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Climate Change and Cultural Heritage: a Landscape Vulnerability Framework

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Climate Change and Cultural Heritage: a Landscape Vulnerability Framework

This paper proposes a new framework for calculating vulnerability indices within archaeological resource management on a landscape-scale. Current approaches consider archaeological sites in isolation from their context within the historic landscape. The new framework advocated in this article assesses the vulnerability of landscape character areas, as defined through historic landscape characterisation. This framework uses a two-step vulnerability index: the first assesses the vulnerability of archaeological sites and landscape features; the second 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. The framework is applied to a brief case study in coastal North Wales, UK.

Keywords: climate change, vulnerability, archaeology, landscape, historic landscape characterisation

Introduction

There is no single definition of vulnerability, as it is used across many disciplines in relation to a wide range of systems, phenomena, and hazards (Barnett et al. 2008). For the purpose of this paper, vulnerability will refer to the accepted use within the disciplines of archaeology and physical geography, namely the probability that a system or phenomenon will experience harm because of a hazard or threat, whether a short-term event or long-term stress (Accardo et al. 2003; Turner *et al*. 2003). This definition of vulnerability is considered a function of three factors: exposure, sensitivity (or susceptibility) and adaptive capacity (or coping capacity or resilience) (e.g. Balica and Wright 2010; Balica *et al*. 2012; Glick and Stein 2010; Nguyen *et al*. 2016). Exposure is the likelihood that a system will be affected by a threat as a result of its location. For instance, a coastal town has higher exposure, and therefore higher vulnerability, to storm surges compared to an inland town. Sensitivity is defined as the degree to which the exposed elements of a system are affected by the threat, which influences the probability of damage occurring to or within the system. Adaptive capacity is the capacity of a system to respond to change, maintain its functions, and cope with the consequences. This can be influenced by anthropogenic factors, but can also be an inherent attribute of the system. Anthropogenic adaptive capacity can include institutional planning, technology such as warning systems, and defence infrastructure (Nguyen *et al.* 2016). Other systems, such as ecosystems, can have inherent adaptive capacity influenced by factors such as species diversity and abundance, evolutionary adaptive potential, and connectivity of ecosystem patches (Whitney *et al.* 2017). The adaptive capacity of a particular system can be influenced by both anthropogenic and inherent factors, so this paper uses ‘adaptive capacity’ to refer to both anthropogenic and inherent aspects of system resilience. In general, the adaptive capacity of built heritage and archaeological features is influenced by anthropogenic systems, while that of ‘living’ heritage features, such as ancient woodland and historic parks, is influenced by the robustness of species and ecosystems.

A high level of vulnerability will result from high exposure, high susceptibility and low adaptive capacity; an increase in adaptive capacity or a decrease in exposure or susceptibility will reduce the overall vulnerability of a system.

Vulnerability indices (VIs) are created and used to assess the potential impact of natural and anthropogenic hazards on historical and archaeological assets (e.g. Boruff and Cutter 2007; Hegde and Reju 2007; McLaughlin *et al*. 2002; McLaughlin and Cooper 2010; Thieler and Hammar-Klose 2000). However, there are conceptual weaknesses in the way that historical and archaeological assets are framed within most VI studies. These weaknesses influence the methodologies and results of these studies, and the subsequent outcomes for archaeological resource management.

This article proposes a landscape-scale framework (Landscape Vulnerability Framework) for archaeological VIs. The need for vulnerability studies to address landscapes rather than sites in isolation can be illustrated with an example from England's coastline. Coastal erosion is known to have already 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). The town of Dunwich on the coast of Suffolk, with a current population of less than 200 (Office for National Statistics 2013), was once a large port. In 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 James leper chapel, Maison Dieu hospital and Franciscan Friary were all damaged or destroyed in the 18th century (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 the loss of the heritage of the town and the historic character of the urban landscape. The projected impacts of future climate change, such as sea-level rise and an increased frequency of extreme weather, will only exacerbate the risk of erosion to coastal regions.

