

# Expanding the Geoconservation Toolbox: Integrated Hazard Management at Dynamic Geoheritage Sites

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**Abstract** This article discusses the developing field to make use of visually impressive and artistic digital tools to document geoheritage sites. Whilst applauding the contribution these techniques make to records of heritage, such techniques should not replace physical access and conservation. To improve conservation of natural sites, technology must support rather than substitute geoconservation measures. As a tourism “honeypot”, the Giant’s Causeway is Northern Ireland’s most significant heritage resource, representing a dynamic and contested space, around and within which managers and stakeholders capitalise on the world class values. This article reports on a “digital documentation” approach which aims to support day-to-day management decisions, by provision of online hazard management tools. Digital documentation involves collecting a range of heritage data within a single geographical information system. Slope failure and visitor data are collected using global positioning system technology, and the site is scanned using terrestrial light detection and ranging to produce a 3D model. This provides managers and stakeholders with integrated hazard assessment tools, necessary to make informed decisions. The approach represents a shift from re-active to pro-active management and promotes expansion of the geoconservation toolbox through appropriate application of digital technologies.

**Keywords** Geoheritage sites · Geoconservation · Digital technologies · Terrestrial LiDAR · Geographical information system

## Introduction

The International Union for the Conservation of Nature (IUCN) defines protected areas as “geographical spaces,

recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values” (Dudley 2008). Scottish Natural Heritage (2003) defines natural heritage as an index of inherited “flora and fauna, geological and physiographical features, natural beauty and amenity”. Dynamism is recognised as an intrinsic feature of natural heritage sites, and in many cases, recognition of natural change has become a founding principle of their designation (Smith et al. 2010). Entitled “Protecting and Sharing”, the 7th ProGEO International Symposium on the Conservation of Geological Heritage confirmed a high level of commitment to develop and implement standard approaches for protecting geoheritage sites. Many submissions discussed quantitative and qualitative assessment schemes for protecting new and existing sites. Such approaches help define, recognise and dedicate geoheritage sites; however, they rarely provide practical and flexible tools which support day-to-day management at what are often dynamic and consequently hazardous sites. This article reports on a “digital documentation” approach which supports day-to-day management of geoheritage sites by provision of online hazard assessment tools. The approach is aimed at individual sites, not as a strict methodology, but as a guide which ensures digital documentation facilitates day-to-day management of dynamic and contested spaces. The approach aims to support the essential process of geoheritage site inscription, whilst improving long-term conservation through informed management decisions.

## Background

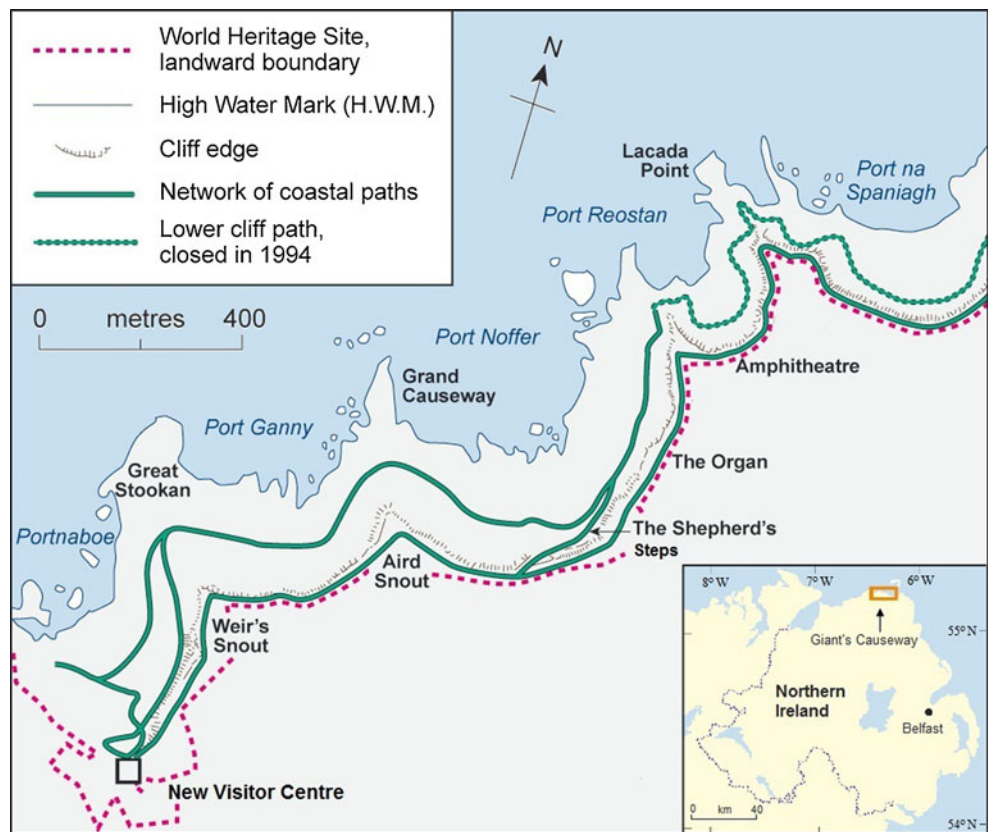
As a tourism “honeypot”, the Giant’s Causeway, located on the north coast of County Antrim (Fig. 1), is Northern Ireland’s key heritage resource and represents a contested space around and within which stakeholders

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Professor Bernard Smith passed away 31st October 2012.

