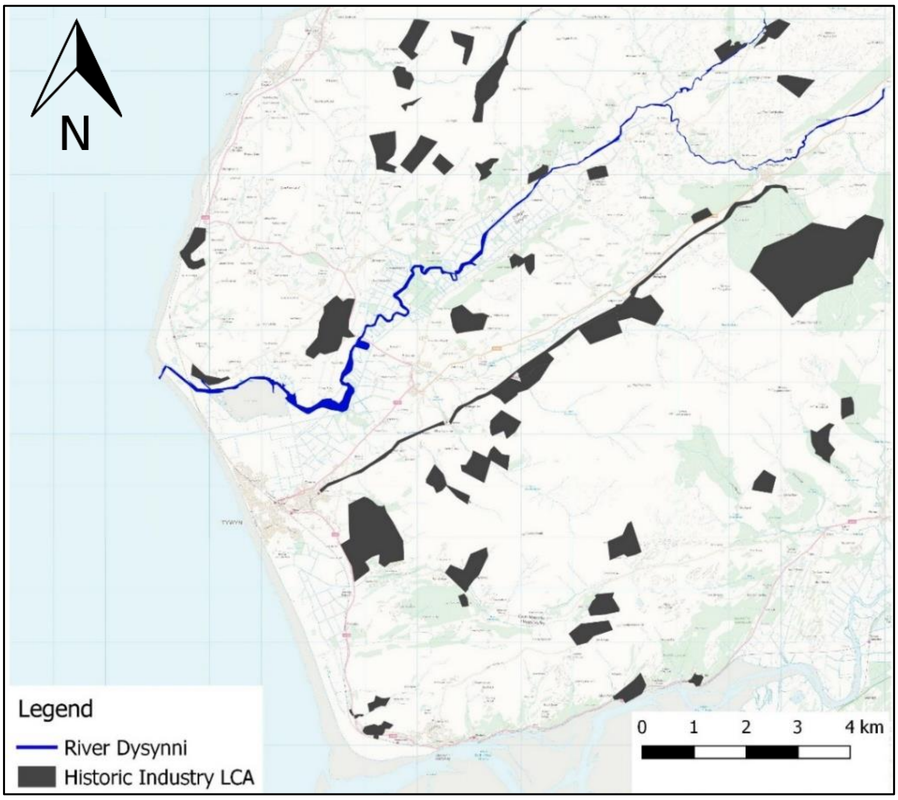


Figure Ap2.2. *Map to indicate the areas of the Dysynni valley characterised as Historic Industry LCA. Crown copyright and database right 2019 Ordnance Survey 100025252*

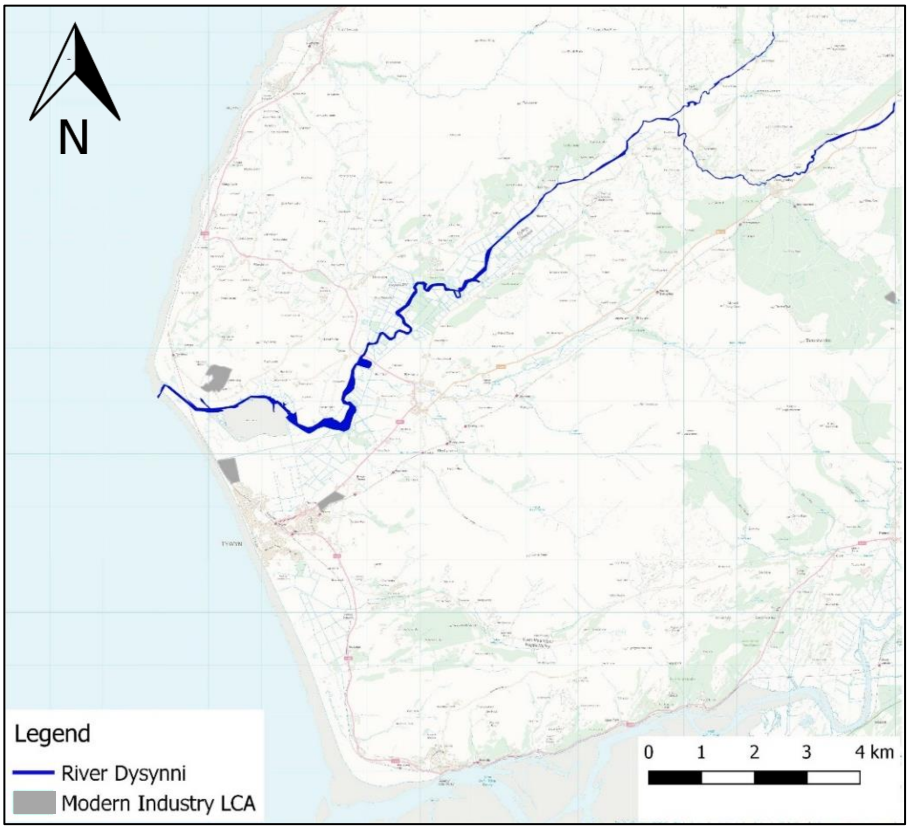


Figure Ap2.3. *Map to indicate the areas of the Dysynni valley characterised as Modern Industry LCA. Crown copyright and database right 2019 Ordnance Survey 100025252*

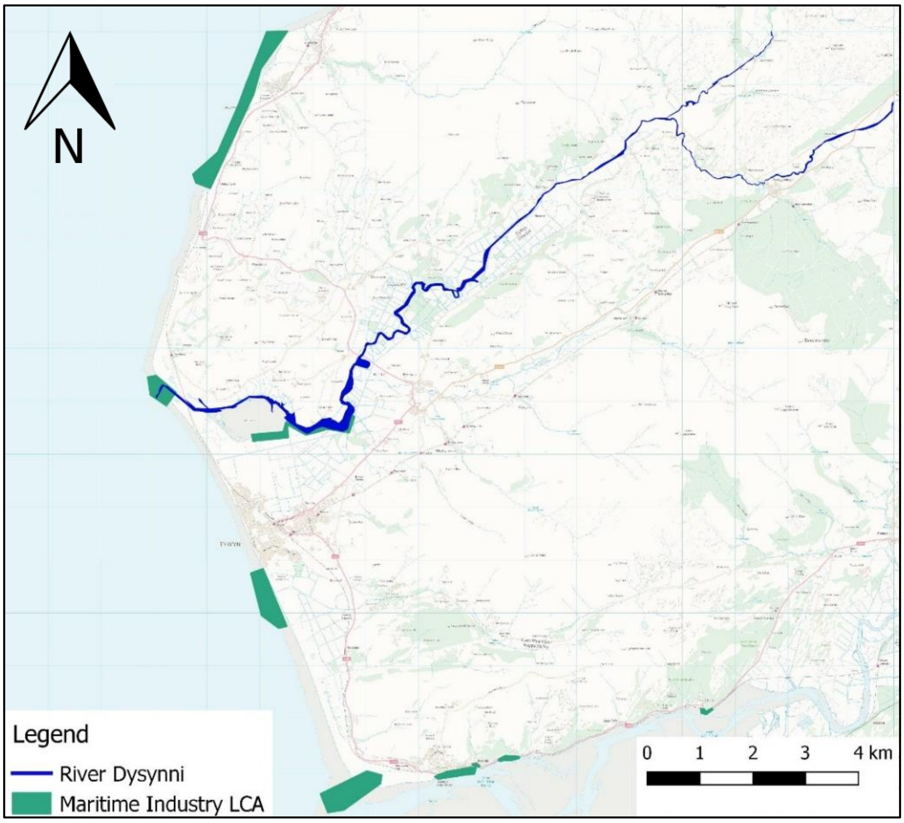


Figure Ap2.4. *Map to indicate the areas of the Dysynni valley characterised as Maritime Industry LCA. Crown copyright and database right 2019 Ordnance Survey 100025252*

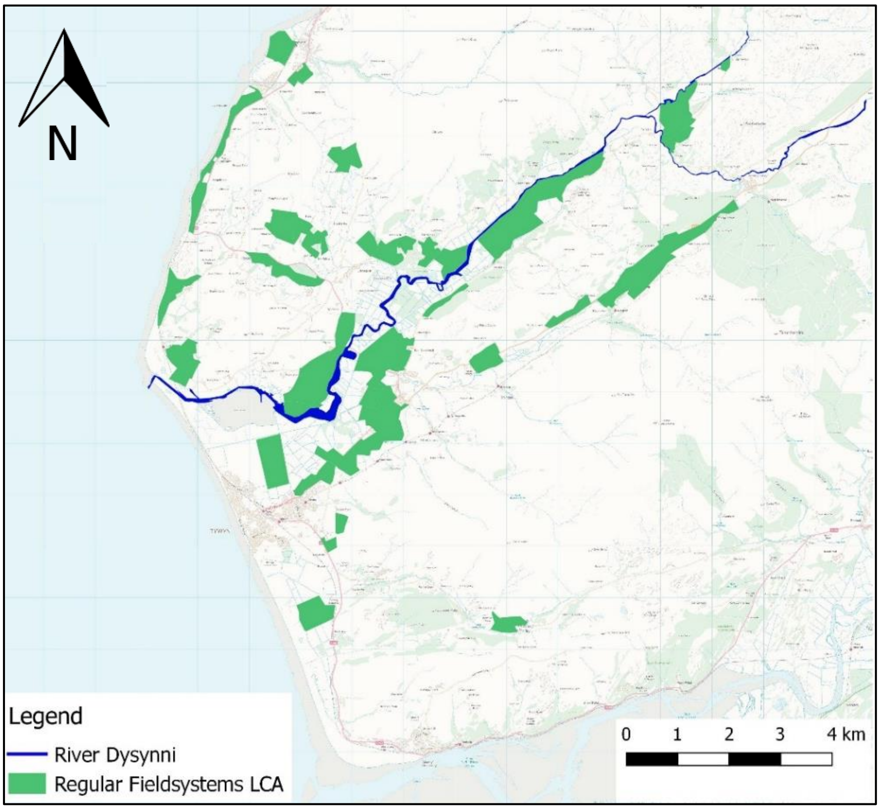


Figure Ap2.5 *Map to indicate the areas of the Dysynni valley characterised as Regular Fieldsystems LCA. Crown copyright and database right 2019 Ordnance Survey 100025252*