Several studies assess the vulnerability of archaeological heritage to environmental processes (e.g. Daire *et al*. 2012; Reeder *et al*. 2012; Reeder-Myers *et al*. 2015; Westley *et al*. 2011; Westley and McNeary 2014). However, these studies base their VIs on historic or observed rates of environmental change, and therefore do not consider the ways in which climate change is predicted to alter current environmental processes. For example, under a medium emissions scenario, UKCP09 projects a likely increase in winter precipitation of 30-40% on the UK west coast, and a decrease in summer precipitation of 10-20% in in the south of the UK by 2080, relative to 1961-1990 (UKCP09: Watts *et al*. 2015). Under the same emissions scenario, the IPCC projects a mean rise in global sea-level of 0.52m by 2081-2100 compared to the period 1986-2005 (Palmer *et al*. 2016). In the unlikely scenario that all intended nationally determined contributions (INDCs) submitted to the UNFCCC prior to the Paris COP21 Agreement were met, global temperatures are still predicted to increase by 2.7°C by 2100 compared to 1990 (Gütschow *et al*. 2015). These major changes in global climate and regional weather systems will have dramatic effects in the environmental processes that impact archaeological heritage. Sea-level rise will cause the intertidal zone to shift inland, subjecting new sites to potential damage through inundation and wet/dry cycles (Anderson *et al*. 2017). Changes to precipitation patterns may lead to desiccation of previously wetland sites during the summer months, and an increase in gullying erosion and flooding during the winter (Cassar and Pender 2003). It is for this reason that the Landscape Vulnerability Framework uses near-future climate projections (up to c.2100) to assess the vulnerability of cultural heritage assets and landscapes, rather than basing VI assessments on current or historic weather conditions.

This article first reviews and identifies limitations with the current approaches used in VI assessments for archaeology, in particular in relation to natural hazards. It then proposes a Landscape Vulnerability Framework for VIs that addresses the limitations within current approaches. The implications for archaeological heritage management will also be demonstrated using a brief case study from coastal North Wales, UK. In this article, cultural heritage will be used to refer to physical heritage assets such as archaeological remains and historic buildings, and the influence they have on local culture (for instance creating a physical connection with local history, continuing traditional land-use practices, and imparting a sense of place and belonging). It can also be used to refer to intangible elements of culture such as language, customs, artistic expression and values, however these aspects of cultural heritage are beyond the scope of this paper.

Current approaches to vulnerability indices in archaeological heritage management

A vulnerability index is a tool used to quantify the likelihood that an asset will be affected by predicted threats. VIs are derived from indicators such as distance to shoreline and rate of erosion, which are themselves proxies for threats posed by complex and uncertain systems like climate change (Balica *et al*. 2012; Barnett *et al*. 2008). The quantification of vulnerability using these indicators makes it feasible to compare different entities, such as cities, areas of coastline, or archaeological sites. Quantification, and therefore comparability, also increases decision-makers' understanding of the systems in question, and can inform more efficient resource management by identifying the areas that are most at risk and the reasons for variations in vulnerability (Balica *et al*. 2012; Boruff and Cutter 2007; Glick and Stein 2010; Reeder *et al*. 2012).

Glick and Stein (2010) argue that there is no single correct approach for calculating VIs, as the suitability of the approach depends on the object and purpose of the vulnerability assessment. These factors, and the difficulties attempting to simplify complex systems such as climate change, mean that there have been hundreds of attempts to create VIs (Barnett *et al*. 2008). This section reviews the most common approaches to vulnerability assessment within archaeology, covering studies worldwide, in places such as the Caribbean, USA, France, and Northern Ireland. 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 and areas whose vulnerability is being assessed.

The following review was limited to the use of VIs to assess the vulnerability of archaeological sites – 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, however the proposed Landscape Vulnerability Framework could be applied to any threat.

Variables

Most VI projects have been desk-based, allowing a wider geographical are 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. Chadwick-Moore 2014; Pendleton *et al*. 2005; Reeder *et al*. 2012; Reeder-Myers *et al*. 2015; Van Rensselaer 2014; Westley *et al*. 2011; 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; they neglect the resilience of the site to threats. For instance, an archaeological site may be buried and well preserved, or constructed of durable materials, and therefore have much greater resilience to any threat than a site in the same location that is exposed and susceptible to damage (Daire *et al*. 2012). This can also been seen in a vulnerability model for Bering Land Bridge National Preserve by the US National Park Service, which 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).