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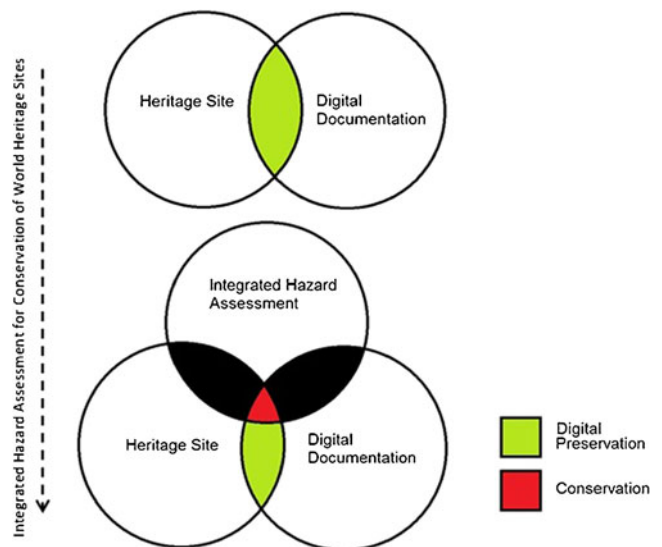
**Fig. 1** Location of Giant's Causeway and Causeway Coast World Heritage Site



capitalise on world class aesthetic, scientific, educational, historical and cultural values. The socio-economic value of the Giant's Causeway and wider Causeway Coast is reflected in the National Trust's 2011 Business Plan which estimates the area receives one million visitors per year and is worth in excess of £100m to the regional economy. Described as a “spectacular, dynamic coastal landscape of Atlantic waves, rugged cliffs, unparalleled geological formations, secluded bays and magnificent views”—slope failure, visitor pressures and climate change create significant challenges for the National Trust. To manage these challenges effectively, the National Trust aims to be pro-active in understanding where specific processes occur, their probability of occurrence and likely impacts.

It is possible, if not probable, that protected area designations, traditionally aimed at preservation of biodiversity, are not flexible enough to protect geoheritage sites against natural, let alone anthropogenic, change (IUCN 2010). In response to perceived limitations of protected area designations to achieve long-term conservation, a number of organisations are supporting application of visually impressive and artistic tools to document heritage sites. CyArk and the Scottish Ten Project have been successful in securing funding to digitally capture a list of World Heritage Sites using terrestrial light detection and ranging (LiDAR) (Lee

2009). Whilst applauding the contribution made to heritage records, these techniques should not replace physical access and conservation. To conserve dynamic sites, technology must move beyond simple documentation and support rather than substitute geoconservation. One solution may be promotion of digital documentation for the purposes of hazard management. This marks a shift



**Fig. 2** Integrated hazard assessment for conservation of natural heritage sites

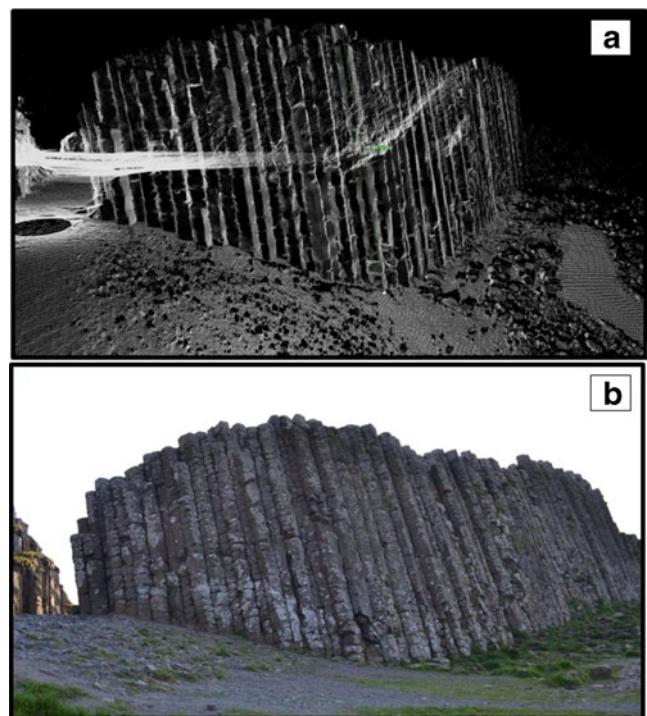
from digital preservation towards pro-active conservation of dynamic heritage sites (Fig. 2).

Whether defined historically as “wise-use” or temporarily as “sustainable-use”, conservation has developed as a means of avoiding scarcity of environmental goods and services (Keren and Roelofsma 1995). Geodiversity provides the basic foundations of all environmental goods and services upon which present and future generations depend. It is understood that geodiversity provides “essential benefits for society through profound influences on landscape, habitats and species, the economy, historical and cultural heritage, education, health and well-being” (SNH 2011). Protected areas help provide for life's essentials, safeguard species and habitats, act as economic engines and provide a sense of place and meaning, settings for healthy outdoor living, recreation and some of life's most joyous moments (Dudley et al. 2010). The advantages of conserving geodiversity in protected geoheritage sites are well documented and understood. There are, however, significant problems in communicating these values to policy makers who have been conditioned to focus on protecting biodiversity regardless of natural or anthropogenic change. Communication difficulties are compounded by diverse conservation terminologies, multiple and occasionally incompatible geodiversity audit systems and an increasingly youthful global population that is more interested in digital entertainment and internet-based social networking than on the natural world and outdoor recreation (Payan 2012).

Recent fragility in global financial markets has prompted reviews of income and expenditure from individuals through to national governments. Environmental policies and corresponding expenditure have been subject to guidelines urging thrift. In the UK, efforts to produce a national ecosystem assessment have been criticised by conservation practitioners, who understand that the true value of nature cannot be conveyed with a currency symbol (Monbiot 2011). Geomorphologists, in particular, fear that the government's white paper on the environment underestimates the value of nature by omitting—“geodiversity, the physical basis of our planet” (Gray 2011). Within the UK, perhaps the greatest opportunity for a transition to pro-active management at dynamic sites lies on the government's concept of “big society” which aims to “create a climate that empowers local people and communities, building a big society that will take power away from politicians and give it to people” (Cabinet Office 2011). This approach can create fierce competition for resources and finance, but has potential to improve the quality of conservation schemes, as with increased emphasis on local support, only the most inclusive projects will survive. Much like

the features they manage, conservation practitioners and site managers will have to demonstrate dynamism and flexibility in approach. Thoughtful application of digital documentation can provide the foundations required for a more pro-active, dynamic and inclusive approach to geoconservation. New operational guidelines from the World Heritage Centre (2012) support this approach, favouring investment in capacity building exercises and activities which enhance the role of local communities.