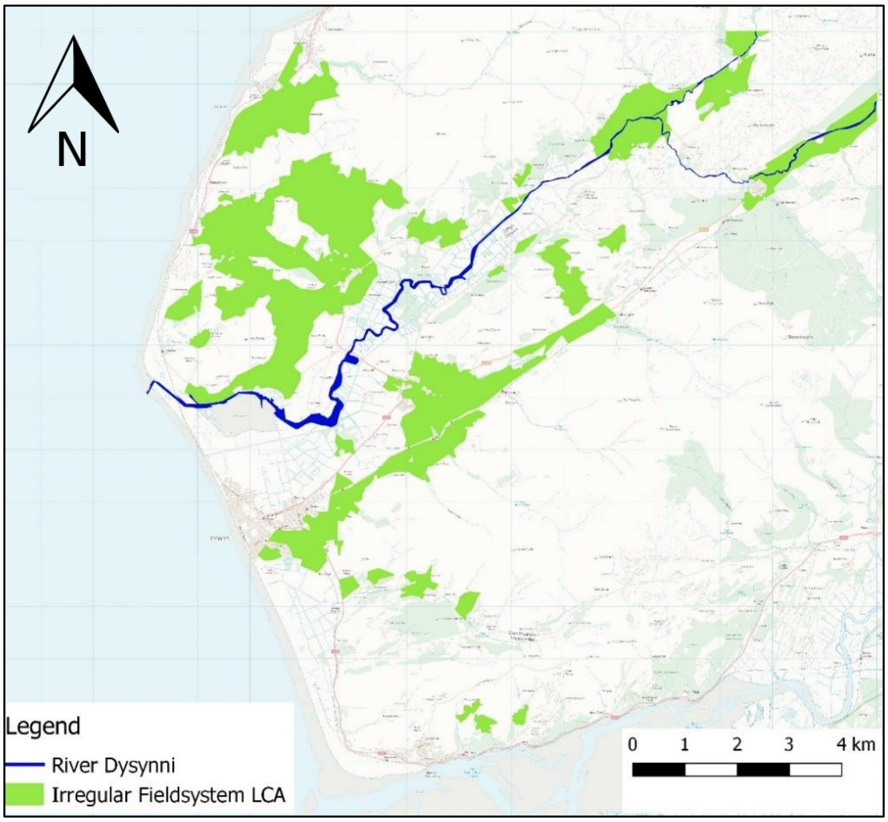


Figure Ap2.6*. Map to indicate the areas of the Dysynni valley characterised as Irregular Fieldsystem LCA. Crown copyright and database right 2019 Ordnance Survey 100025252*

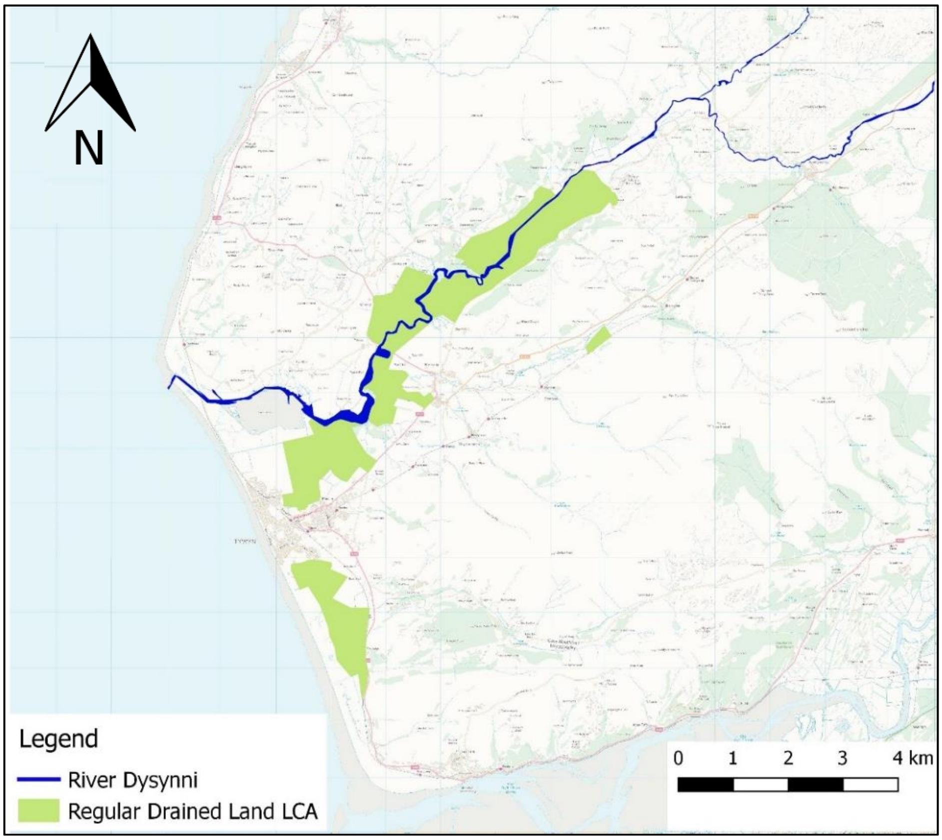


Figure Ap2.7. *Map to indicate the areas of the Dysynni valley characterised as Regular Drained Land LCA. Crown copyright and database right 2019 Ordnance Survey 100025252*

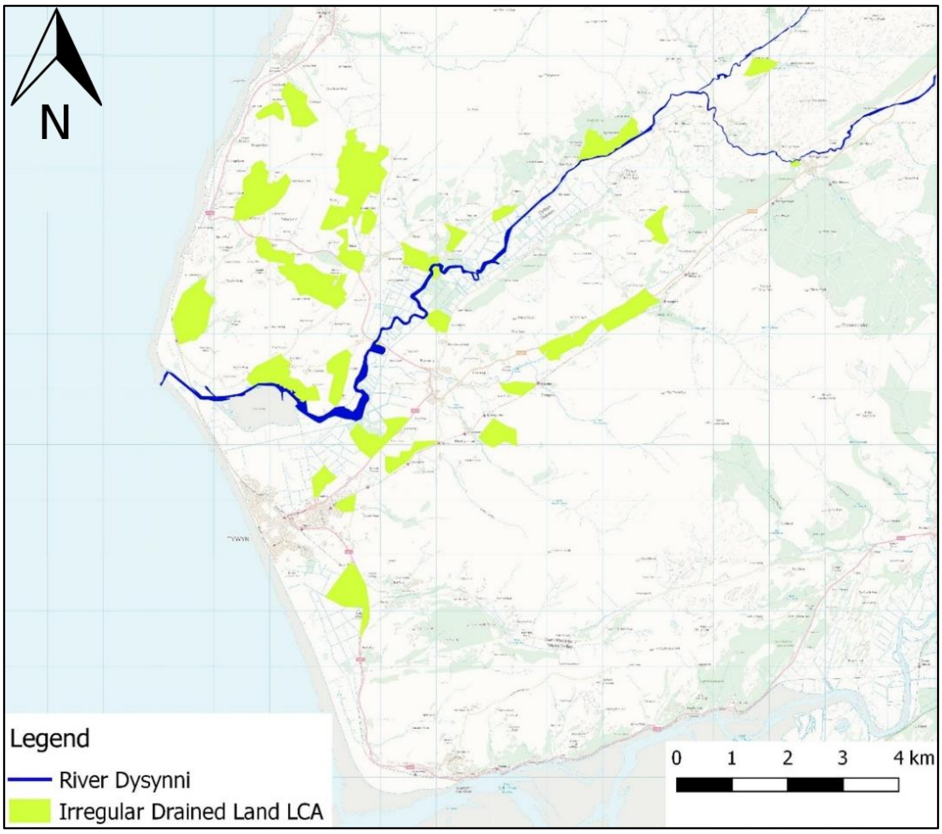


Figure Ap2.8. *Map to indicate the areas of the Dysynni valley characterised as Irregular Drained Land LCA. Crown copyright and database right 2019 Ordnance Survey 100025252*

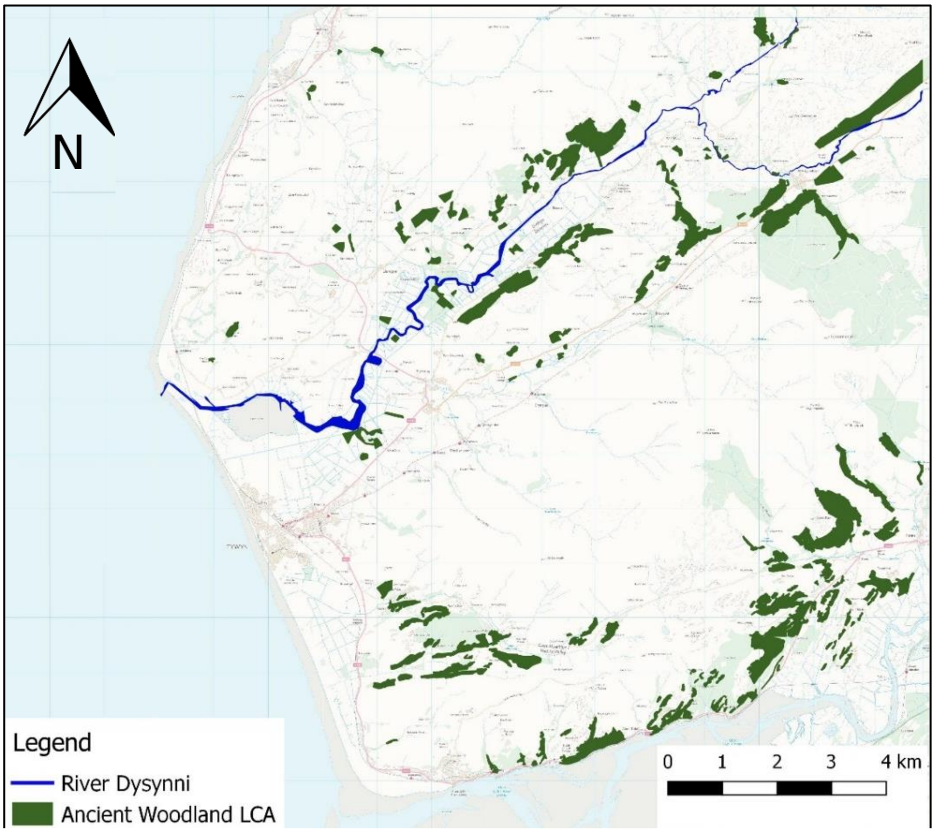


Figure Ap2.9. *Map to indicate the areas of the Dysynni valley characterised as Ancient Woodland LCA. Crown copyright and database right 2019 Ordnance Survey 100025252*