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. For example, 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 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; Reeder *et al*. 2012; Westley *et al*. 2011) However, relative VIs reduce the potential for inter-regional comparison.

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. Reeder-Myers 2015; Westley *et al*. 2011). 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 Chadwick-Moore 2014; Grossi *et al*. 2007; Westley *et al*. 2011). 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; Reeder-Myers *et al*. 2015; Westley and McNeary 2014). 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*. 2014; Fitzpatrick *et al*. 2013; Minos Minopolous 2015).

Objects

The majority of the studies focus specifically on archaeological 'sites'. Reeder *et al*. (2012:189) 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*. (2012:175) say that their research looks at sites comprising "all remains of built structures of anthropogenic origin or materials transformed by human activities." Three studies (Chadwick-Moore 2014; Robinson *et al*. 2010; 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. Chadwick-Moore 2014; Fitzpatrick *et al*. 2006; Reeder-Myers 2015; Van Rensslelaer 2014; Westley *et al*. 2011). 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

(1992:29) 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). Therefore, 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 will 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.

That is not to say that site-specific VIs cannot be useful for cultural heritage management. Assessments of significant heritage sites can provide insight into the specific management requirements of each site (see Daly 2013's detailed assessment of Skellig Michael and Brú na Bóinne, Ireland). However, for the most part vulnerability assessments that include a large number of sites within a landscape fail to acknowledge the interconnectivity between sites and how they influence the historic landscape (see below).

A Landscape Vulnerability Framework

The preceding review identified several limitations with the most common approaches to VIs in archaeological heritage management. Most studies focus on the hazards to which sites are exposed, and not the susceptibility and resilience of the sites to hazards. This accounts for only one of the three factors influencing vulnerability, according to its accepted definition. A second limitation is that most studies do not account for the future influence of climate change. The majority predict the likelihood of exposure to a hazard based on past trends such as historic or observed rates of erosion or sea-level rise. This neglects the impact that climate change will have on natural systems, and may therefore miscalculate the impact the systems and their resulting phenomena may have on archaeological heritage. Finally, previous studies focus on ‘sites’ as a unit of investigation without consideration of the historicity of the landscape of which sites are constituents.

This article proposes an alternative framework to vulnerability assessment for archaeological heritage that addresses the limitations outlined above. The framework assesses the vulnerability of historic landscapes to threats such as future climate change. This section will summarise the concept of the historic landscape and explain why it is an important consideration in vulnerability studies. It then introduces Historic Landscape Characterisation (HLC) as a method of landscape analysis. The scope of the landscape vulnerability framework is then described, including which vulnerability variables are included, and which threats are considered. Finally, the Landscape Vulnerability Framework is applied to a brief case study.

Historic Landscape

The concept of the ‘historic landscape’ has existed in the academic literature since at least the 1950s, with JB Jackson and WG Hoskins amongst the most frequently cited authors who are credited with inspiring and popularising the idea (e.g. Wylie 2007: 30-53). At heart, the idea is simple, even common-sensical: our landscapes were created through historical processes, and the traces of those processes are visible in the present-day physical fabric and in cultural representations of landscapes. The historic landscape can therefore be compared with and analysed like other human-made objects, such as artefacts or texts. Fairclough *et al*. (2002, p.70) describe the historic landscape as “an artefact of past land-use, social structures and political decisions”. This considers the structure of a landscape, such as field boundary morphology, settlement structure, and the location of industry, as a product of a long history of human activities that continues up to the present day (Fairclough 2003a, 2003b, 2006). A historic landscape perspective therefore does not assume that modern changes are intrinsically destructive or valueless, but rather it treats modernity as another layer of historicity in the formation of landscapes (Bradley *et al*. 2004).

The historic landscape can be analysed and interpreted using Historic Landscape Characterisation (HLC) (see Fairclough 2003a; Fairclough 2006; Turner 2006). In HLC, attributes such as field boundary morphology, the location of historic and modern industry and settlement, and archaeological features, are used to define landscape character areas (LCAs), such as Historic Settlement, Ancient Enclosed Land, Military etc. (e.g. Cornwall County Council 2011). HLC identifies and maps areas in which previous and current land use is evident in the visual structure of the landscape, so the landscape's character is influenced by the cumulative outcome of human activity.