Digital documentation of a heritage site can effortlessly achieve digital preservation; however, when undertaken in conjunction with and for the purpose of integrated hazard assessment, the approach can help facilitate conservation of irreplaceable sites. Geoheritage is a dynamic concept and its associated features are often in a state of flux. Unlike engineering and cultural heritage applications, digital documentation projects can never fully document a natural site. Even if a common 3D documentation technique (terrestrial LiDAR) could operate like a modern video camera, minute environmental changes in the milliseconds and nanoseconds between frames would be missed. At best, terrestrial LiDAR scans of a geoheritage site provide a snapshot of the conditions at the time of recording (Fig. 3). Except for the ability to view areas in 3D and take accurate measurements of features of 3D digital documentation, on its own, it provides relatively few benefits over traditional panchromatic photographs. In isolation, digital documentation only acts as a substitute for geoconservation.



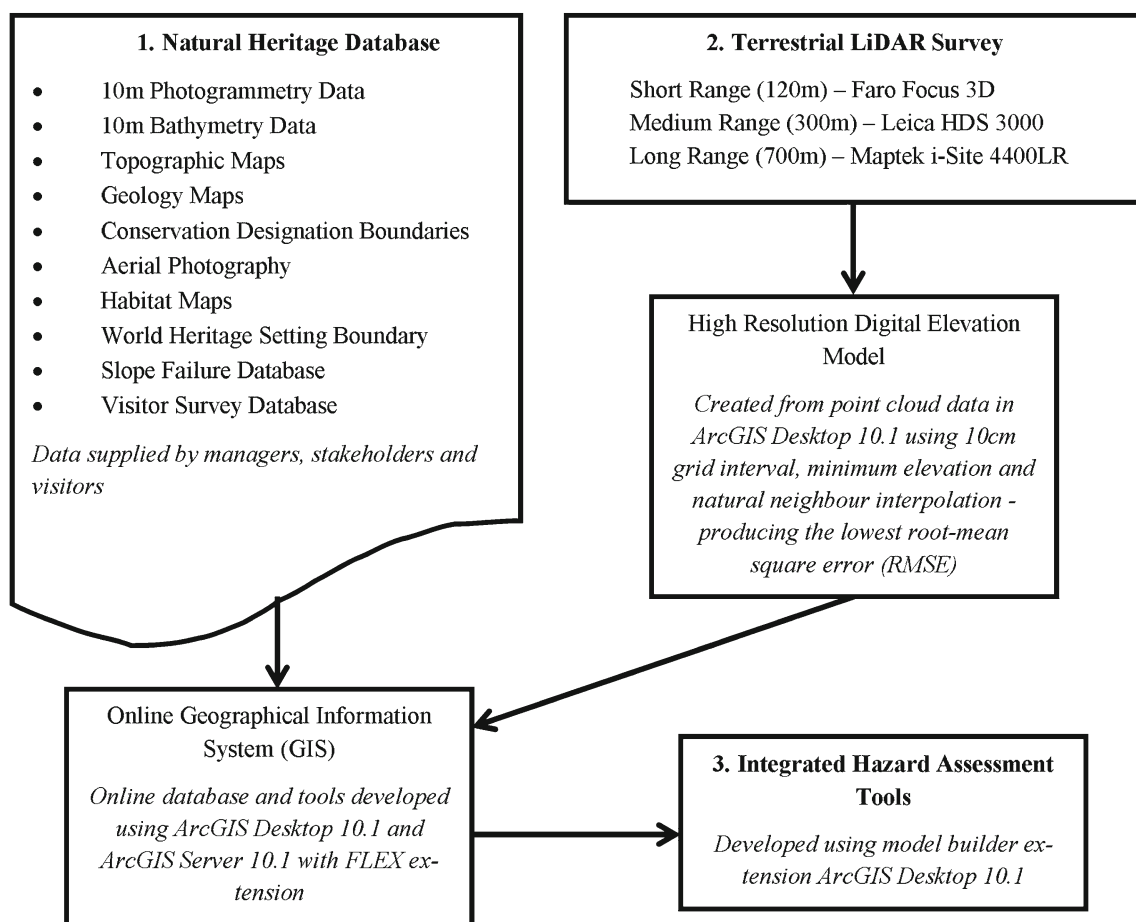
**Fig. 3** Terrestrial LiDAR scan of the Giant's Loom (a) and photograph of the same location (b)

Many researchers and organisations who use terrestrial LiDAR for the production of digital elevation models (DEMs) subscribe to the definition of DEMs as “data files which contain ‘bare earth’ or minimum elevation values, at a fixed grid interval for a specified terrain area” (SIC 2012, p. 1). In recent decades, data collection and processing techniques have enabled finer grid intervals and production of more detailed DEMs. Terrestrial and airborne LiDAR and photogrammetry data can now be used to produce DEMs with resolutions of 10 cm/pixel or finer. Increasingly, organisations such as the Centre for Earth Observation (2012) and NASA (2008) have begun to describe these models as high-resolution DEMs (HRDEMs). HRDEM terminology is poorly defined, and there is currently no defined grid interval at which a DEM qualifies for HRDEM status. What is clear is that researchers and organisations appear to use the term HRDEM to suggest their model is of a finer resolution than an existing, coarser DEM. A major advantage of terrestrial LiDAR is improved coverage on vertical surfaces where airborne LiDAR and photogrammetry tend to miss complex topography (Mills and Barber 2006). Digital documentation with terrestrial LiDAR offers greater flexibility

at dynamic geoheritage sites where landforms, landscapes and processes are often complex and diverse.

### Research Objectives and Methodology

Using the Giant's Causeway as a case study, this project presents a new approach to digital documentation which supports pro-active management of dynamic sites (Fig. 4). The primary objective of the research is to present a flexible methodology which raises awareness of the benefits and limitations of digital documentation (primarily terrestrial LiDAR) at dynamic geoheritage sites. Presentation of this methodology will demonstrate how application of digital documentation can pro-actively contribute to integrated hazard management and provides an opportunity to mark the boundary between relatively simple digital preservation on one hand and digital conservation through provision of integrated management tools on the other. The following steps outline a new digital documentation methodology for dynamic geoheritage sites:



**Fig. 4** Digital documentation for integrated hazard assessment

1. Create an electronic database of available natural heritage data.
2. Undertake terrestrial LiDAR surveys to provide data required to build a 3D model upon which natural heritage data can be georeferenced.
3. Integrate natural heritage and 3D data within a single online geographical information system (GIS) and analyse using tools developed through geographic information sciences.

