Proceedings of the Geologists' Association xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Proceedings of the Geologists' Association

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

A qualitative risk assessment for the impacts of climate change on nationally and internationally important geoheritage sites in Scotland

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ARTICLE INFO

Article history:
Received 22 November 2016
Received in revised form 7 November 2017
Accepted 13 November 2017
Available online xxx

Keywords:
Geosites
Climate change
Risk assessment
Geoheritage
Geoconservation
Geodiversity

ABSTRACT

Climate change is a significant concern for nature conservation in the 21 st century. One of the goals of the 2014 Scottish Climate Change Adaptation Programme is to identify the consequences of climate change for protected areas and to put in place adaptation or mitigation measures. As a contribution to the process, this paper develops a methodology to identify the relative level of risk to nationally and internationally important geological and geomorphological sites in Scotland from the impacts of climate change. The methodology is based on existing understanding of the likely responses of different types of geosite to specific aspects of climate change, such as changes in rainfall, rising sea levels or increased storminess, and is applied to assess the likelihood of damaging impacts on groups of similar geoheritage features in sites with similar characteristics. The results indicate that 80 (8.8%) of the ~900 nationally and internationally important geoheritage sites in Scotland are at 'high' risk from climate change. These include active soft-sediment coastal and fluvial features, finite Quaternary sediment exposures and landforms in coastal and river locations, active periglacial features, sites with palaeoenvironmental records, finite or restricted rock exposures and fossils. Using this risk-based assessment, development of indicative geoheritage climate-change actions have been prioritised for these sites. Depending on the characteristics of the sites, management options may range from 'do nothing' to rescue excavations and posterity recording. Monitoring is an essential part of the management process to trigger evidence-based interventions.

1. Introduction

The world's climate has always fluctuated due to a range of geological, biological, atmospheric, oceanographic and astronomical factors. However, there is now scientific consensus that climate variations over the last ~150 years can only be explained by the impacts of human activities acting in conjunction with natural factors (Stocker et al., 2013). The pace of change is not even across the world, with some places more affected than others. Left unchecked, these changes will accelerate (Defra, 2009; Jenkins et al., 2009; http://ukclimateprojections.metoffice.gov.uk/), with significant consequences for nature and society. In contrast to biodiversity, the impacts of climate change on geosites and geoheritage have received comparatively little attention, particularly from the perspective of risk assessment and mitigation (Prosser et al., 2010; Sharples, 2011; Brazier et al., 2012; Brown et al., 2012a,b; Crofts and Gordon, 2015).

In Scotland, climate change is likely to result in extensive landscape modification (Land Use Consultants, 2011), with the greatest changes expected in coastal areas, along river corridors and in the uplands (Werritty et al., 2002; Werritty and Chatterton, 2004; Orr et al., 2008; Brazier et al., 2012; Brown et al., 2012a,b; Wallingford et al., 2012; Ramsbottom et al., 2012; Werritty and Sugden, 2012; Hansom et al., 2017). The potential impacts of climate change in the UK on both biodiversity (Walmsley et al., 2007) and geodiversity (Prosser et al., 2010) have been reviewed, and their effects on all aspects of the natural heritage in Scotland are now widely recognised (Scottish Natural Heritage, 2016). As a result, Scottish parliamentary actions on climate change include measures for the natural heritage, which address the management of protected areas for biodiversity and geodiversity.

The 'Climate Ready Scotland' Scottish Climate Change Adaptation Programme (Scottish Government, 2014) sets out Scottish Ministers' objectives, policies and proposals to tackle

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https://doi.org/10.1016/j.pgeola.2017.11.003
0016-7878/

the climate change impacts identified for Scotland in the UK Climate Change Risk Assessment (ASC, 2016), as required by section 53 of the Climate Change (Scotland) Act 2009 (Scottish Government, 2009). Objective N2 of this programme is to 'Support a healthy and diverse natural environment with capacity to adapt', and as one of the actions to fulfil this objective, Scottish Natural Heritage (SNH), the Scottish Government's adviser on all aspects of nature and landscape, was tasked to 'Identify the consequences of climate change for protected places and the Natura network and put in place adaptive measures'. For geodiversity, this required an assessment of geoheritage features within Sites of Special Scientific Interest (SSSIs), which are protected under the Nature Conservation (Scotland) Act (2004) (Scottish Government, 2004).

Nationally and internationally important geoheritage features within the SSSI network in Great Britain are underpinned by the Geological Conservation Review (GCR). Undertaken by the Nature Conservancy Council between 1977 and 1990, and subsequently managed by the Joint Nature Conservation Committee (JNCC), the GCR was a major initiative to identify and describe those sites of national and international importance that together show all the key scientific elements of the geoheritage of Britain (Ellis et al., 1996; Ellis, 2011). These sites have attributes that range from sequences of contemporary sediments and geomorphological processes to ancient rocks, together with fossils, minerals and features of the landscape that make a special contribution to the understanding and appreciation of Earth science and the geological history of Britain. Scotland has over 900 GCR sites, selected for around 100 subject categories (known as 'GCR Blocks'), encompassing the range of geological and geomorphological features of Britain. Each GCR site is selected to demonstrate a single geological or geomorphological topic, and many of these have been subsequently incorporated as protected features in approximately 500 designated SSSIs. GCR sites for different topics may coincide or overlap and it is possible for multiple GCR sites, representing different Earth science topics, to be protected within a single SSSI. Therefore, to assess the climate change risk to geoheritage features in SSSIs, the process developed must assess the risk to ~900 GCR sites.