Some HLC projects have identified the potential for assessing the vulnerability of landscape character. For instance A Guide to Using the Cumbria Historic Landscape Characterisation Database for Cumbria's Planning Authorities states that: "[c]haracter areas also facilitate the identification of the most vulnerable aspects of local landscape character" (Newman and Newman 2009: 11). Indeed, Historic England state that "Historic Landscape Characterisation (HLC) shows the need for broader historic landscape-based [conservation] policies as well [as those that focus on individual sites and monuments]" (Clarke *et al*. 2004: 27). These examples acknowledge the potential for LCAs to be objects of vulnerability assessment. However, to date, archaeological vulnerability assessments have maintained the focus on sites and features, without acknowledging the wider implications on the landscape as a whole. Therefore, the Landscape Vulnerability Framework proposed in this article assesses the vulnerability of LCAs to threats such as climate change. This uses a cumulative approach;

the VI score for archaeological and historical features is used as a variable for calculating the vulnerability of LCAs.

New Framework: Vulnerability Variables

Most VIs employ a one-step approach to assessing vulnerability, with all variables incorporated within a single equation (e.g. Alexandrakis *et al*. 2010; Chadwick-Moore 2014; Daire *et al*. 2012; Daly 2014; McLaughlin and Cooper 2010; Van Rensselaer 2014 - Reeder *et al*. 2012 is an exception). The Landscape Vulnerability Framework uses two equations. First, it calculates the vulnerability of 'landscape character features' (LCFs), before scaling these up to consider threats to the LCAs. LCFs are parts of a landscape that influence the character of LCAs, such as drystone walls, historic military defensive features, and areas of ancient and plantation woodland. This can include archaeological 'sites', natural/living features, and buildings and transport routes that are still in use. This first equation calculates the vulnerability of LCFs, with a focus on the susceptibility and resilience of LCFs to climate change impacts. The second VI equation works at the level of the LCA: it calculates the vulnerability of LCAs using the vulnerability of the LCFs (as calculated using the first equation), the susceptibility of the LCA to soil erosion, and exposure to projected sea-level rise and coastal erosion. These two stages to the calculation will now be explained in depth.

Stage 1 - 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. However, 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) argue that the variables used in VIs should be "measurable, accessible, transferable, easy to be applied in practice, and not redundant" (p.24). Therefore, the variables used in this study were chosen on the basis of their accessibility and their transferability between regions.

Five variables are considered in the vulnerability equation for the LCFs: current levels of preservation (a), resistance of the remains (b), resistance of the local substrate (c), the susceptibility of the LCF to projected temperature changes (d), and the susceptibility of the LCF to projected precipitation changes (e). Table 1 provides an example of how these variables may be classified in the VI.

$$V = \frac{a+b+c+d+e}{5} \tag{1}$$

Variables *a* and *b* address the susceptibility and adaptive capacity of the LCF, variable *c* addresses the exposure of the LCF, and variables *d* and *e* address the susceptibility of the LCF. For variables *a*, *b* and *d,* fieldwork may be required to determine the current level of preservation, and to gather data on the constituent materials of the LCFs. Some landscapes may have been subject to previous archaeological surveys, so the location, type and form of the LCFs may already have been recorded. In this case, up-to-date archaeological or monument databases will suffice as a record for the state of LCFs. A small number of site-visits should nevertheless be undertaken to ground-truth the available archaeological information and determine its suitability for satisfying the VI. Research using these techniques

Variable *c* can be based on geological survey data, which will indicate which LCFs are located on unconsolidated materials and are therefore more susceptible to erosion. For variable *e*, a model of flow accumulation can be calculated in GIS to identify the areas most susceptible to projected increases in precipitation. Flow accumulation is an indication of 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 more likely to experience torrents and gully erosion during high rainfall events (Mitasova *et al*. 1996; Zlocha and Hofierka 2014).