### Natural Heritage Database

Digital documentation involves collecting a range of natural heritage data within a single GIS. Site managers, stakeholders and visitors were invited to supply data relating to natural heritage within the Giant's Causeway and Causeway Coast World Heritage Site. ESRI ArcGIS Desktop 10.1 facilitated integration and organisation of previously isolated and consequently limited datasets. Data were contributed by the National Trust, the Northern Ireland Environment Agency, Planning Service, Geological Survey of Northern Ireland, Department of Agriculture and Rural Development and the Causeway Coast and Glens Heritage Trust. Visitors at the World Heritage Site (WHS) voluntarily contributed data through an innovative citizen sensor survey which tracked their location within the site at 10-s intervals using small GT-120 GPS trackers

produced by Mobile Actions. Finally, a Microsoft Windows 2008 Server was established to administer ESRI ArcGIS Server 10.1. This established an Internet Information Service and space to publish an integrated database containing all available data layers. An online administrative connection between ESRI ArcGIS Desktop 10.1 and ESRI ArcGIS Server 10.1 enabled interaction with the natural heritage data through an online interface based upon the Adobe Flex platform (Fig. 5).

### Terrestrial LiDAR Survey

A terrestrial LiDAR survey was conducted to provide a platform upon which to assess the suitability of terrestrial LiDAR for digital documentation of natural heritage and production of HRDEMs on a landscape scale. The terrestrial LiDAR survey at the Giant's Causeway was conducted from 292 scan locations using a Faro Focus 3D 120 laser scanner at 20-m intervals along the public footpath network. Scan positions were surveyed using a Leica Smartnet 1200 differential GPS system to provide georeferenced elevation data at a minimum resolution of 1 pt/0.1 m. Average 3D GPS accuracy for each scan location was 0.035 m. Individual scans were stitched together using the Faro Scene 5.0 software package which enabled automatic triangulation and scan placement based on identification and naming of

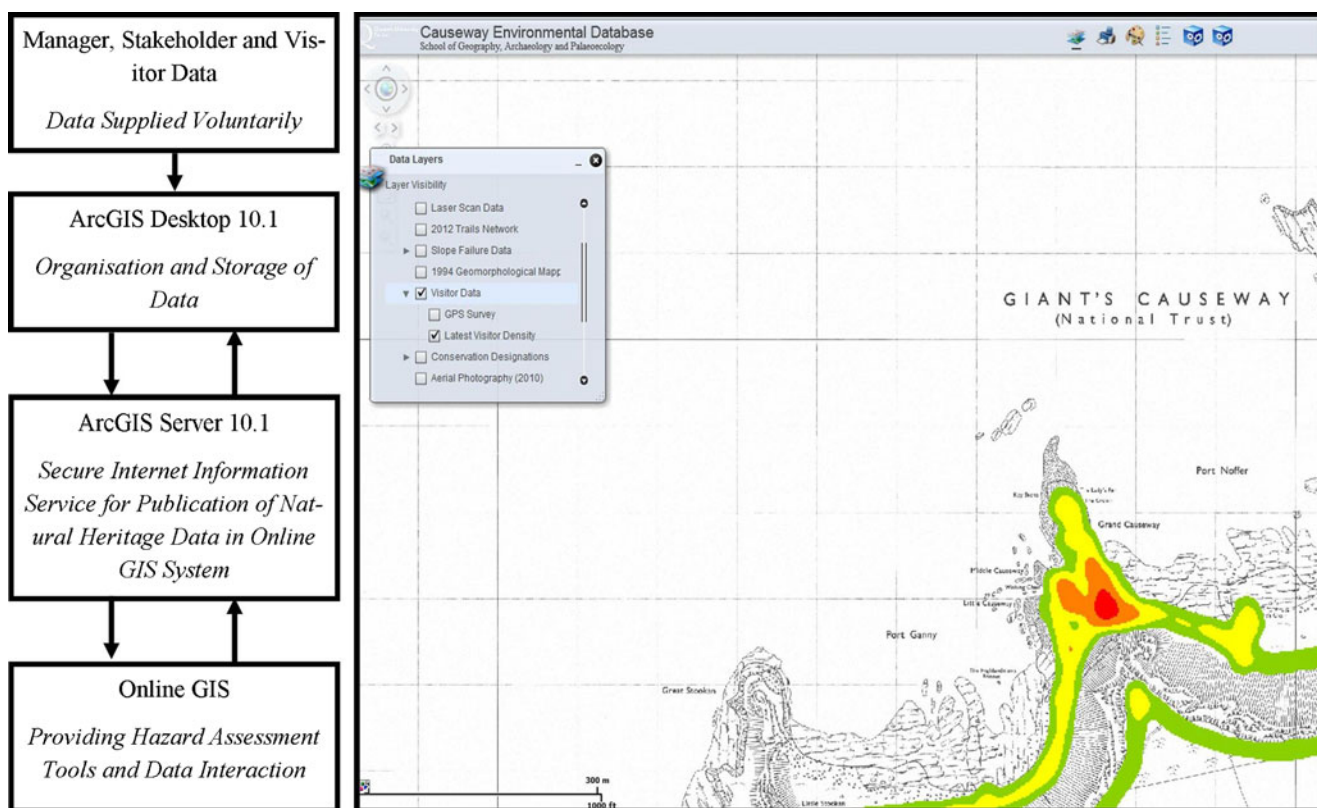


Fig. 5 Access to natural heritage data through online GIS (ArcGIS Server 10.1 with Flex Extension)

artificial white spherical targets (75 mm radius) placed within the scan range.