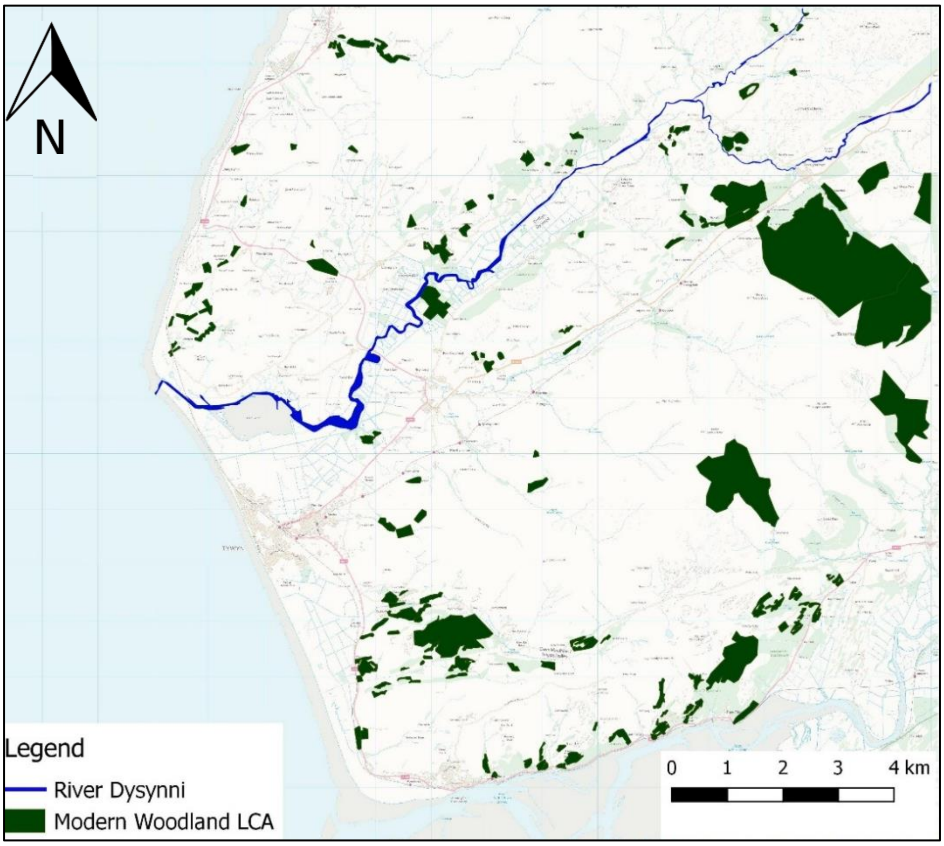


Figure Ap2.10. *Map to indicate the areas of the Dysynni valley characterised as Modern Woodland LCA. Crown copyright and database right 2019 Ordnance Survey 100025252*

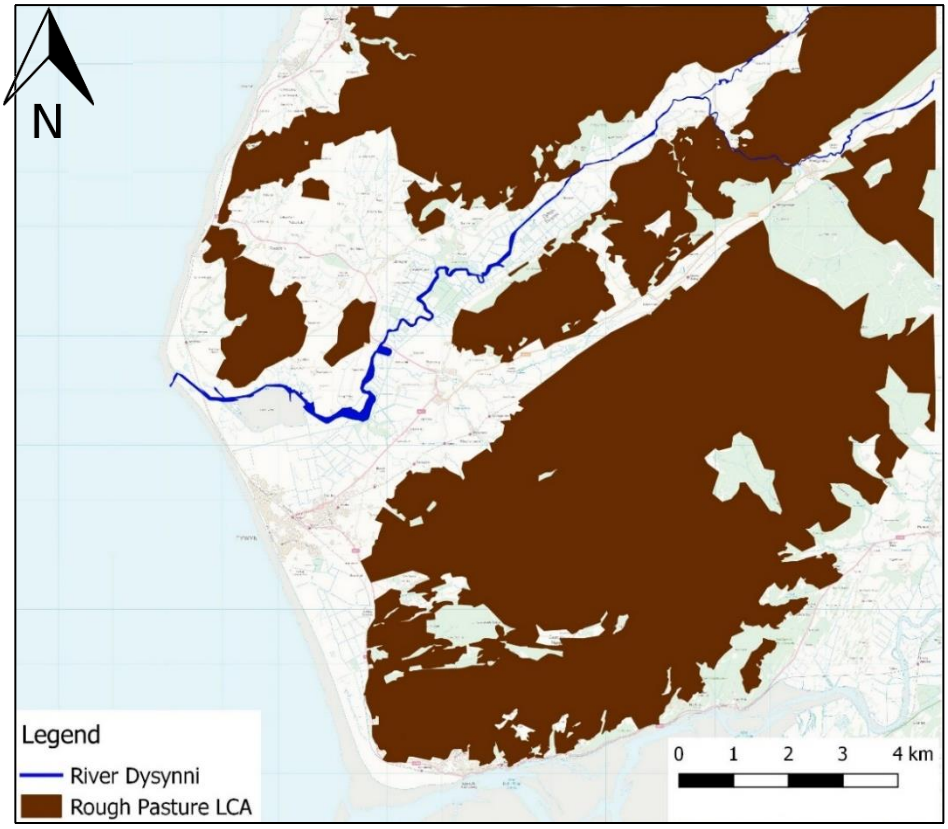


Figure Ap2.11. *Map to indicate the areas of the Dysynni valley characterised as Rough Pasture LCA. Crown copyright and database right 2019 Ordnance Survey 100025252*

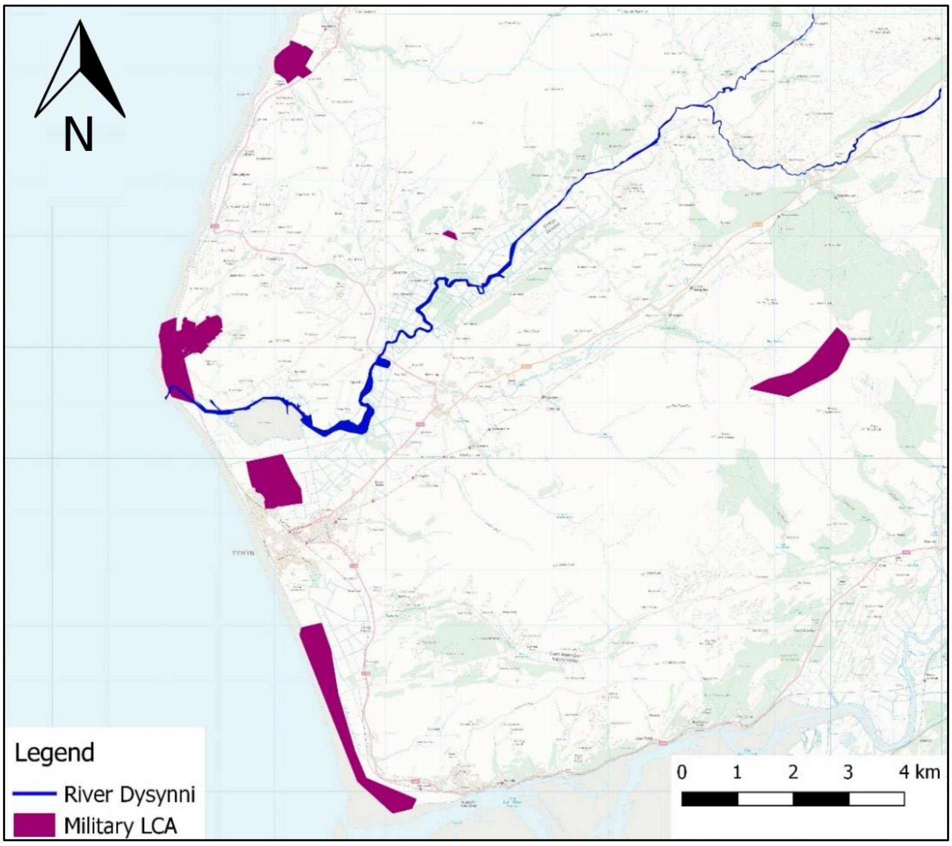


Figure Ap2.12. *Map to indicate the areas of the Dysynni valley characterised as Military LCA. Crown copyright and database right 2019 Ordnance Survey 100025252*

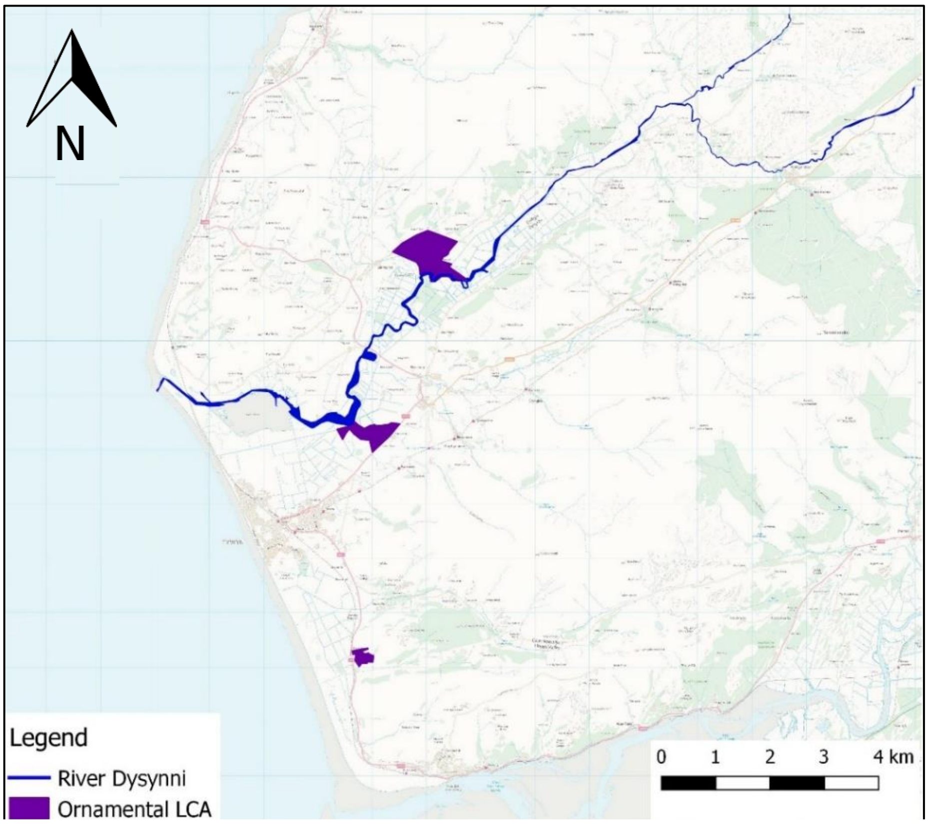


Figure Ap2.13*. Map to indicate the areas of the Dysynni valley characterised as Ornamental LCA. Crown copyright and database right 2019 Ordnance Survey 100025252*

