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Community driven coastal management: An example of the implementation of a coastal defence bund on South Uist, Scottish Outer Hebrides

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ABSTRACT

Climate change and extreme weather events present a range of natural hazards for the islands of the Scottish Outer Hebrides. The coastline of the island of South Uist suffered extensive erosion and shoreline change as a result of a highly destructive storm during January 2005. Particular sections of coastline are susceptible to flooding that may result in the future from damaging storms and also in the long term as a result of rising sea levels. At Kilpheder extensive areas of low-lying farmland are protected from flooding by a narrow stretch of dunes. Following significant erosion during the 2005 storm, several attempts have been made to 'defend' the area from inundation. In this paper, we describe the nature of the flood sensitivity, the community driven decision making and management approach employed at this site, the capacity of the local community to adapt to coastal change, and describe the performance of the implemented coastal defences.

1. Introduction

Much of the western coast of South Uist is part of the South Uist Machair National Scenic Area, an area of outstanding natural beauty which provides a habitat for many endangered species of fauna and flora. The machair is a very rare habitat type with a global distribution of 30–40 000 ha and has a high cultural, social, and economic significance to the local people. Recent storms have drawn attention to the perceived sensitivity of the coastline to extreme weather events, and there are concerns that climate change and rising sea-levels will add to the threat. Due to a sediment deficit much of the coastline is eroding and in 1977 thirty-eight percent of the coast lacked a protective dune cordon (Mather and Ritchie, 1977). In these areas the coast is susceptible to over wash and flooding, with the latter being a particular concern due to the negative gradient inland from the coastal edge

There is also a crucial social dimension to the issue of coastal change in the Outer Hebrides; in South Uist the land suitable for cultivation is limited to a narrow strip close to the coast with a large proportion of the island's population reliant on crofting (a low intensity form of traditional agriculture practiced in the highlands and islands of Scotland) for all or part of their income. The Outer Hebrides currently suffers from one of the highest rates of depopulation in the UK and any threat to the cultivated machair area from shoreline change, perceived or real, may exacerbate this problem. The sandy west coast of South Uist has adapted and evolved naturally to changing sediment and sea level conditions throughout the Holocene. Given the current scenario of rising sea-level and sediment deficit the coastline is likely to migrate inland with the machair landforms rolling back until a new equilibrium position is reached (Hansom and Angus, 2001). However, the typical human response is to defend the existing coastline and prevent retreat, particularly where important infrastructure is at risk (in this case, agricultural land). There has been considerable pressure from the communities of South Uist for responsible authorities to take action and erect coastal defences in the wake of a severe storm in January 2005.

In this paper the sandy headland known as the Luib at Kilpheder is used as a case study to assess some of the strengths and

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weaknesses of the traditional ICZM approach in the island of South Uist. The site is characterised by very low-lying topography and lacks a dune cordon at the centre of the headland, making it particularly susceptible to flooding, over-wash, and erosion. In the 'Great Storm' of January 2005, Kilpheder experienced severe erosion and in the aftermath of the storm there was pressure from the local community to defend the existing coastline in this area. The physical sensitivity of this site to storm damage is detailed, followed by an analysis of the community driven decision making process which led to the erection of a coastal defence bund against the advice of coastal experts. The performance of the defence bund is described, and lessons that can be learned from the ICZM process and the specific management strategy employed at Kilpheder are discussed.

2. Background

2.1. Study area

Kilpheder is a sandy headland located towards the southern end of South Uist's west coast, in the Scottish Outer Hebrides (Fig. 1). The Atlantic coastline of South Uist is about 35 km long, has a mesotidal range, and faces the northern Atlantic. Straight beaches, large bays, and soft headlands make up most of the coastline, although there are some rocky headlands to the north. The climate is mild with wet winters and dry summers. Most storms approach from the south and southwest (Dawson et al., 2007). South Uist has a low population density and the coastline is relatively undeveloped. Despite this the coast has been influenced by human activities throughout the historic period, including seaweed gathering, cultivation, sand and gravel extraction, livestock access, and marram cutting. More recently human activity has focused on coastal defences.

The machair overlies a strandflat surface composed of Lewisian gneiss (Cooper et al., 2012), which extends offshore as a low gradient shelf. The machair coast developed during the early and mid-Holocene when large volumes of sand were brought onshore by rising sea-levels (Ritchie, 1979). These sediments were reworked by marine and aeolian processes to form an extensive dune complex. A reduction in the rate of relative sea level rise approximately 6 500 years ago is suggested to have caused the machair to switch from a predominantly accreting sedimentary system to one characterised largely by erosion and recycling of sediments (Hansom and Angus, 2001).

