Ocean & Coastal Management 132 (2016) 80–89

Contents lists available at ScienceDirect

Ocean & Coastal Management

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

A national coastal erosion susceptibility model for Scotland

James M. Fitton [a, *], Jim D. Hansom [a], Alistair F. Rennie [b]

[a] School of Geographical and Earth Sciences, East Quad, University of Glasgow, G12 8QQ, UK
[b] Scottish Natural Heritage (SNH), Great Glen House, Inverness, IV3 8NW, UK

ARTICLE INFO

Article history:
Received 18 May 2016
Received in revised form
17 August 2016
Accepted 22 August 2016
Available online 31 August 2016

Keywords:
Coastal management
Coastal erosion
Physical susceptibility
GIS
Scotland

ABSTRACT

The upland nature of the Scottish landscape means that much of the social and economic activity has a coastal bias. The importance of the coast is further highlighted by the wide range of ecosystem services that coastal habitats provide. It follows that the threat posed by coastal erosion and flooding has the potential to have a substantial effect on the socioeconomic activity of the whole country. Currently, the knowledge base of coastal erosion is poor and this serves to hinder the current and future management of the coast. To address this knowledge gap, two interrelated models have been developed and are presented here: the Underlying Physical Susceptibility Model (UPSM) and the Coastal Erosion Susceptibility Model (CESM). The UPSM is generated within a GIS at a 50 m^2 raster of national coverage, using data relating to ground elevation, rockhead elevation, wave exposure and proximity to the open coast. The CESM moderates the outputs of the UPSM to include the effects of sediment supply and coastal defence data. When validated against locations in Scotland that are currently experiencing coastal erosion, the CESM successfully identifies these areas as having high susceptibility. This allows the UPSM and CESM to be used as tools to identify assets inherently exposed to coastal erosion, areas where coastal erosion may exacerbate coastal flooding, and areas are inherently resilient to erosion, thus allow more efficient and effective management of the Scottish coast.

1. Introduction

Coastal areas have historically been utilised for human settlement on account of an abundance of the natural resources required for survival and development (Özyurt and Ergin, 2009). Within the UK, living close to the coast remains desirable today as a consequence of the vast range of ecosystem services and benefits that coasts provide. Jones et al. (2011) identify that even though coastal habitats occupy only 0.6% of the UK's land area, they account for approximately £48 bn (adjusted to 2003 values) of ecosystem benefits. Ecosystem service valuations for Scotland are not readily available, however with a coastline length of 18,670 km (Angus et al., 2011), (approximately 64% of UK's total coastline, and 12.5% of the European total according to Pranzini and Williams (2013)) the ecosystem services derived from Scottish coastal habitats are likely to be significant.

The geography of Scotland, with a highly undulating hinterland, long and indented coastline, together with a large number of islands (Fig. 1), means that much of the economic, social, and cultural assets within Scotland are largely located at the coast. Approximately 70% of the Scottish population (ca. 3.5 million people) live within 10 km of the coast (Scottish Executive, 2005). Coastal populations tend to have high proportions of older residents, transient populations, low employment levels, and high seasonality of work, together with physical isolation, and poor transport links (Zsamboky et al., 2011). Economically, the coast supports industries including oil and gas installations, ports, fishing, agriculture, aquaculture, links golf, and tourism (The James Hutton Institute, 2013). Consequently, coastal hazards such as flooding and erosion have the potential to substantially impact upon both people who live near the coast, and the Scottish economy. The Scottish coastal zone is therefore a resource which offers many opportunities, but also requires careful management to allow all stakeholders to benefit (Scottish Government, 2014).

Within Scotland, the risk posed by the hazard of flooding (both fluvial and coastal) has received much attention from the Scottish Environment Protection Agency (SEPA) yet, by comparison, coastal erosion has seen limited attention at a national level. This bias was noted by the Climate Change Risk Assessment (CCRA) for Scotland which states that "*maps of past erosion, current state and future*

* Corresponding author.
E-mail addresses: james.fitton@glasgow.ac.uk (J.M. Fitton), jim.hansom@glasgow.ac.uk (J.D. Hansom), alistair.rennie@snh.gov.uk (A.F. Rennie).