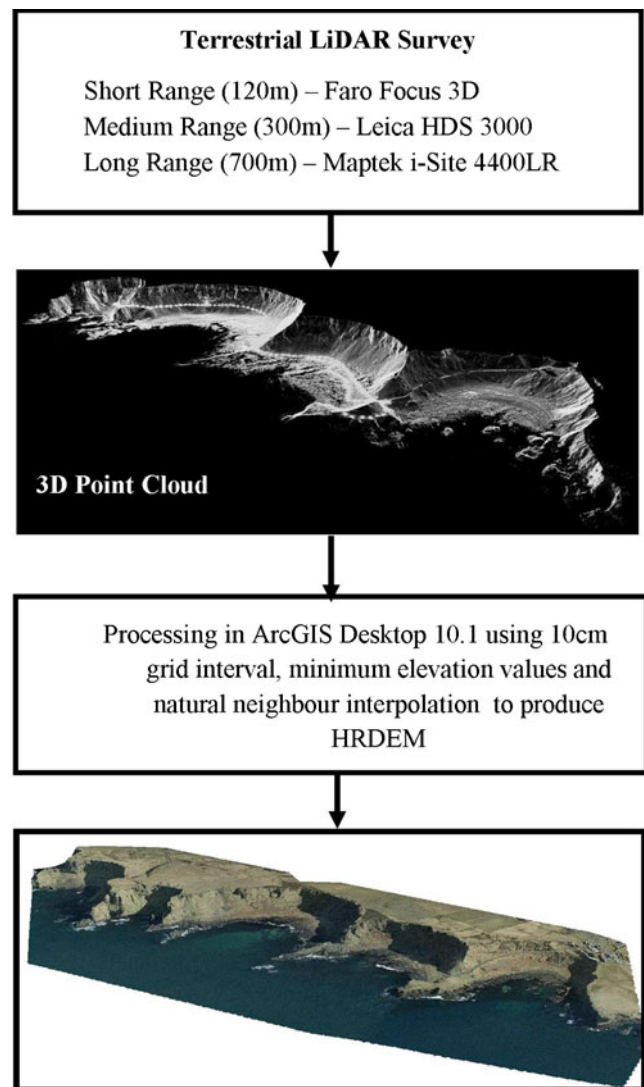
The term HRDEM has been adopted to distinguish between a 10-m/pixel DEM produced by Land and Property Services NI (LPSNI) from existing photogrammetry data and a 10-cm/pixel HRDEM produced using LiDAR data obtained from the Faro Focus 3D 120. ESRI ArcGIS Desktop 10.1 was used to interpolate a HRDEM for the Giant's Causeway using a 10-cm/pixel grid interval and natural neighbour interpolation. Recorded elevation values were compared with “accepted” elevation values from LPSNI's 10-m/pixel DEM. This approach provided a root mean square error (RMSE) of 0.875. Linear interpolation was also considered; however, this produced a slightly higher RMSE of 0.883. The US Department of the Interior's (1998) technical instructions for DEM production suggest RMSE is used to describe the vertical accuracy of a DEM. The new 10-cm/pixel HRDEM was integrated with the online GIS system to provide a 3D foundation upon which natural heritage data could be referenced and analysed (Fig. 6).

#### Integrated Hazard Assessment Tools

Digital documentation was undertaken with a view to unlocking the full potential of previously isolated datasets through integrated hazard assessment. The HRDEM provides data-rich foundations upon which to georeference the online Heritage Database. Using tools developed through GIS and functionality provided by ESRI ArcGIS Desktop 10.1 Model Builder, it is possible to create and share geoprocessing tasks through an online ArcGIS Flex application. The National Trust identified slope failures, visitor pressures and climate change as significant day-to-day management challenges. Defining hazard as “a source of potential harm” (Johansen 2010, p. 2), two key online hazard tools were devised to help managers assess where specific processes occur, their probability of occurrence and likely impacts. The tools include a slope failure and visitor density calculator and sea level impact model for habitats along the coast.

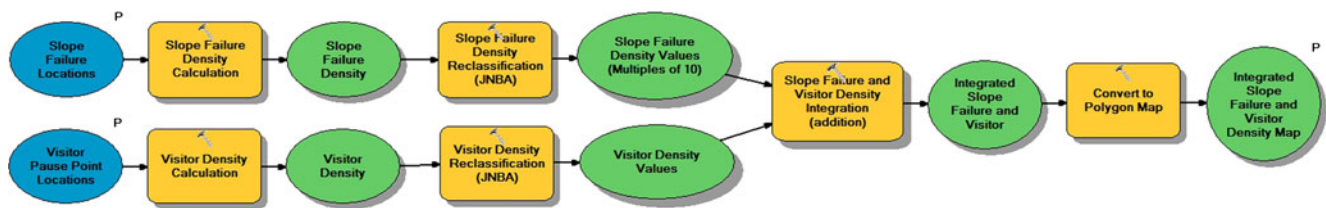
#### *Slope Failure and Visitor Density Calculator*

Smith et al. (2010) established a mechanism for recording slope failures using a handheld Garmin e-Trex 10 GPS device as part of a geomorphological mapping exercise to baseline slope instability at the Giant's Causeway. This database provides a source of data for the development of slope failure density maps (Fig. 7). This is considered a simple yet essential first step in understanding where specific processes are likely to occur and, in broad terms, their probability of occurrence.



**Fig. 6** Terrestrial LiDAR data conversion to HRDEM (draped orthophotography)

A GPS visitor survey operated from 14 February to 3 March 2011. Four GPS lanyards were provided at random during morning and afternoon sessions 7 days a week, and in total, 80 visitors participated in the survey and 45,554 individual data points were recorded. The Mobile Actions GT-120 GPS devices were carried for the duration of the visit and handed back at the end for data retrieval. To minimise deviation from natural behaviour, visitors were informed that the devices would accurately record the distance travelled (much like a pedometer) and they were free to explore the site at their leisure whilst observing all safety information provided by the National Trust. The survey was conducted on a voluntary basis with guarantee of complete anonymity. Locations where visitors had a tendency to pause (speed=0 km/h) were extracted to provide baseline data (Fig. 7).