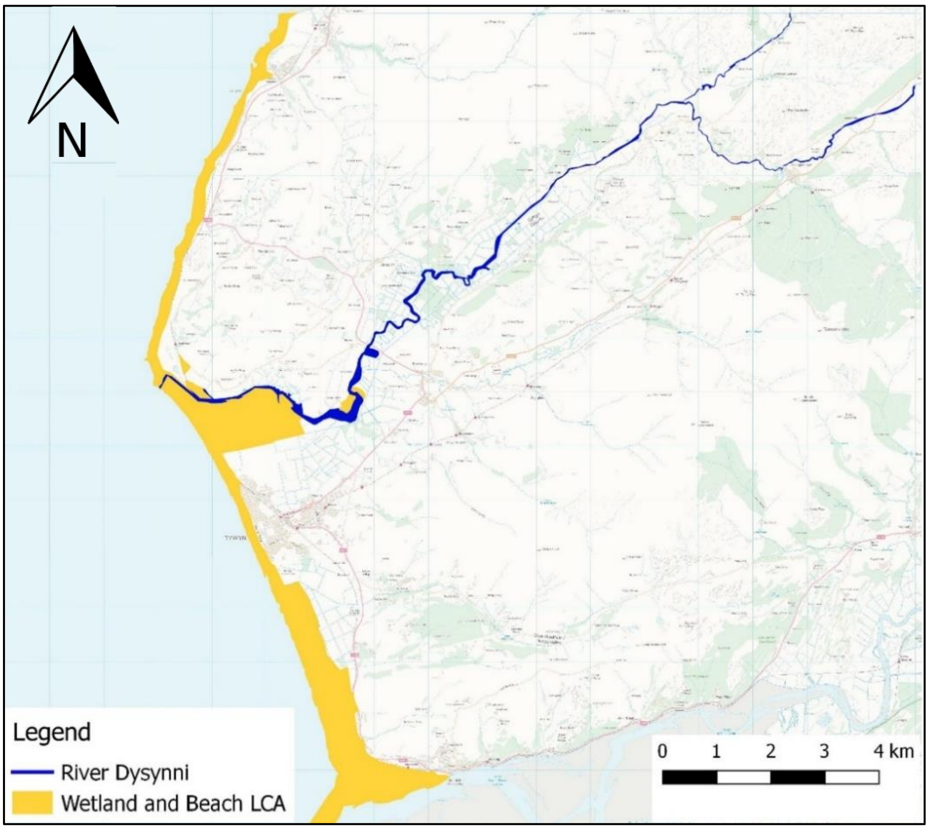


Figure Ap2.14*. Map to indicate the areas of the Dysynni valley characterised as Wetland and Beach LCA. Crown copyright and database right 2019 Ordnance Survey 100025252*

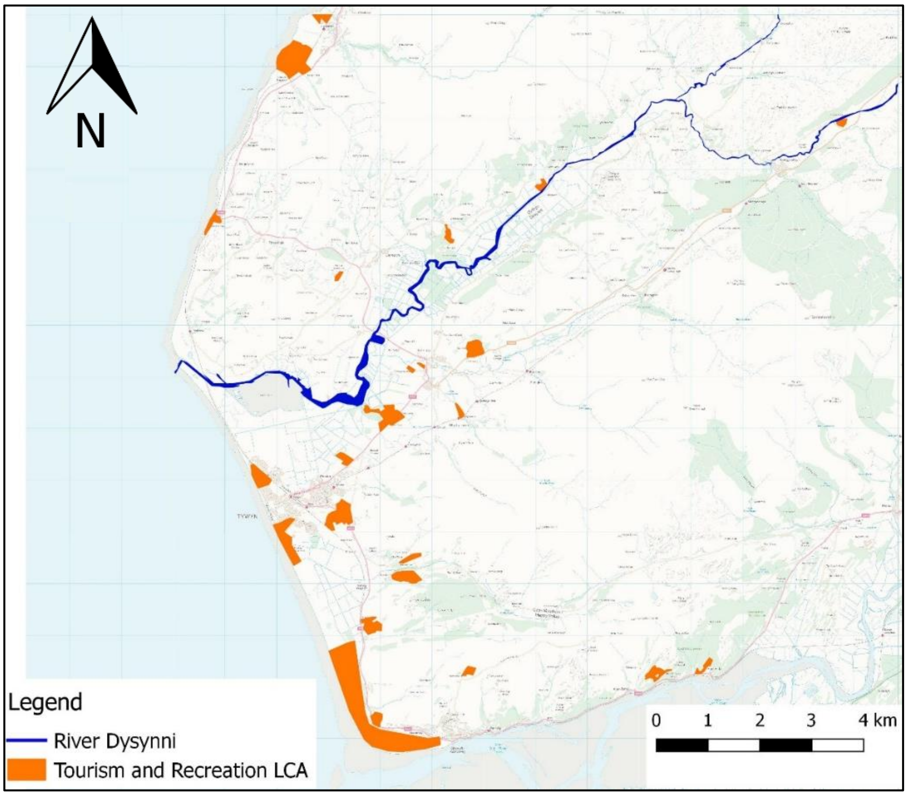


Figure Ap2.15*. Map to indicate the areas of the Dysynni valley characterised as Tourism and Recreation LCA. Crown copyright and database right 2019 Ordnance Survey 100025252*

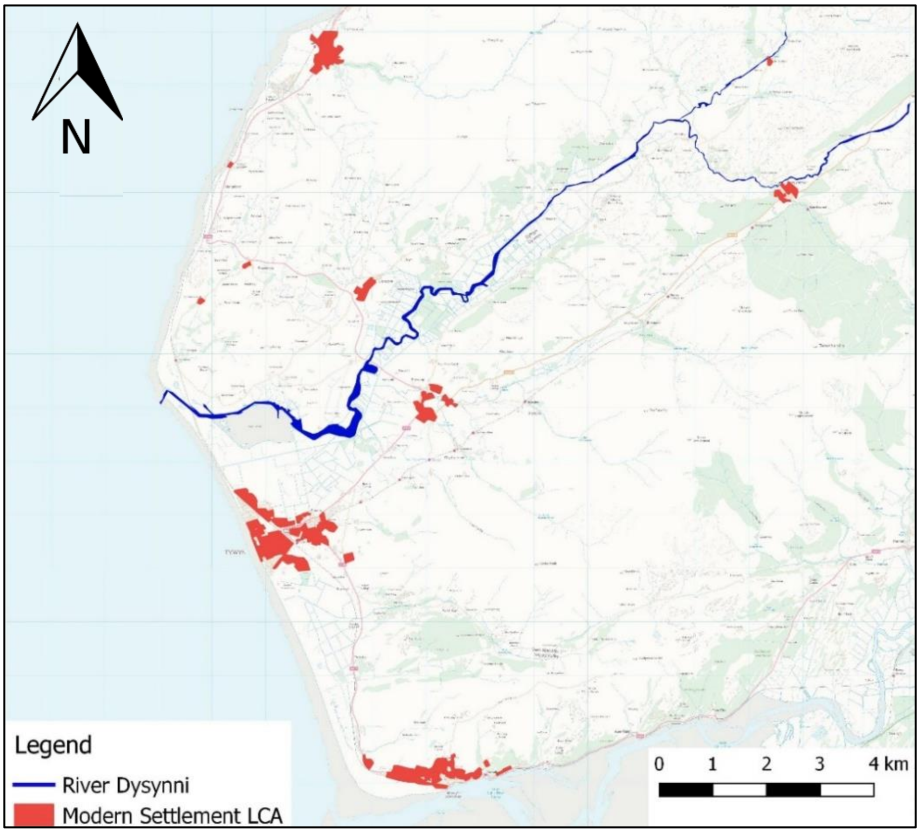


Figure Ap2.16*. Map to indicate the areas of the Dysynni valley characterised as Modern Settlement LCA. Crown copyright and database right 2019 Ordnance Survey 100025252*

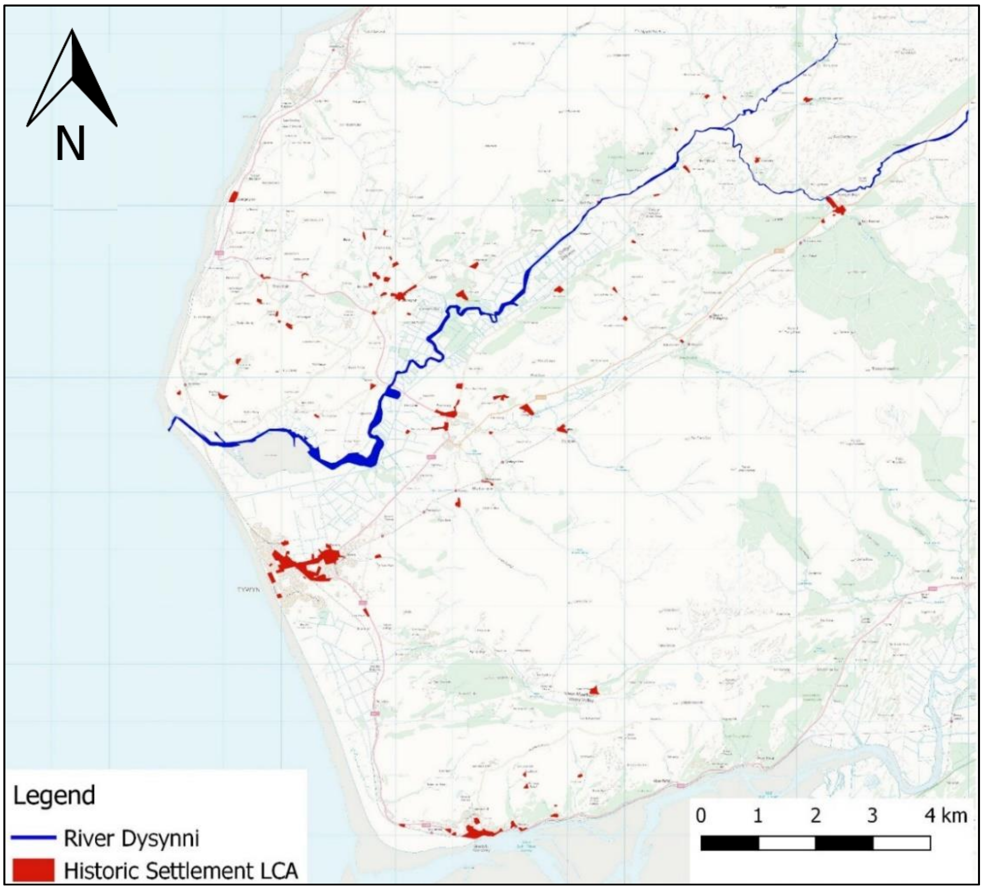


Figure Ap2.17. *Map to indicate the areas of the Dysynni valley characterised as Historic Settlement LCA. Crown copyright and database right 2019 Ordnance Survey 100025252*