http://dx.doi.org/10.1016/j.ocecoaman.2016.08.018

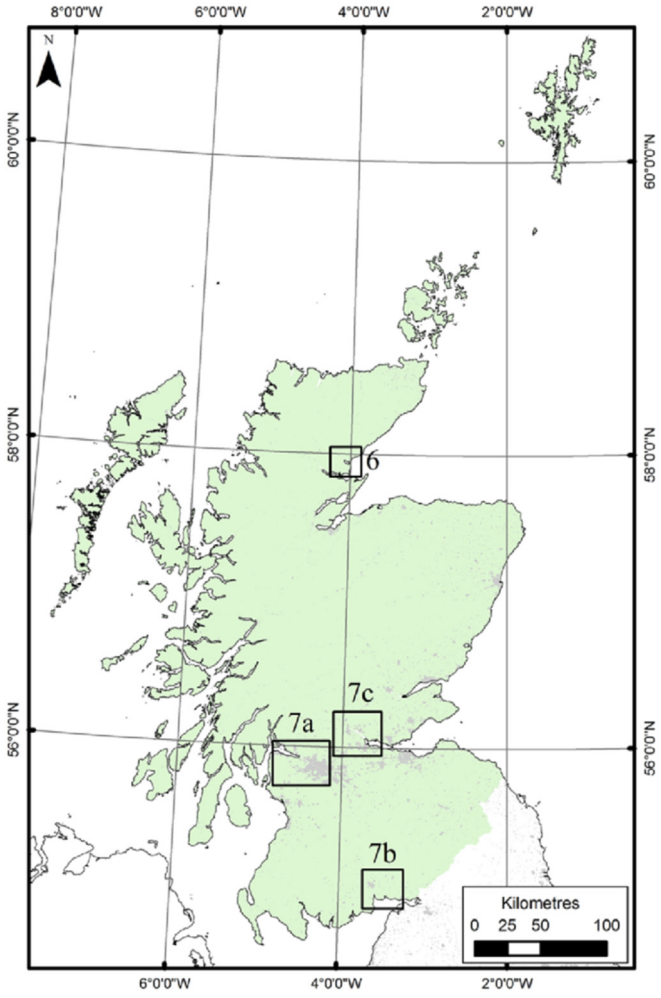

Fig. 1. Scotland's mainland and islands (shaded in green) which has an estimated coastal length of 18,670 km (Angus et al., 2011). Black boxes show the locations of the areas within Figs. 6, 7a–c. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

erosion conditions are required" (Defra, 2012, p.191). This was further highlighted by Dr. Aileen McLeod, the Scottish Minister for Environment, Climate Change and Land Reform, who in her Ministerial Address at the annual SNIFFER Flood Risk Management Conference (2015) stated that "*coastal erosion and coastal flooding are unquestionably linked but there is a great deal of uncertainty around current evidence about coastal erosion*". This is a potentially significant limitation considering that coastal erosion may exacerbate coastal flooding by removing the natural landforms and habitats (beaches, dunes and saltmarshes) which provide a coastal defence ecosystem service. In Scotland, sand dune, saltmarsh, and machair habitats are predicted to reduce by 36%, 25%, and 8% respectively by 2060 from 1900 levels (Beaumont et al., 2014). In Scotland, there is a paucity of information on the locations where coastal erosion is occurring and at what rate. Only four local authorities (LAs) have an operational Shoreline Management Plan that identifies erosional sites (Angus, Dumfries and Galloway, East Lothian, and Fife) equating to 7% of Scotland's shoreline. A further two LAs (North Ayrshire and South Ayrshire) are currently developing an SMP which will cover a further 2% of the coast (Hansom and Fitton, 2015). The remaining 91% of the coastline has yet to be assessed in detail in terms of coastal erosion.

Additionally, there is an absence of information concerning where coastal erosion could potentially occur in the future i.e. the inherent susceptibility of the coast to erosion. This is of particular relevance when considering the potential impacts of future climate change. The CCRA for Scotland (Defra, 2012) states that more frequent extreme weather and rising sea levels will instigate changes in coastal evolution as a result of climate change (further supported by Masselink and Russell, 2013; Ramieri et al., 2011 Zhang et al., 2004). The Climate Change (Scotland) Act 2009 requires Scottish Ministers to develop a Scottish Climate Change Adaptation Programme, which addresses the identified risks. Coastal erosion has implications for agriculture, tourism industry, transport sector, infrastructure, buildings, urban environment along with cultural and natural heritage interests. Government, Agencies and Local Authorities have obligations to incorporate coastal erosion within their work. Therefore, a pressing need exists to improve the understanding of coastal erosion within Scotland at a national scale, so that the potential direct and indirect impacts on coastal populations and assets can be fully assessed and so to better inform sustainable coastal management. This paper aims to introduce two interrelated models that aim to address the above need in Scotland: the Underlying Physical Susceptibility Model (UPSM) and Coastal Erosion Susceptibility Model (CESM). Below we detail the methodology and validation of the model and discuss the potential applications of its outputs for coastal management in Scotland. Forthcoming linked papers will detail a) the application of the CESM to identify the socioeconomically vulnerable population and key assets that are potentially exposed to coastal erosion and b) how the CESM will support the current and future approach to coastal management in Scotland.

2. Methodology

Large spatial scale erosion assessments are difficult to produce because coastal processes are complex, locally nuanced and require significant amounts of data to model. As a result there are few examples of national scale coastal erosion models within the literature, with much research focussing primarily either on local or regional scale erosion models e.g. Alves et al. (2011), Fernandez-Nunez et al. (2015), Lins-de-Barros and Muehe (2011), Reeder-Myers (2015). However, two studies, Eurosion (2004) and Mclaughlin and Cooper (2010), attempt to produce coastal erosion assessments that can be used at a national scale. Eurosion (2004) was an EU-wide project across 20 countries (including Scotland) aimed at understanding and quantifying coastal erosion within Europe. The project created data that could be used at national scales to give a general overview of the erosion status within and between countries. However, the outputs lacked detail (the coastal polyline outputs were at 1:100,000 scale) and when used to further inform management at regional scales, proved difficult to use without other complimentary assessments (the generation of which was beyond the scope of the original Eurosion project). An alternative method was developed by Mclaughlin and Cooper (2010) who produced a coastal erosion assessment for Northern Ireland at various different spatial scales: national (500 m^2 raster), regional (25 m^2 raster) and local (1 m^2 raster). This 'nested' method allows consistent management decision-making across a range of spatial scales. Additionally, Eurosion and many other studies portrayed erosion data as a line (a vector output) with various classifications according to the methodology of the assessment e.g. Harvey and Woodroffe (2008), Lins-de-Barros and Muehe (2011), Reeder et al. (2010). This line normally represents erosion data that occurs along the coastline but it may also include data representing offshore or inland conditions. On the other hand, instead of plotting a line Mclaughlin and Cooper (2010), Hegde and Reju (2007), and Alves et al. (2011) use a cell based or raster output which represents