**Fig. 7** Methodology for integrating slope failure and visitor GPS data for the production of a hazard assessment map (ArcGIS 10.1 Model Builder module)

The georeferenced slope failure and visitor GPS data provide foundations required to produce high-resolution density maps. Kernel density with a 2-m output resolution and 20-m search radius was selected to provide simple, smooth and clear outputs for online processing and viewing (Harris and Brunson 2010). The final density outputs were reclassified from very low to very high based upon Jenk's natural break algorithm (Table 1). This classification process requires users to specify the number of classes required (in this case, five). A set of random values are generated and provide initial class boundaries. The mean value for each initial class is calculated; the sum of the squared deviations of class members from the mean values is computed, and the total sum of squared deviations (TSSD) is recorded. Individual values in each class are systematically assigned to adjacent classes by adjusting the class boundaries to see if the TSSD can be reduced. This is an iterative process, which ends when within-class variance is as small as possible and between-class variance is as large as possible (Cromley 1996). For visitor and slope failure density, Jenk's natural breaks provides clearly defined boundaries.

Once the integrated hazard assessment methodology (Fig. 7) has been compiled in ESRI ArcGIS Desktop 10.1, the model is shared as a geoprocessing tool through ESRI ArcGIS Server 10.1. Geoprocessing tools can be accessed online through the use of “geoprocessing widgets”, supplied with the Adobe FLEX extension. To calculate an up-to-date integrated slope failure and visitor density hazard map, the end user clicks the geoprocessing icon, and the process runs on the server, returning a result map when the calculations are complete (Fig. 8).

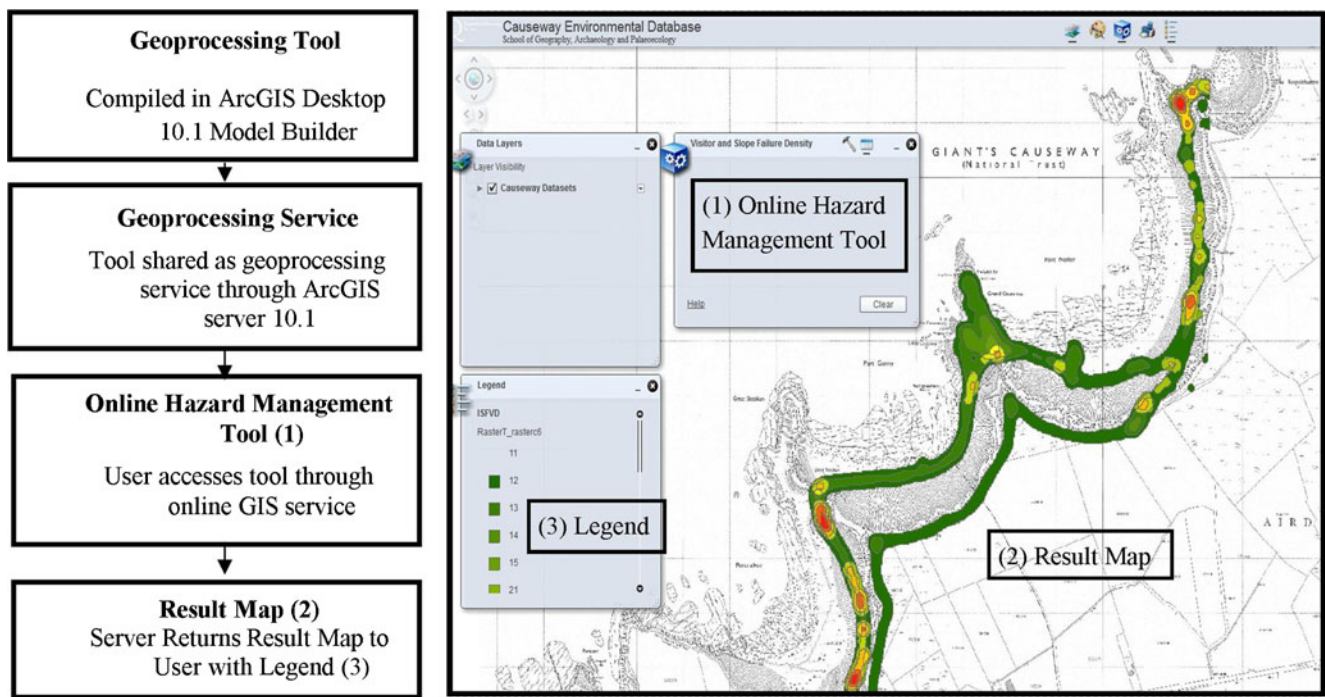
**Table 1** Jenks natural breaks classification

Slope failure density, 10—very low, 50—very high	Visitor density, 1—very low, 5—very high				
	1	2	3	4	5
10	11	12	13	14	15
20	21	22	23	24	25
30	31	32	33	34	35
40	41	42	43	44	45
50	51	52	53	54	55

The integrated hazard assessment map (Fig. 8) provides a point of reference for site managers when making decisions about visitor and staff safety across the World Heritage Site. Areas of low slope failure density are instantly recognisable through the use of green shading. Risk is considered to increase with time spent stationary in an active slope failure zone. Much of the lower footpath experiences very low slope failure densities with visitor density ranging from medium to very high at key features such as the Grand Causeway, Great Stookans and the Ampitheatre (Fig. 1). Visitor density appears very low on paths which connect key features. Much of the upper footpath network experiences very low slope failure densities and low to medium visitor densities around key viewpoints at Portnaboe, Aird's Snout and the Shepherd's Steps (Fig. 1). Areas of increased slope failure density are coded in yellow, orange and red. A small but significant area of medium slope failure density occurs around the Grand Causeway where visitor density is also high to very high (Fig. 8). Similar pockets of medium failure density occur along the lower path between the Grand Causeway and the Amphitheatre. These zones are interspersed with areas of high to very high failure and visitor density (Fig. 8). The Amphitheatre, Shepherds Steps and an area south of the Organ represent more hazardous areas where high slope failure and visitor densities coincide. Like the site itself, the online hazard tool and associated maps are dynamic. As new slope failure and visitor data are received, the output maps respond accordingly.