Appendix 3: Vulnerability Assessment

Table Ap3.1: Sites visited during the logistical and technical test

Table Ap3.2: Scores for each variable for the pilot study features

Table Ap3.3: Landscape Character Features sampled for each Landscape Character Area

Table Ap3.4: Number of sites that characterise each Landscape Character Area

Table Ap3.5: Stage 1 Vulnerability Index results for each Landscape Character Feature assessed, in ascending order of Stage 1 score

Table Ap3.1: *Sites visited during the logistical and technical test*

ID	Record Number	Name	Type	Form	Period	Parish
1	11049	Trackway	Trackway	earthwork/soil mark	Roman	Whittlesey
2	2741	Suet Hills Barrow	Barrow	earthwork	Bronze Age	Whittlesey
3	2814	Whittlesey Butter Cross	Market Cross	Standing monument	Post-medieval	Whittlesey
4	2928	St Mary's Church	Church	Building	Medieval	Whittlesey
5	3917	Whitecross Stone	standing stone	monument	Medieval	Whittlesey
6	50457	Pillbox	Pillbox	building	Modern	Whittlesey
7	1380	Outbuilding	Building	Ruined Building	Medieval	Fletton
8	01411	St Margarets Church	Parish Church	Building, structure	Medieval	Fletton
9	2973	Fletton Churchyard Cross	Cross	Standing Monument	Medieval	Fletton
10	50585	Saxon Villas	Building	Buildings	Post-medieval	Fletton
11	53704	Fletton Playing Fields	Ridge and Furrow	Earthwork	Medieval	Fletton
12	53820	The Nene Viaduct (Great Northern Bridge 184)	Railway Bridge	Structure	Post-medieval	Fletton

***Table Ap3.2**: Scores for each variable for the logistical and technical test features*

ID	PRN/NPRN	Name	Level of Preservation (1-5)	Resistance of Remains (1-5)	Resistance of Substrate (1-5)	Susceptibility to temperature change (1-5)	Susceptibility to Precipitation Change (1-5)	Vulnerability Score
3	2814	Whittlesey Butter Cross	2	1	3	1	1	1.6
4	2928	St Mary's Church	1	1	3	1	1	1.4
5	3917	Whitecross Stone	2	1	3	1	1	1.6
6	50457	Pillbox	2	1	1	1	1	1.2
8	1411	St Margaret's Church	1	1	1	1	1	1
10	50585	Saxon Villas (5)	1	1	3	1	1	1.4
11	53704	Fletton Playing Fields Ridge and Furrow (1)	1	3	1	2	3	2
12	53820	The Nene Viaduct (Great Northern Bridge 184) (6)	1	1	1	1	4	1.6

Table Ap3.3: *Landscape Character Features sampled for each Landscape Character Area*

Identifier	Name	Type	Form	Location (x,y)	Type of Assessment
Ancient LCA					
PRN 1740	Domen Ddreiniog; Motte; Dyffryn Dysynni	Motte	Earthwork	259690, 303600	Visit
Aerial Photograph CUCAP_BUB_63_7775	Feature 7 Cropmark	Complex	Buried features	260846, 303557	Visit
Aerial Photograph Oblique_2006_2909	Feature 4 Cropmark	Square enclosure	Buried features	260490, 303198	Visit
NPRN 501068	Allt-Lwyd, Pillow Mound V	Pillow mound	Earthwork	260388, 307232	Visit
PRN 4931	Castell y Bere	Castle	Building	266750, 308540	Visit
NPRN 301736	Tal-Y-Gareg Hillfort	Hillfort	Earthwork	257415, 303585	Visit
NPRN 310263	Square Barrow Cemetery, Croes Faen	Barrow Cemetery	Buried Features	259820, 301860	Visit
NPRN 524780	Submerged Forest, Tywyn	Submerged Forest	Topography	258511, 298584	Visit
PRN 16601	Peat Exposured, Tywyn	Peat Deposit	Buried Features	258550, 298530	Visit
NPRN 302862	Craig-Yr-Aderyn, Hillfort, Birds Rock	Hillfort	Earthwork	264513, 306834	Visit
NPRN 407753	Craig Yr Aderyn, Cairn	Cairn, Enclosure	Structure	264700, 306570	Visit
PRN 2977	Enclosure, Hut Circle, Allt Lwyd	Enclosure	Structure	260630, 307420	Desk-Based
PRN 5382	Burnt Mound, Happy Valley	Burnt Mound	Structure	261220, 299700	Desk-Based
PRN 4852	Cairn, Trum Gelli	Cairn	Structure	265560, 301430	Desk-Based
NPRN 500914	Cwm-Llwyd, Possible Cairn Iv	Cairn	Earthwork	261964, 308763	Desk-Based
NPRN 286634	Stone Circle, Trum Gelli Se Slopes	Stone Circle	Structure	266275, 300173	Desk-Based

PRN 4938	Standing Stone, Llanfihangel Y Pennant	Standing Stone	Structure	266220, 307970	Desk-Based
Historic Industry LCA					
NPRN 501054	Allt-Lwyd, Stone Quarry Vii	Stone Quarry	Earthwork	260461, 307137	Visit
NPRN 501053	Allt-Lwyd; Stone Quarry Iii	Stone Quarry	Earthwork	260496, 307118	Visit
PRN 21875	Pant Y Cae Mine, Tywyn	Lead Mine	Earthwork	261800, 299200	Visit
PRN 20563	Level, Foel Ty'r Gawen	Level	Structure	262200, 307100	Visit
PRN 26339	Quarry, Tirgawen	Quarry	Earthwork	262243, 307174	Visit
PRN 20561	Quarry, Wern	Quarry	Earthwork	264400, 307000	Visit
NPRN 500993	Twllydarren, Trackway Iv	Trackway	Earthwork	262587, 308933	Desk-Based
NPRN 500889	Peniarth Slate Quarry, Path	Path	Earthwork	262596, 309140	Desk-Based
NPRN 286508	Shaft, Cwm Pandy	Shaft	Earthwork	262970, 302235	Desk-Based
NPRN 500855	Bodwylan, Causeway	Causeway	Earthwork	260817, 309322	Desk-Based
PRN 9237	Cwmcwm Incline Drumhouse, Llanfihangel-Y-Pennant	Winder House	Building – Ruin	269130, 305230	Desk-Based
PRN 9207	Bryn Eglwys Quarry Slate Mill, Llanfihangel-Y-Pennant	Slate Mill	Ruins	268960, 305710	Desk-Based
NPRN 500888	Peniarth Slate Quarry, Caban	Quarry Building	Ruins	262565, 309128	Desk-Based
PRN 9254	Bryn Eglwys Quarry Building 4, Llanfihangel-Y-Pennant	Quarry Building	Building - Ruins	269280, 305090	Desk-Based
NPRN 41337	Rhyd-Yr-Onen Station	Railway Station	Building	261510, 302190	Desk-Based
PRN 20746	Dolgoch Viaduct, Talyllyn	Viaduct	Structure	265050, 304500	Desk-Based
PRN 9211	Beudynewydd Incline, Llanfihangel-Y-Pennant	Inclined Plane	Earthwork	269200, 305720	Desk-Based
NPRN 500869	Cwm-Llwyd, Spoil Heap I	Spoil Heap	Earthwork	262850, 309365	Desk-Based
Modern Industry LCA					
NPRN 525497	Engine Shed And Works, Ton-Fanau Quarry	Engine Shed;	Building	256919, 303275	Visit

		Engineering works			
NPRN 525492	Granite Quarry, Ton-Fanau	Quarry	Earthwork	257161, 303324	Visit
PRN 9271	Bryn Eglwys Quarry Reservoir 1, Llanfihangel-Y-Pennant	Reservoir	Structure	269890, 303940	Desk-Based
PRN 20495	Granite Quarry, Bach Y Sil Nr Towyn	Granite Quarry	Structure	257000, 303500	Desk-Based
Maritime Industry LCA					
PRN 59667	Line Of Boulders, Aberdyfi	Feature	Structure	260180, 295950	Visit
NPRN 525477	Boathouse, Ynysmaengwyn	Boat House	Structure	259691, 302499	Visit
NPRN 518856	Aberdyfi Fish Trap 1	Fish Trap	Structure	260201, 295815	Visit
NPRN 518857	Aberdyfi Fish Trap 2	Fish Trap	Structure	260087, 268874	Visit
PRN 59658	Structure, Remains Of, NW Of Coed Y Gweddill	Structure	Structure	257735, 308543	Desk-Based
NPRN 411279	Concrete Slipway, Fron-Goch	Slipway	Structure	266380, 297140	Desk-Based
PRN 25085	Wharf, Aberdyfi	Wharf	Structure	261713, 295988	Desk-Based
409087	Llangelynin Fish Trap	Fish Trap	Other Structure	256870, 307300	Desk-Based
59661	Structure, Remains Of, NW Of Cae-Du	Structure	Structure	256820, 306200	Desk-Based
411870	Peat Cuttings, Submerged Forest, Towyn	Peat cutting	Structure	258400, 298800	Desk-Based
Regular Fieldsystems					
Aerial Photograph CUCAP_BUB_63_7775	Feature 7 Cropmark	Complex	Buried features	260846, 303557	Visit
Aerial Photograph Oblique_2006_2909	Feature 4 Cropmark	Square enclosure	Buried features	260490, 303198	Visit
NPRN 310263	Square Barrow Cemetery, Croes Faen	Barrow Cemetery	Buried Features	259820, 301860	Visit
Aerial Photograph Oblique_995093_51	Feature 17	Cropmark	Buried Feature	260099, 301969	Visit
NPRN 275900	Bryn-Crug Cropmark Complex, South-West Area	Complex	Buried features	260390, 303420	Visit