The variables addressing projected temperature (*d*) and precipitation change (*e*) are based on the most up-to-date available information on projected climate change in the study area. The temporal extent of most integrated model assessments and emission scenarios within climate change research focus solely on the current century (up to 2100) (e.g. Collins *et al*. 2013; Meinshausen *et al*. 2011). The uncertainties inherent in climate models, future greenhouse gas 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. However, using near-future (21st-century) climate projections will provide data that is more relevant for informing future archaeological heritage management than VIs based on historic levels of precipitation, erosion, or temperature variation.

When undertaking the fieldwork at all or a sample of LCFs, it is important to cover a variety of types of feature in order to factor in the variability of feature types and their differing vulnerability. The specific nature of the variability in LCF types will be context-specific and influenced by the landscape and LCFs under scrutiny, so the approach taken will require a qualitative judgement by the researchers undertaking the study. A useful approach may be to base feature variability on the materials that constitute the feature and influence its susceptibility to threats like erosion and desiccation. For instance, sampling could be based on different material categories: earthwork, stone or rubble, and brick or concrete features. Categorising and sampling the features in this way would account for the variation in vulnerability of different types of features more effectively than taking a random sample, which may not cover all LCF types.

The number of LCFs that should be included in the VI also depends on the context; in a landscape with little variability in LCFs, fewer may need to be sampled than in a landscape with lots of variation in LCF-type. This is because the second equation (see below) uses the mean LCF vulnerability as a variable to measure LCA vulnerability. Furthermore, some LCAs may contain a high number of discrete features, such as mineshafts, whereas others are characterised by spatially extensive LCFs such as field-systems or woodland. Therefore, the appropriate sample size of LCFs to include in the VI is dependent on the landscape context, the LCA and the type of LCFs that characterise it. Critically, the researchers must have sampled sufficient LCFs to be confident that the results are representative of the whole population.

Stage 2 - Vulnerability of Landscape Character Areas

A vulnerability score for the LCAs is calculated using the following variables: the vulnerability of the LCFs that characterise the LCA (*f* – the outcome of the first VI equation), the proportion of the LCA that is threatened by sea-level rise and inundation (*g*), the proximity of the LCA to an eroding stretch of shoreline (*h*), and the susceptibility of the soil types in the LCA to erosion (*i*) (see Table 2). The latter two variables were chosen as indicators of the exposure of LCAs to climate change impacts, while the former three variables address the susceptibility and resilience of the character of the LCA WRONG. This equation will be applied to each of the LCAs established in the HLC.

$$LCA\ V = \frac{f+g+h+i}{4} \qquad (2)$$

Variables *g* and *h* address the issue of exposure to the threat, in this case climate change. The areas threatened by sea-level rise and inundation (variable *g*) can be modelled using digital elevation models in GIS, based on national, regional and global sea-level projections (e.g.

Church *et al*. 2013). The recent rate of shoreline erosion can be informed by comparing the location of the mean high-water mark on modern and historic maps, or in areas with high erosion rates by using aerial photographs and LiDAR. This method only considers scenarios in which future rates of shoreline erosion reflect current or historic rates. However, it does indicate the areas in which the geomorphological conditions and coastal processes result in higher rates of erosion, and therefore where erosion is likely to continue in the future. Due to the uncertainties regarding future emission levels and the reaction of the climate system to increased radiative forcing (Burke *et al*. 2015), there are inherent difficulties with basing vulnerability assessments on predicted future conditions rather than historic or current trends. Therefore, for complex processes such as coastal erosion, identifying areas at risk based on the location of a presently actively eroding shoreline may be as reliable as developing a complex model to predict future erosion.

Variable *i* addresses the susceptibility of the whole LCA to soil erosion, rather than just the susceptibility of the LCFs within it. This can be calculated using soil survey data, which, if available, includes information such as the soil type, rate of drainage, and susceptibility to certain threats (e.g. Cranfield University 2018).

An important objective with this framework is to identify the absolute vulnerability of LCAs to climate change, rather than their relative vulnerability. As previously discussed, several studies exclude certain 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 homogenous 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.