*Sea Level Impact Model—Habitats*

In 2007, the National Trust commissioned a report to scope climate change impacts at coastal sites around Northern Ireland. Major predictions from this report, based on a range of human greenhouse gas emission scenarios, suggested a mean local sea level rise of between 0.1 and 1 m over the next 100 years, with potential for a 1/50-year 4-m storm surge event to occur 1/25 years. Using the 10-cm HDREM and habitat data from the Natural Heritage Database, it is possible to model which habitats will be impacted by various local sea level scenarios. First, predicted sea level is selected from the HRDEM using the raster calculator function in ArcGIS Desktop 10.1. By inputting the simple algebraic formula “HRDEM ≤ predicted sea level value”, the

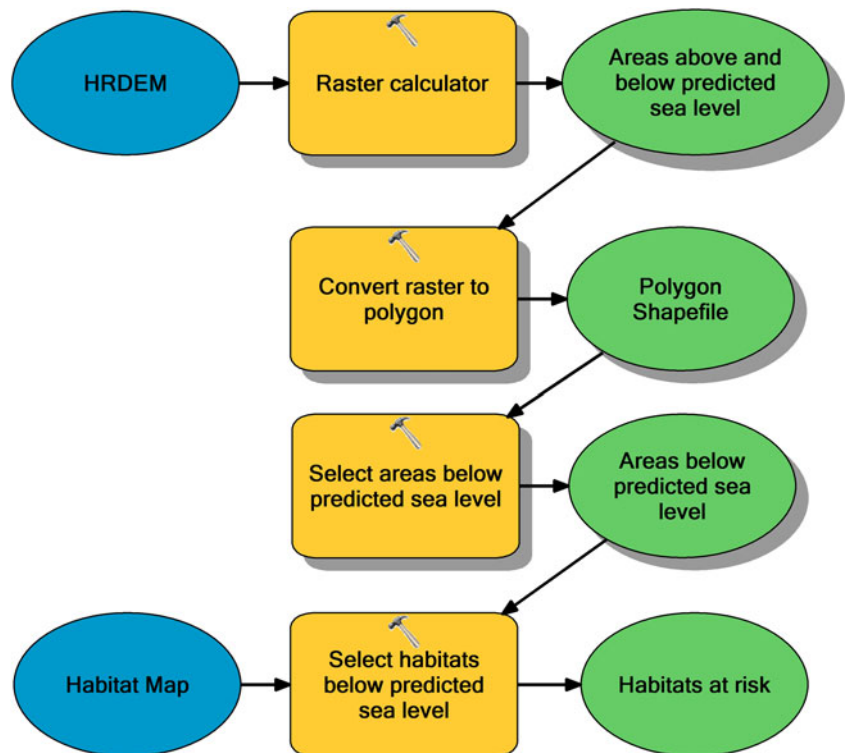


**Fig. 8** Integrated slope failure and visitor density hazard assessment and result map

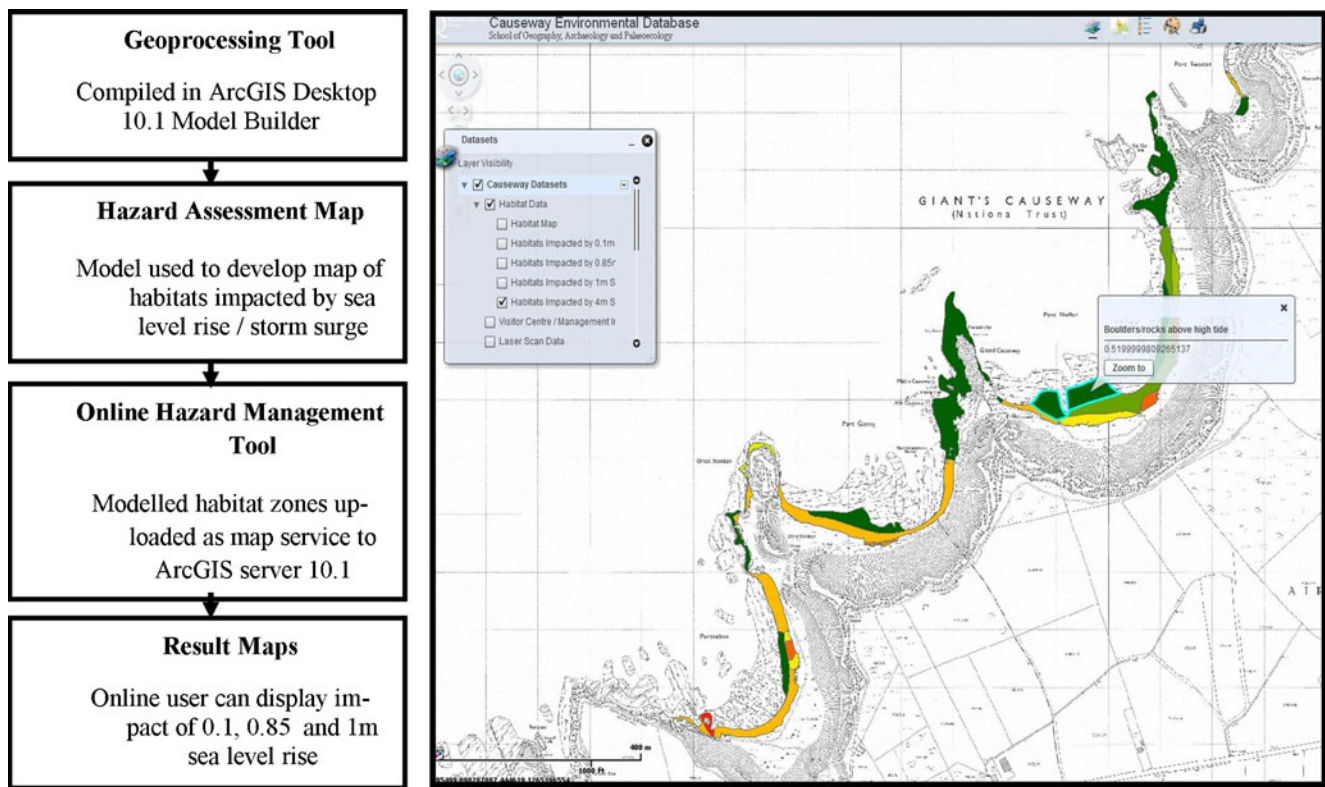
raster calculator produces a new raster surface which displays areas which lay above and below the predicted mean sea level. This raster surface is converted to a polygon shapefile, and areas below the modelled sea level scenario are used to clip the habitats' layer to display impact areas and habitat type (Fig. 9). ESRI ArcGIS Server 10.1 current-

ly does not provide functionality to enable the end user to specify a custom value for modelled sea level scenarios. The tools are therefore developed around predefined values of 0.1, 0.85 and 1 m based on low, medium and high CO<sub>2</sub> emission scenarios in the “Future Coastal Scenarios Report” (Orford et al. 2009). This tool comes with a strong “health