PRN 59660	Ty Coch Farm, Remains Of, W Of Bodgadfan	Farmstead	Complex	257010, 306540	Desk-Based
PRN 59658	Structure, Remains Of, NW Of Coed Y Gweddill	Structure	Structure	257735, 308543	Desk-Based
NPRN 302238	Cil- Cemmaes	House	Building	262120, 304960	Desk-Based
PRN 59786	Wall, Remains Of, Ynysmaengwyn	Wall	Buried Features	260100, 301990	Desk-Based
Irregular Fieldsystems LCA					
NPRN 409817	Tollgate Cottage, Tywyn	Toll House	Building	259723, 299484	Visit
PRN 4932	Cairn, Site Of, Llanfihangel Y Pennany	Cairn	Structure	267040, 308780	Visit
NPRN 412911	Llanfendigaid Earthworks	Defended Enclosure	Earthworks	256684, 304845	Visit
Aerial Photograph RAF_1450_3006	Feature 16	Circular Enclosure	Buried feature	259849, 302061	Visit
PRN 1739	Castell Mawr Hillfort, S Of Rhoslefain	Hillfort	Earthwork	258020, 304780	Desk-Based
PRN 3820	Tomen Cil Y Parc, Tumulus/Motte, Site Of, Dysynni	Barrow	Earthwork	261020, 302530	Desk-Based
PRN 38117	Cattle Shed, Mynydd Pencoed	Cow shed	Building	267680, 309880	Desk-Based
NPRN 409398	Llanfihangel-Y-Pennant, Ruin To East Of Village	Farmhouse	Ruins	267510, 308930	Desk-Based
NPRN 409397	Maes-Y-Llan Stone Spread	Stone Pile	Buried feature	267030, 309150	Desk-Based
Regular Drained Land LCA					
Aerial Photograph Oblique_935065_14	Feature 10	Circular enclosure	Buried Feature	259206, 302279	Visit
Aerial Photograph Oblique_995093_51	Feature 17	Cropmark	Buried Feature	260099, 301969	Visit
Aerial Photograph RAF_1468_4004	Feature 46	Cropmark	Buried Feature	258907, 299873	Visit
PRN 18387	Afon Dyffryn Channel, Flood Banks And Main Drain, Tywyn	Flood Defences	Earthwork	258700, 299450	Visit
PRN 4811	Cropmark, N Of Croes Faen	Cropmark	Buried feature	259530, 301970	Desk-Based
PRN 4812	Cropmark, N Of Croes Faen	Cropmark	Buried feature	259660, 301810	Desk-Based
Irregular Drained Land LCA					

PRN 34190	Glan Y Morfa, Bryncrug	Farmstead	Building	261190, 304100	Visit
PRN 4932	Cairn, Site Of, Lanfihangel Y Pennany	Cairn	Structure	267040, 308780	Visit
NPRN 412911	Llanfendigaid Earthworks	Defended Enclosure	Earthworks	256684, 304845	Visit
Aerial Photograph RAF_1450_3006	Feature 16	Circular enclosures	Buried featuers	259849, 302061	Visit
NPRN 40913	Caethle Mill	Woollen Mill	Not recorded	259720, 299350	Desk-Based
Ancient Woodland					
PRN 57995	Building And Walled Garden, E Of Bod Talog	Walled Garden	Structure	260183, 299536	Visit
Ancient Woodland Inventory	Tirgawen Ancient Woodland	Ancient Woodland	Ancient Woodland	262732, 306896	Visit
PRN 26309	Bank, Tirgawen	Bank	Earthwork	262716, 306813	Visit
PRN 2986	Ffynnon Y Fron, Dysynni	Well	Structure	260940, 306370	Desk-Based
PRN 26326	Wall, Tirgawen	Wall	Structure	262779, 306953	Desk-Based
PRN 57954	Cormorant Cottage, E Of Peniarth-Uchaf	Building	Building	263486, 307371	Desk-Based
PRN 57957	Building, W Of Coach-House And Stables At Peniarth-Uchaf	Building	Building	263254, 307432	Desk-Based
PRN 26307	Building Platform, Tirgawen	Building platform	Structure	262724, 306820	Desk-Based
Modern Woodland LCA					
2016 OS Map	Bwlch Modern Woodland	Modern Woodland	woodland	256966, 305350	Visit
PRN 26330	Path, Tirgawen	Path	Earthwork	262736, 307503	Visit
NPRN 302615	Bwlch, Field Boundary Marker	Boundary Stone	Structure	256980, 305270	Visit
PRN 26328	Boundary Bank, Tirgawen	Boundary Bank	Earthwork	262711, 307282	Desk-Based
PRN 26329	Gateway, Tirgawen	Gateway	Structure	262687, 307274	Desk-Based
3037	Hafotty-Hendre	Farmstead	Building	267680, 306340	Desk-Based
9191	Moelfre Trough, Llanfihangel-Y-Pennant	Trough	Structure	268160, 305470	Desk-Based
Rough Pasture LCA					
PRN 26323	Drystone Wall, Tirgawen.	Wall	Structure	262574, 307077	Visit

PRN 26317	Barn, Tirgawen	Barn	Structure	262550, 307057	Visit
PRN 20563	Level, Foel Ty'r Gawen	Level	Structure	262200, 307100	Visit
L1 Survey, Porter 2017	Feature 22	Sheepfold	Structure	264874, 306928	Visit
L1 Survey, Porter 2017	Feature 23	Farmstead	Structure	264842, 306922	Visit
NPRN 286569	Peat Cutting, Trum Gelli	Peat cutting	Earthwork	265478, 301704	Desk-Based
PRN 9208	Bryn Eglwys Quarry Bridge 2, Llanfihangel-Y-Pennant	Bridge	Structure	269050, 305700	Desk-Based
NPRN 286621	Boundary Bank, Braich Ddu Se Peak	Boundary Bank	Earthwork	267944, 300897	Desk-Based
NPRN 501077	Allt-Lwyd, Bank Xi	Bank	Earthwork	260237, 307733	Desk-Based
NPRN 286541	Boundary, Nant Braich-Y-Rhiw N Slopes	Boundary	Earthwork	262905, 302180	Desk-Based
NPRN 501127	Cwm-Llwyd, Sheep Wash Ii	Sheep wash	Structure	261683, 308774	Desk-Based
NPRN 501117	Cwm-Llwyd, Sheep Pen Vi	Sheep Pen	Earthwork	261530, 308561	Desk-Based
NPRN 501211	Bodwylan, Clearance Cairn Iii	Clearance Cairn	Structure	261466, 309532	Desk-Based
PRN 26343	Sheepfold, Tirgawen	Sheep fold	Structure	262238, 307006	Desk-Based
NPRN 500985	Cwm-Llwyd, Sheep Pen Iii	Sheep pen	Earthwork	262427, 309638	Desk-Based
NPRN 286512	Clearance Cairn, Nant Braich-Y-Rhiw N Slopes	Clearance Cairn	Earthwork	263250, 301240	Desk-Based
NPRN 286544	Sheep Fold, Nant Y Bala	Sheep fold	Ruins	263887, 301160	Desk-Based
NPRN 286506	Ditch, Nant Braich-Y-Rhiw N Slopes	Ditch	Earthwork	263206, 301778	Desk-Based
NPRN 286533	Sheep Fold, Dolau-Gwyn	Sheep fold	Ruins	265162, 302464	Desk-Based
Military LCA					
NPRN 411783	Pillbox, The Crossing, Aberdyfi	Pillbox	Building	259540, 296350	Visit
PRN 7281	Military Camp, Tonfanau	Complex	Buried features	256500, 304300	Visit
NPRN 301971	Tywyn Memorial Hospital	Hospital	Building	259100, 300506	Visit
NPRN 404790	Neptune Hall, Neptune Road, Tywyn	House	Building	258061, 299926	Visit

PRN 7287	Rifle Range, Tywyn	Firing Range	Structure	258650, 298780	Visit
PRN 18395	Pill-Box, Tywyn	Pillbox	Structure	258530, 298860	Visit
PRN 29514	Shooting Butt, Tywyn	Shooting Stand	Earthwork	258680, 298840	Desk-Based
NMRW 270343	Pillbox (Type Fw3-23), Towyn	Pillbox	Building	259000, 297760	Desk-Based
Ornamental LCA					
PRN 4420	Peniarth Gardens, Llanegryn	Garden	Landscape	261200, 305400	Visit
PRN 11886	Dovecote, Ynysmaengwyn, Tywyn	Dovecote	Structure	259816, 302328	Visit
NPRN 525477	Boathouse, Ynysmaengwyn	Boat House	Structure	259691, 302499	Visit
NPRN 54224	Ynysmaengwyn;Ynys-Y-Maengwyn, Structures On South Side Of Yard Northwest Of Ruined Mansion, Bryn-Crug	Cottage	Building	259860, 302330	Desk-Based
NPRN 28635	Peniarth Estate Office	Estate Office	Building	261200, 305440	Desk-Based
PRN 12431	Peniarth House, Dysynni	House	Building	261215, 305401	Desk-Based
NPRN 28716	Rhowniar	Mansion	Building	259991, 298220	Desk-Based
Wetland and Beach LCA					
PRN 59667	Line Of Boulders, Aberdyfi	Feature	Structure	260180, 295950	Visit
PRN 997	Pont Dysynni Bridge	Bridge	Structure	259904, 303848	Visit
PRN 18385	Afon Dyffryn Gwyn Outfall, Tywyn.	Outfall Sewer	Structure	258250, 299350	Visit
NPRN 524780	Submerged Forest, Tywyn	Submerged Forest	Topography	258511, 298584	Visit
NPRN 518856	Aberdyfi Fish Trap 1	Fish Trap	Structure	260201, 295815	Visit
NPRN 518857	Aberdyfi Fish Trap 2	Fish Trap	Structure	260087, 268874	Visit
PRN 16601	Peat Exposured, Tywyn	Peat Deposit	Buried Features	258550, 298530	Visit
NPRN 411870	Peat Cuttings, Submerged Forest, Towyn	Peat Cutting	Structure	258400, 298800	Visit
NPRN 409087	Llangelynin Fish Trap	Fish Trap	Structure	256870, 307300	Desk-Based