The aim of this study was to develop and apply a systematic risk assessment using expert judgement to inform climate change adaptation management for geoheritage features in SSSIs. Primarily the risk assessment was needed as a tool for deciding which sites to prioritise for development of geoheritage climate-change actions. First, we outline the relevant aspects of climate change considered most likely to impact geoheritage features. We then group the ~900 GCR sites in Scotland into Climate Change Risk Categories, with features in each Category likely to respond to climate change in a similar way. Each Category was then evaluated for the likelihood of any given aspect of climate change affecting it and for the risk of detrimental impact from climate change, to give an overall qualitative risk assessment. We then discuss the results and the geoconservation management options and provide examples of indicative geoheritage climate-change actions for sites assessed to be at high risk. The main focus of the paper is on the direct impacts of climate change, but indirect impacts that may also arise from human responses (e.g. the erection or extension of sea-defences to mitigate coastal erosion) were also considered (Prosser et al., 2010).

2. Methodology

The latest climate projections for the UK, UKCP09 (Defra, 2009; Jenkins et al., 2009; http://ukclimateprojections.metoffice.gov.uk/), are based on strong and credible climate science and form the basis for assessing the impacts of climate change on geoheritage sites. They show how various aspects of climate could change, under three different greenhouse gas emissions scenarios, by the middle and end of the 21st century, including changes in average summer and winter temperatures, changes in rainfall patterns and sea-level rise. These will, in turn, have likely consequences, such as drier ground in summer, decreased freeze-thaw activity in winter, increased river flooding and erosion, increased coastal erosion and inundation or changes in vegetation cover, all of which may affect geoheritage features. The effects of any given aspect of climate change on a specific geoheritage feature will depend on the nature of the interest and the characteristics of the site where it is present (Prosser et al., 2010): for example, whether it is an exposure of a very restricted fossil resource or of an extensive sedimentary sequence; whether it is an active river channel or a relict glacial moraine; whether it is close to, or distant from, the coast or a river; or whether it is a hard rock sea cliff or a soft sandy coast.

Individually assessing all ~900 GCR sites in a robust and systematic way would be a lengthy task. Equally, the number of sites under consideration means that a purely intuitive approach, for example experts listing those sites they considered most at risk in their own fields of knowledge, could result in sites being overlooked or inconsistent levels of risk being assigned across different fields. The premise of the methodology adopted here (Fig. 1) is that, if the sites and the geoheritage features they contain can be grouped into site categories that are likely to respond in similar ways to the various aspects of climate change, then the task becomes both more manageable and easier to moderate in terms of aligning the input of different experts and making a consistent assessment across a wide variety of sites. The approach taken in this study resulted in a single level of assessed risk for each group of several features (comprising one Site Category) rather than, for example, a ranked list of features or sites. This Site Category approach involves a degree of generalisation that must be borne in mind when assessing and applying the results. The Site Categories selected here also include only the range of GCR sites present in Scotland.

The following sections deal with the aspects of climate change considered likely to affect geoheritage feature in Scotland, the selection and definition of Site Categories, and the risk assessment process. The full methodology is described by Wignall et al. (2018); only the key stages are outlined here (Fig. 1).

2.1. Selecting relevant aspects of climate change

The first step in the risk assessment process (Fig. 1) was to identify those aspects of climate change considered to be most likely to affect geoheritage sites in Scotland, based on current understanding of the direct impacts of climate change (e.g. Harrison et al., 2001; Gordon et al., 2008; Prosser et al., 2010; Brazier et al., 2012). The likely major changes, under all the emissions scenarios, are warmer and wetter winters, hotter and drier summers and rising sea levels (Table 1). There are also likely to be more extreme weather events (e.g. storms and floods).

Indirect impacts of climate change that may arise from human responses (Prosser et al., 2010) were specifically excluded from the risk assessment rating, but are taken into account in the development of the indicative geoheritage climate-change actions (Section 4). Existing structures, such as coastal defences or flood embankments, were treated as immovable objects (Section 2.2) that may, for example, restrict the evolution of an active geomorphological system, although in some cases this may be overcome by managed realignment.

The likely direct impacts of climate change on geoheritage sites are relatively varied (Prosser et al., 2010), and not all will apply in Scotland. Extreme events are likely to have the greatest impact.

Please cite this article in press as: R.M.L. Wignall, et al., A qualitative risk assessment for the impacts of climate change on nationally and internationally important geoheritage sites in Scotland, Proc. Geol. Assoc. (2018), https://doi.org/10.1016/j.pgeola.2017.11.003