Case study: Dysynni Valley, North Wales, UK

This section provides a brief example of the way that the Landscape Vulnerability Framework was applied to a coastal landscape in North Wales. The Dysynni Valley, Gwynedd, is designated as a Landscape of Special Historic Importance by Cadw, the Welsh Government's historic environment service, as this region has a long and rich history of human settlement. Most known archaeological sites are in the upland areas, due to the disruption caused by centuries of agricultural activity in the lowlands, as well as a 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. Furthermore, there is a wealth of evidence of the importance of the area to early Welsh Christianity, such as inscribed stones and almost 100 extant churches and chapels (GAT 2019; RCAHMW 2019). Military structures along the coast also indicate the influence of modern conflict on the character of this landscape. The valley floodplain lies below 10m OD (Ordnance Datum) up to 10km inland along the river valley, making it vulnerable to the impacts of climate change such as sea-level rise, storm surges and high rainfall events (Kriebel *et al*. 2015). HLC was applied to the Dysynni Valley using information from historical and modern OS maps, aerial photography, national archaeological databases, and geophysical surveys (see Figure 1). Seventeen LCAs were established based on the evidence of current and historical land-uses in the landscape, including pastoral agriculture, post-medieval industrial activity like mining, and Second World War military activity.

LCFs such as historic buildings, archaeological sites, parks and gardens, and field boundaries, were identified using Level 1 surveys and the Historic Environment Record (HER) and National Monuments Record Wales (NMRW) databases. In total, 1,455 LCFs were identified in the study area, approximately 180km^2. As it was not feasible to visit all

LCFs to assess their level of preservation, 64 LCFs were visited to ground-truth the information in the HER and NMRW databases. This assessed whether the information and description included in these databases would be suitable for undertaking the VI without visiting each LCF. Following the methodology outlined above, a range of LCFs were selected based on their different constituent materials. The outcomes of this fieldwork indicated that the archaeological databases were suitable for assessing the level of preservation and resistance of the LCFs for the purposes of this VI. Following this initial assessment, a further 81 LCFs in the archaeological databases were assessed using the VI, to increase the number of LCFs assessed to 145, 10% of the total population. Those chosen were proportional across all LCAs and were also in proportion with the different constituent material groups in each LCA (Brick and Concrete; Stone and Rubble; Living and Organic; Earthwork).

For the second VI, exposure to coastal erosion was calculated by identifying areas of eroding coastline by comparing the location of Mean High-Water Springs between the first-edition OS map with the current OS map. Sea-level rise projections were based on the Risk of Flooding from Rivers and Seas (RoFRS) data available to download from the Welsh Government's GeoPortal (lle.gov.uk). The RoFRS projections were broken down into level of risk: High (1-in-30 chance of flooding), Medium (1-in-30 to 1-in-100), Low (1-in-100 to 1-in-1000), and Very Low (greater than 1-in-1000). These projections took account of existing flood defences, including the height and condition of the defences. Susceptibility to soil erosion was based on soil data provided by the British Geological Survey (Cranfield University 2018).

Results

The vulnerability results for the assessed LCFs range from 1.975 to 4.4, but are mainly distributed between 2 and 3 (see Table 3). When displayed on a map (Figure 2), the results show that the LCAs at greatest risk are those located in the most low-lying and coastal areas, due to the high risk of flooding along the valley and coastline and the threat of coastal erosion.

Figure 2 also shows the VI score for each LCF visited. This shows that in some cases the vulnerability of the LCF does not align with the vulnerability of the LCA as a whole. For instance, some earthwork features near Tirgawen (A) were classified as at higher risk, but they characterise the Rough Pasture LCA, which has low vulnerability, so they should not necessarily be prioritised for management. In contrast, on the beach near Penllyn (B), some military features were classified as lower risk as they were made of resistant materials such as brick. However, their location in relation to flood and erosion risk is such that the military LCA should be prioritised for further research, monitoring and management due to the high risk posed to it by climate change. This highlights the importance of assessing the vulnerability of the historic character of the landscape, rather than individual archaeological sites.

Discussion and Conclusion

This article proposes a Landscape Vulnerability Framework for archaeological resource management, which addresses fundamental limitations with the most commonly used current methods for calculating VIs for archaeological sites and landscapes. Primarily, in developing a framework to assess the vulnerability of the archaeological resource on a wider (landscape) spatial scale, this paper aims to shift the focus of vulnerability studies in archaeological resource management towards the wider impact on historic landscapes, rather than looking only at sites in isolation.