PRN 24002	Sea Bank, Dysynni Marshes	Sea Defences	Structure	256698, 302603	Desk-Based
PRN 59661	Structure, Remains Of, NW Of Cae-Du	Structure	Structure	256820, 306200	Desk-Based
PRN 59658	Structure, Remains Of, NW Of Coed Y Gweddill	Structure	Structure	257735, 308543	Desk-Based
Tourism and Recreation					
PRN 25077	Golf Course Aberdyfi	Golf Course	Designed Landscape	259510, 296652	Visit
NPRN 409862	Brynffynon; Bryn-Y-Ffynnon	House	Building	261875, 303615	Visit
PRN 11886	Dovecote, Ynysmaengwyn, Tywyn	Dovecote	Structure	259816, 302328	Visit
NPRN 404790	Neptune Hall, Neptune Road, Tywyn	House	Building	258061, 299926	Visit
PRN 25069	Railway Bridge, Aberdyfi	Railway Bridge	Structure	261124, 295988	Desk-Based
NPRN 28714	Rhowniar, Cruck Hall	House	Building	259720, 298240	Desk-Based
NPRN 28551	Maengwyn Street 5,6,7	Dwelling	Building	258000, 300000	Desk-Based
Modern Settlement LCA					
NPRN 421672	Christ The King Catholic Church, Aberdyfi	Church	Building	260958, 296012	Visit
NPRN 301971	Tywyn Memorial Hospital	Hospital	Building	259100, 300506	Visit
PRN 7285	Promenade, Tywyn	Promenade	Complex	257850, 300360	Visit
NPRN 420927	Marconi Bungalowws, Tywyn	Settlement	Building	259505, 300183	Visit
888	Marconi Wireless Station Site Of Tywyn, Tywyn	TELEGRAPH STATION	Building - Roofed	259500, 300100	Desk-Based
409657	Plas Penhelig	House	Building	262139, 296333	Desk-Based
Historic Settlement					
NPRN 308288	Pont Fathew, Bryncrug	Bridge	Structure	260900, 303320	Visit
NPRN 409862	Brynffynon; Bryn-Y-Ffynnon	House	Building	261875, 303615	Visit

25084	Literary Institute, Former Bath House, Aberdyfi308288	Literary And Scientific Institute	Building	261707, 295997	Visit
25117	No. 2 Mervinia Terrace, Aberdyfi	Terraced House	Building	261838, 296096	Visit
NPRN 43861	St Cadfan's Church, Tywyn	Church	Building	258824, 300951	Visit
405304	The Vicarage, Outbuilding, National Street	Coach House	Building	258862, 300798	Visit
28396	Frankwell Street; 16-17; Almshouses Tywyn	Almshouse	Building	258950, 300860	Visit
34946	Talyllyn Railway; Tal-Y-Llyn Railway	Railway	Complex	258550, 300450	Visit
NPRN 404790	Neptune Hall, Neptune Road, Tywyn	House	Building	258061, 299926	Visit
4804	St. Cadfan's Chapel, Site Of, Tywyn Churchyard	Chapel	Earthwork	258830, 300960	Desk-Based
4798	St. Cadfan's Inscribed Stone, Tywyn Church	Inscribed Stone	Structure	258820, 300950	Desk-Based
28250	Cae'r Berllan: Gate Piers And Wall	Gate Post	Structure	266300, 307800	Desk-Based
4408	Caeberllan Garden, Llanfihangel-Y-Pennant	Garden	Landscape	266297, 307786	Desk-Based
41620	Corbett Arms Hotel - Coach Hse	Out-Building	Building	258870, 300998	Desk-Based
4800	Stone Setting, Tywyn Churchyard	Stone Setting	Structure	258770, 300940	Desk-Based

Table Ap3.4: *Number of sites that characterise each LCA*

LCA	Number of LCFs	LCFs assessed in Vulnerability Index	Percentage of LCFs included in Vulnerability Index (%)
Ancient	218	17	8
Historic Settlement	161	15	9
Modern Settlement	10	6	60
Historic Industry	263	18	7
Modern Industry	5	4	80
Maritime Industry	43	10	23
Regular Fieldsystems	46	9	20
Irregular Fieldsystems	49	9	18
Regular Drained Land	22	7	32
Irregular Drained Land	17	5	29
Ornamental	25	7	28
Tourism and Recreation	24	7	29
Ancient Woodland	46	8	17
Modern Woodland	22	7	32
Rough Pasture	702	19	3
Wetland and Beach	26	12	46
Military	28	8	29

Table Ap3.5*: Stage 1 Vulnerability Index results for each Landscape Character Feature assessed, in ascending order of Stage 1 score*

PRN/NPRN	Name	Level of Preservation (1-5)	Resistance of Remains (1-5)	Resistance of Substrate (1-5)	Susceptibility to Temperature Change (1-5)	Susceptibility to Precipitation Change (1-5)	**Stage 1 Score**	LCA
421672	Christ The King Catholic Church, Aberdyfi	1	1	1	1	1	**1**	Modern Settlement
28714	Rhowniar, Cruck Hall	1	1	1	1	1	**1**	Tourism and Recreation
409657	Plas Penhelig	1	1	1	1	1	**1**	Modern Settlement
308288	Pont Fathew, Bryncrug	1	1	3	1	1	**1.4**	Historic Settlement
34190	Glan Y Morfa, Bryncrug	1	1	1	1	3	**1.4**	Irregular Drained Land
25117	No. 2 Mervinia Terrace, Aberdyfi	1	1	2	1	2	**1.4**	Historic Settlement
525497	Engine Shed And Works, Ton-Fanau Quarry	1	1	2	1	2	**1.4**	Modern Industry
43861	St Cadfan's Church, Tywyn	1	1	3	1	1	**1.4**	Historic Settlement
301971	Tywyn Memorial Hospital	1	1	3	1	1	**1.4**	Modern Settlement; Military
404790	Neptune Hall, Neptune Road, Tywyn	1	1	3	1	1	**1.4**	Tourism and Recreation; Military; Historic settlement
28250	Cae'r Berllan: Gate Piers And Wall	2	2	1	1	1	**1.4**	Historic Settlement
28635	Peniarth Estate Office	1	1	3	1	1	**1.4**	Historic Settlement; Ornamental
41337	Rhyd-Yr-Onen Station	1	1	3	1	1	**1.4**	Historic Industry
41620	Corbett Arms Hotel - Coach Hse	1	1	3	1	1	**1.4**	Historic Settlement
20746	Dolgoch Viaduct, Talyllyn	1	1	2	1	2	**1.4**	Historic Industry
12431	Peniarth House, Dysynni	1	1	3	1	1	**1.4**	Historic Settlement; Ornamental
25085	Wharf, Aberdyfi	1	1	2	1	2	**1.4**	Maritime Industry
997	Pont Dysynni Bridge	2	1	3	1	1	**1.6**	Wetland and Beach

25084	Literary Institute, Former Bath House, Aberdyfi	1	1	2	2	2	**1.6**	Historic Settlement
301736	Tal-Y-Gareg Hillfort	1	2	2	2	1	**1.6**	Ancient
11886	Dovecote, Ynysmaeng wyn, Tywyn	2	1	3	1	1	**1.6**	Ornamental; Tourism and Recreation
405304	The Vicarage, Outbuilding , National Street	1	1	3	1	2	**1.6**	Historic Settlement
28396	Frankwell Street; 16-17; Almshouse s Tywyn	1	1	3	1	2	**1.6**	Historic Settlement
34946	Talyllyn Railway; Tal-Y-Llyn Railway	1	1	4	1	1	**1.6**	Historic Settlement
7285	Promenade , Tywyn	1	1	4	1	1	**1.6**	Modern Settlement
420927	Marconi Bungalows, Tywyn	1	1	3	1	2	**1.6**	Modern Settlement
28551	Maengwyn Street 5,6,7	1	1	4	1	1	**1.6**	Tourism and Recreation
28716	Rhowniar	1	1	4	1	1	**1.6**	Ornamental
57953	Cormorant Cottage, E Of Peniarth-Uchaf	3	1	2	1	1	**1.6**	Ancient Woodland
25069	Railway Bridge, Aberdyfi	1	1	4	1	1	**1.6**	Tourism and Recreation
24002	Sea Bank, Dysynni Marshes	2	1	3	1	1	**1.6**	Wetland and Beach
409862	Brynffynon; Bryn-Y-Ffynnon	1	1	2	1	4	**1.8**	Historic Settlement; Tourism and Recreation
501054	Allt-Lwyd, Stone Quarry Vii	3	2	2	1	1	**1.8**	Historic Industry
4931	Castell Y Bere	3	1	3	1	1	**1.8**	Ancient
18385	Afon Dyffryn Gwyn Outfall, Tywyn.	2	1	4	1	1	**1.8**	Wetland and Beach
286512	Clearance Cairn, Nant Braich-Y-Rhiw N Slopes	2	2	2	2	1	**1.8**	Rough Pasture
286544	Sheep Fold, Nant Y Bala	3	2	2	1	1	**1.8**	Rough Pasture
302238	Cil-Cemmaes	2	1	3	1	2	**1.8**	Regular Fieldsystems

888	Marconi Wireless Station Site Of Tywyn, Tywyn	1	1	3	1	3	**1.8**	Military; Modern Settlement
26343	Sheepfold, Tirgawen	3	2	2	1	1	**1.8**	Rough Pasture
4798	St. Cadfan's Inscribed Stone, Tywyn Church	2	2	3	1	1	**1.8**	Historic Settlement
4938	Standing Stone, Llanfihangel Y Pennant	2	2	3	1	1	**1.8**	Ancient
411783	Pillbox, Tywyn	3	1	4	1	1	**2**	Military; Wetland and Beach
501053	Allt-Lwyd; Stone Quarry Iii	3	2	2	1	2	**2**	Historic Industry
501068	Allt-Lwyd, Pillow Mound V	1	1	2	2	4	**2**	Ancient
409817	Tollgate Cottage, Tywyn	1	1	3	1	4	**2**	Irregular Fieldsystems
21875	Pant Y Cae Mine, Tywyn	4	2	2	1	1	**2**	Historic Industry
4932	Cairn, Site Of.	1	1	1	2	5	**2**	Irregular Drained Land; Irregular Fieldsystems
525492	Granite Quarry, Ton-Fanau	3	2	3	1	1	**2**	Modern Industry
302615	Bwlch, Field Boundary Marker	3	2	2	1	2	**2**	Modern Woodland; Regular Fieldsystems
3037	Hafotty-Hendre	3	2	3	1	1	**2**	Modern Woodland
54224	Ynysmaengwyn;Ynys-Y-Maengwyn, Structures On South Side Of Yard Northwest Of Ruined Mansion, Bryn-Crug	4	1	3	1	1	**2**	Historic Settlement; Ornamental
286634	Stone Circle, Trum Gelli Se Slopes	3	2	2	1	2	**2**	Ancient
9208	Bryn Eglwys Quarry Bridge 2, Llanfihangel-Y-Pennant	4	2	1	1	2	**2**	Rough Pasture
9254	Bryn Eglwys Quarry Building 4, Llanfihangel-Y-Pennant	3	2	3	1	1	**2**	Historic Industry