**Fig. 9** Methodology for assessing impact of sea level rise on protected habitats (ArcGIS 10.1 Model Builder Module)







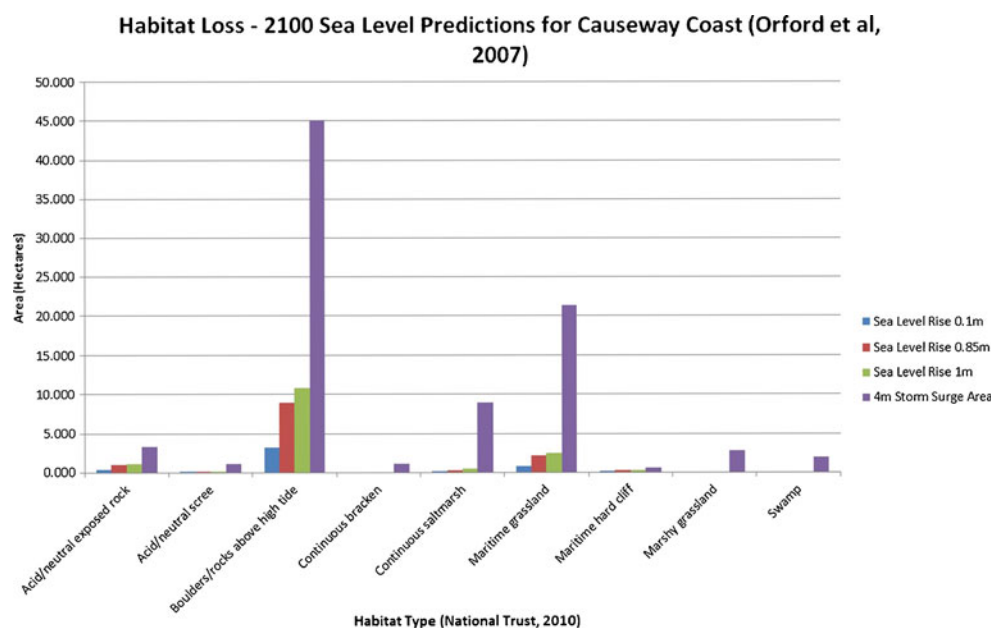
**Fig. 10** Sea level rise and storm surge impact on protected habitats

warning”—local sea level change scenarios are based on models which have not yet been subject to falsifiability, i.e. the scenarios should in no way be regarded as inevitable.

Future sea level and storm surge impact on protected habitats can be viewed by selecting the required scenario in the “habitat data” store on the online database (Fig. 10). The ability to provide the end user with customisable raster calcu-

lator functions would significantly improve the flexibility of this tool. Managers could customise sea level rise and storm surge predictions based on the latest climate and weather data. There is also scope to expand the tool by developing the chart functions of ESRI ArcGIS Server 10.1. This could provide the end user with a bar chart indicating the habitat types and area of impact under different climate scenarios. At present, this

**Fig. 11** Charting habitat loss to sea level rise and storm surge impact



can be achieved by exporting the geoprocessing tool results from ESRI ArcGIS desktop 10.1 to Microsoft Excel 2010 (Fig. 11), but options for interacting with these data are limited online.

## Results and Conclusion

Results from this work demonstrate how digital documentation can provide a plethora of information with which to better understand dynamic and often hazardous sites. Online GIS tools facilitate integration of visitor and slope failure data and equip the National Trust with ephemeral hazard assessment maps with which to monitor safety risks within the WHS (Fig. 8). This approach allows nature to guide the management response. Visitors and staff can be directed away from hazardous areas. It is also possible to use visitor density as a proxy for visitor pressure at key geological features. Further integration of visitor and habitat data would facilitate an assessment of visitor impacts on priority habitats and species.

This project also demonstrates how a visually impressive and artistic digital tool (terrestrial LiDAR) can be used to provide data upon which natural heritage data can be georeferenced, integrated and analysed. At the Giant's Causeway, this has been used to provide a very simple assessment of potential habitat loss for a range of climate change scenarios (Fig. 11). Fundamentally, this work demonstrates how digital documentation effortlessly achieves digital preservation, but when combined with integrated hazard assessment enables managers to identify where specific processes occur, their potential impact and in a broad sense the likelihood of occurrence. Periodic re-survey of key features with terrestrial LiDAR could enable an assessment of landform and landscape change. Integration of LiDAR data with geological maps and climate scenarios could facilitate an assessment of the impact of potential climate change on features of Outstanding Universal Value. At its most basic level, this research allows the National Trust to assess the impact that potential climate change scenarios could have on key habitat designations which provide strong legal protection. What are the implications for the Special Area of Conservation designation if a potential 4-m storm surge results in the loss of 8 ha of protected salt marsh (Fig. 11)?—The answer may have serious consequences for the protection of an irreplaceable geoheritage site.

Researchers are only just beginning to assess the potential for digital documentation to support physical access and practical conservation. The National Trust (NI) has embraced this approach, supporting this research project which documents the Giant's Causeway and Causeway Coast World Heritage Site through terrestrial laser scanning and its integration with available natural heritage data in an

online GIS. Through integration of previously separate and consequently limited datasets, it is hoped that digital documentation facilitates hazard assessment. This approach aims to ensure that managers work in tandem with a site's natural dynamics, allowing documented nature to guide their actions. At the Giant's Causeway, it is hoped this approach will help managers balance the requirements of large visitor numbers with safety considerations created by almost daily slope failures. At other natural heritage sites and on a global scale, it is hoped the approach enables managers to better assess where specific processes are likely to occur, their likelihood of occurrence and probable impacts. Perhaps this will help ensure that remote access does not replace physical access and practical conservation at dynamic and irreplaceable geoheritage sites.

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