Site-focussed vulnerability assessments neglect the importance of the structure and character of the historic landscape for cultural heritage, and are therefore not useful for informing archaeological heritage management on a scale wider than site designation and conservation. As well as the example of Dunwich (see Introduction), there are several instances of areas in which the historic character of the landscape has been lost or dramatically altered due to coastal processes. For instance, the south-east coastline of England is characterised by defensive structures and fortifications that have been built in all periods of history since pre-Roman times (Bromhead and Ibsen 2006). However, coastal erosion and landslides have caused many of these coastal defences to be damaged or destroyed. Not only is the loss of each of these archaeological features significant, but it also threatens the military and defensive character of the landscape as a whole. Furthermore, the case study in Figure 2 indicates that the vulnerability of landscapes are not always correlated with the vulnerability of their individual components. Therefore, it is important for vulnerability assessments to acknowledge the wider context of the cultural heritage and landscape character, rather than focussing solely on archaeological 'sites' in isolation and without regard to their context.

Another criticism of many VIs used in archaeology is that the quantified threats are based on current or recent historic conditions or trends. In the context of rapid environmental and ecological change, and changing socio-political attitudes towards cultural heritage and landscape management, it is crucial to be more forward-looking when identifying the factors that may threaten historical assets. Therefore, the Landscape Vulnerability Framework incorporates relevant projections from climate models . The proposed framework could also be applied to other threats to cultural heritage, such as urban development and extractive industries. To adapt the VI to incorporate these threats, factors such as governmental and local council policies regarding the location of development or permissions for extractive industries should be included in the VI, in place of the climate-related variables. This maintains the focus on likely future threats, rather than just extrapolating historic trends in the location of development.

In terms of heritage management, the information generated by using this framework is useful for informing holistic heritage management within a landscape, and reveals broader trends than would be evident in site-specific research. The framework does still include consideration of archaeological features, as they influence the historic and visual character of the landscape. However, they are used as proxies for the vulnerability of an element of the landscape character within the LCA VI, so the focus remains on the LCAs and historic landscape as a whole.

With an increasing threat to coastal archaeology from the impacts of climate change worldwide, it is unlikely that the resources exist to protect all archaeological sites at risk. Therefore, it is important to consider a broader perspective on cultural heritage management, to identify the key areas of importance to local heritage (Landorf 2009).

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Table 1. Description and division of the variables used to calculate the vulnerability score for archaeological sites

Table 1 : Description and division of the variables used to calculate the vulnerability score for archaeological sites		
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 located on unconsolidated sediments in areas with very low flow accumulation (<50).	3
	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

Table 2. Description and division of the variables used to calculate the vulnerability score for LCAs

Table 2: Description and division of the variables used to calculate the vulnerability score for LCAs

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
% of LCA at risk of flooding and storm surge	<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 2.88m OD) and/or >70% at high RoFRS	5
Proximity to unprotected eroding shoreline	None of the LCA is 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
Susceptibility of soil type to erosion (information from British Geological Survey)	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	2

the classification chosen should be based on the most common soil characteristics for each LCA	Shallow soils and bare rock in places Risk of soil erosion due to grazing and trampling Slow or impeded drainage Steep slopes	
	Two of the above criteria	3
	Three of the above criteria	4
	Four or more of the above criteria	5

Table 3. LCA VI Results

Table 3: LCA VI Results	
LCA	***Mean LCA VI score***
Modern Settlement	1.975
Historic Settlement	2
Modern Woodland	2.125
Ancient	2.175
Irregular Field Systems	2.225
Irregular Drained Land	2.375
Rough Pasture	2.45
Historic Industry	2.45
Modern Industry	2.5
Tourism and Recreation	2.5
Regular Field Systems	2.7
Ornamental	2.75
Ancient Woodland	2.75
Regular Drained Land	2.775
Military	3.7
Wetland and Beach	4.25
Maritime Industry	4.4

Figure 1. Historic Landscape Characterisation applied to the Dysynni Valley, North West Wales