9271	Bryn Eglwys Quarry Reservoir 1, Llanfihangel-Y-Pennant	3	1	1	1	4	**2**	Modern Industry
57957	Building, W Of Coach-House And Stables At Peniarth-Uchaf	3	1	2	1	3	**2**	Ancient Woodland
38117	Cattle Shed, Mynydd Pencoed	3	2	3	1	1	**2**	Irregular Fieldsystems
4800	Stone Setting, Tywyn Churchyard	3	2	3	1	1	**2**	Historic Settlement
412911	Llanfendigaid Earthworks	1	3	2	2	3	**2.2**	Irregular Drained Land; Irregular Fieldsystems
26339	Quarry, Tirgawen	5	2	2	1	1	**2.2**	Historic Industry
7287	Rifle Range, Tywyn	3	1	4	1	2	**2.2**	Military
0	Feature 23	4	2	2	1	2	**2.2**	Rough Pasture
302862	Craig-Yr-Aderyn, Hillfort;Birds Rock	4	2	2	1	2	**2.2**	Ancient; Rough Pasture
407753	Craig Yr Aderyn, Cairn	4	2	3	1	1	**2.2**	Ancient; Rough Pasture
286533	Sheep Fold, Dolau-Gwyn	3	2	2	1	3	**2.2**	Rough Pasture
270343	Pillbox (Type Fw3-23), Towyn	3	1	5	1	1	**2.2**	Military
501127	Cwm-Llwyd, Sheep Wash Ii	2	2	3	1	3	**2.2**	Rough Pasture
9207	Bryn Eglwys Quarry Slate Mill, Llanfihangel-Y-Pennant	4	2	2	1	2	**2.2**	Historic Industry
4852	Cairn, Trum Gelli	3	2	2	2	2	**2.2**	Ancient
26329	Gateway, Tirgawen	3	2	3	1	2	**2.2**	Modern Woodland
9191	Moelfre Trough, Llanfihangel-Y-Pennant	2	2	2	1	4	**2.2**	Modern Woodland
59667	Line Of Boulders, Aberdyfi	3	3	4	1	1	**2.4**	Maritime Industry; Wetland and Beach
0	Feature 7	1	3	3	2	3	**2.4**	Regular Fieldsystems; Ancient
0	Feature 4	1	3	3	2	3	**2.4**	Regular Fieldsystems; Ancient

4420	Peniarth Gardens, Llanegryn	1	3	1	4	3	**2.4**	Ornamental
26317	Barn, Tirgawen	3	2	2	1	4	**2.4**	Rough Pasture
0	Feature 10	1	3	3	2	3	**2.4**	Regular Drained Land
310263	Square Barrow Cemetery, Croes Faen	1	3	3	2	3	**2.4**	Regular Fieldsystems; Ancient
0	Feature 16	1	3	3	2	3	**2.4**	Irregular Fieldsystems; Irregular Drained Land
0	Feature 17	1	3	3	2	3	**2.4**	Regular Fieldsystems; Regular Drained Land
18395	Pill-Box, Tywyn	4	2	4	1	1	**2.4**	Military; Wetland and Beach
40913	Caethle Mill	3	2	3	1	3	**2.4**	Irregular Drained Land
275900	Bryn-Crug Cropmark Complex, South-West Area;Bryncrug Cropmarks, South-West	1	3	3	2	3	**2.4**	Regular Fieldsystems
286506	Ditch, Nant Braich-Y-Rhiw N Slopes	1	3	2	2	4	**2.4**	Rough Pasture
286541	Boundary, Nant Braich-Y-Rhiw N Slopes	4	3	2	2	1	**2.4**	Rough Pasture
409397	Maes-Y-Llan Stone Spread	4	2	3	2	1	**2.4**	Irregular Fieldsystems
409398	Llanfihangel-Y-Pennant, Ruin To East Of Village	3	2	2	1	4	**2.4**	Irregular Fieldsystems
411279	Concrete Slipway, Fron-Goch	3	2	3	1	3	**2.4**	Ancient
1739	Castell Mawr Hillfort, S Of Rhoslefain	2	3	2	2	3	**2.4**	Irregular Fieldsystems
4811	Cropmark, N Of Croes Faen	1	3	3	2	3	**2.4**	Regular Drained Land
4812	Cropmark, N Of Croes Faen	1	3	3	2	3	**2.4**	Regular Drained Land
59658	Structure, Remains Of, NW Of Coed Y Gweddill	3	2	4	1	2	**2.4**	Regular Fieldsystems; Wetland and Beach

1740	Domen Ddreiniog; Motte;Dyffryn Dysynni	2	3	3	2	3	**2.6**	Ancient
57995	Building And Walled Garden, E Of Bod Talog	2	1	4	4	2	**2.6**	Ancient Woodland
0	Tirgawen Ancient Woodland	2	3	2	4	2	**2.6**	Ancient Woodland
26323	Drystone Wall, Tirgawen.	4	2	3	1	3	**2.6**	Rough Pasture
20563	Level, Foel Ty'r Gawen	5	2	2	2	2	**2.6**	Historic Industry
0	Feature 46	1	3	3	2	4	**2.6**	Regular Drained Land
18387	Afon Dyffryn Channel, Flood Banks And Main Drain, Tywyn	2	3	4	1	3	**2.6**	Regular Drained Land
20561	Quarry, Wern	5	2	3	1	2	**2.6**	Historic Industry
500985	Cwm-Llwyd, Sheep Pen Iii	5	2	2	1	3	**2.6**	Rough Pasture
286621	Boundary Bank, Braich Ddu Se Peak	4	3	2	2	2	**2.6**	Rough Pasture
500888	Peniarth Slate Quarry, Caban	3	2	4	1	3	**2.6**	Historic Industry
500889	Peniarth Slate Quarry, Path	2	3	3	2	3	**2.6**	Historic Industry
500914	Cwm-Llwyd, Possible Cairn Iv	3	2	2	2	4	**2.6**	Ancient
501211	Bodwylan, Clearance Cairn Iii	1	2	4	2	4	**2.6**	Rough Pasture
2986	Ffynnon Y Fron, Dysynni	2	2	3	3	3	**2.6**	Ancient Woodland
20495	Granite Quarry, Bach Y Sil Nr Towyn	3	2	3	1	4	**2.6**	Modern Industry
4804	St. Cadfan's Chapel, Site Of, Tywyn Churchyard	5	2	3	2	1	**2.6**	Historic Settlement
59786	Wall, Remains Of, Ynysmaengwyn	3	2	3	1	4	**2.6**	Regular Fieldsystems
0	Feature 46	1	3	3	2	4	**2.6**	Regular Drained Land

0	Feature 22	4	2	5	1	2	**2.8**	Rough Pasture
286508	Shaft, Cwm Pandy	4	3	2	2	3	**2.8**	Historic Industry
26328	Boundary Bank, Tirgawen	2	3	3	2	4	**2.8**	Modern Woodland
26307	Building Platform, Tirgawen	4	2	4	2	2	**2.8**	Ancient Woodland
4408	Caeberllan Garden, Llanfihangel-Y-Pennant	1	3	1	4	5	**2.8**	Historic Settlement
9237	Cwmcwm Incline Drumhouse, Llanfihangel-Y-Pennant	4	2	3	1	4	**2.8**	Historic Industry
59660	Ty Coch Farm, Remains Of, W Of Bodgadfan	3	2	5	1	3	**2.8**	Regular Fieldsystems
7281	Military Camp, Tonfanau	4	4	3	1	3	**3**	Military; Irregular Drained Land
500855	Bodwylan, Causeway	4	3	3	2	3	**3**	Historic Industry
500869	Cwm-Llwyd, Spoil Heap I	3	4	2	2	4	**3**	Historic Industry
500993	Twllydarren, Trackway Iv	3	3	3	2	4	**3**	Historic Industry
501077	Allt-Lwyd, Bank Xi	4	3	2	2	4	**3**	Rough Pasture
501117	Cwm-Llwyd, Sheep Pen Vi	3	2	4	2	4	**3**	Rough Pasture
9211	Beudynewydd Incline, Llanfihangel-Y-Pennant	4	3	3	2	3	**3**	Historic Industry
2977	Enclosure, Hut Circle, Allt Lwyd	3	3	2	2	5	**3**	Ancient
29514	Shooting Butt, Tywyn	4	3	3	2	3	**3**	Military
3820	Tomen Cil Y Parc, Tumulus/Motte, Site Of, Dysynni	4	3	3	2	3	**3**	Irregular Fieldsystems
26326	Wall, Tirgawen	4	2	4	2	3	**3**	Ancient Woodland
0	Bwlch Modern Woodland	3	3	3	4	3	**3.2**	Modern Woodland
26330	Path; Tirgawen	3	3	3	3	4	**3.2**	Modern Woodland
5382	Burnt Mound, Happy Valley	1	3	2	5	5	**3.2**	Ancient
26309	Bank, Tirgawen	4	3	4	2	4	**3.4**	Ancient Woodland

59661	Structure, Remains Of, NW Of Cae-Du	4	4	4	2	3	**3.4**	Wetland and Beach; Maritime Industry
25077	Golf Course Aberdyfi	1	4	4	4	5	**3.6**	Recreation/Wetland
525477	Boathouse, Ynysmaengwyn	5	4	4	5	1	**3.8**	Ornamental; Maritime Industry
518856	Aberdyfi Fish Trap 1	5	5	3	3	3	**3.8**	Maritime Industry; Wetland and Beach
16601	Peat Exposured, Tywyn	5	5	3	3	3	**3.8**	Wetland and Beach; Ancient
411870	Peat Cuttings, Submerged Forest, Towyn	5	5	3	3	3	**3.8**	Wetland and Beach; Maritime Industry
409087	Llangelynin Fish Trap	5	4	4	3	3	**3.8**	Wetland and Beach
524780	Submerged Forest, Tywyn	5	5	4	3	3	**4**	Wetland and Beach; Ancient
286569	Peat Cutting, Trum Gelli	3	5	4	5	3	**4**	Rough Pasture
518857	Aberdyfi Fish Trap 2	5	5	4	3	4	**4.2**	Maritime Industry; Wetland and Beach