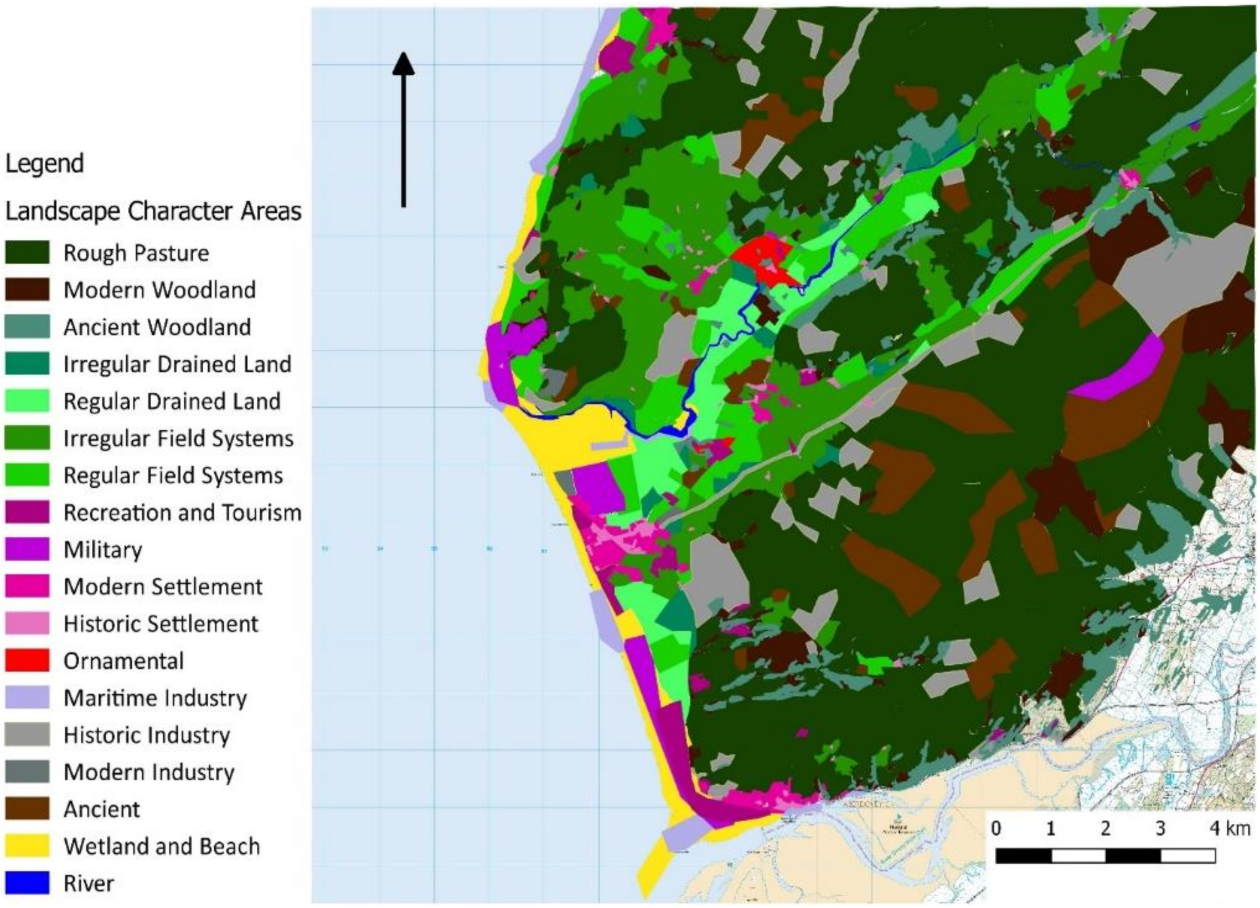
Legend
Landscape Character Areas
Rough Pasture
Modern Woodland
Ancient Woodland
Irregular Drained Land
Regular Drained Land
Irregular Field Systems
Regular Field Systems
Recreation and Tourism
Military
Modern Settlement
Historic Settlement
Ornamental
Maritime Industry
Historic Industry
Modern Industry
Ancient
Wetland and Beach
River
0 1 2 3 4 km

Figure 2. LCF VI scores and LCA VI results