The typical machair system includes the beach, dunes, and the low-lying machair grasslands. The inland limit of the machair is a transitional zone, known locally as the 'blacklands', between the calcareous machair soils and inland peats. This area is also frequently characterised by permanent or seasonal lochans due to its low elevation and seasonal variations in the water table. Along some parts of the machair coast the dune cordon is absent, probably due to marine erosion (Mather and Ritchie, 1977). This is the case at Kilpheder where a ~150 m section of coast at the centre of the headland lacks a dune cordon, leaving the low-lying machair grassland exposed and at risk from wave action and sea-level rise. Kilpheder is also very susceptible to flooding as large areas of the machair grassland are below the level of the highest astronomical tide (HAT) (Fig. 2), which is predicted to be 2.81 m above Ordnance Datum (OD – the vertical datum used by the British Ordnance Survey to define heights on maps) for the period 2005–2015 (Dawson et al., 2008).

2.2. Storms and sea-level rise

The current rate of global relative sea-level rise, based on satellite altimetry data from 1993 to 2010, is ~3.2 mm/yr ± 0.4 mm (Nerem et al., 2010). The Coastal Flooding in Scotland Report (Dawson and Powell, 2012), which provides advice for coastal practitioners, assumes a current rate of relative sea-level rise of ~2 mm/yr in Scotland. The rate of sea-level rise is expected to increase during the 21st Century, leading to best predictions of global mean sea-level rise of between +18 and 59 cm by 2 100 (International Panel on Climate Change (IPCC), 2007). With regards to sea-level rise around the UK, Woodworth et al. (2009) concluded that regional sea-level change predictions from the 2002 UK Climate Impacts Programme remained valid. These predict sea-level change range from −1 to +59 cm for northwest Scotland (Hulme et al., 2002). These rates are generally slightly lower than previous local estimates of sea-level change for the Outer Hebrides, which predict sea-level rise of 35–70 cm by 2 100 (Dawson et al., 2001; Angus and Hansom, 2004).

In addition to the threat of relative sea-level rise, there is also a perception that storminess in the Outer Hebrides is increasing. This is a major concern as marine undercutting is thought to be one of the greatest threats to machair stability. However, there is limited historical evidence to support this. Dawson et al. (2007) found that there had not been a sustained increase in storminess in the Outer Hebrides over the last 40 years. This is in agreement with the

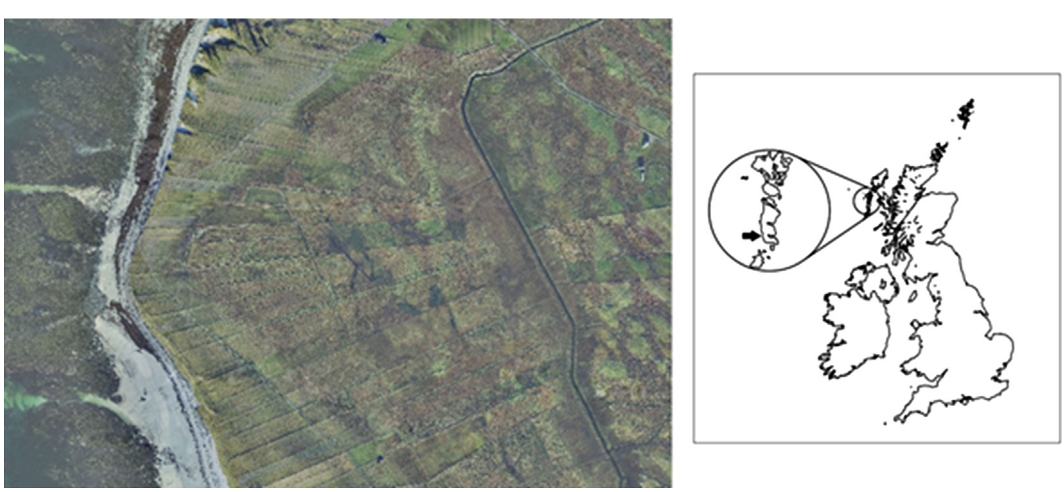

Fig. 1. Location of the study area (adapted from Thorsen et al., 2010). Aerial imagery ©SNH on behalf of Western Isles Data Partnership.

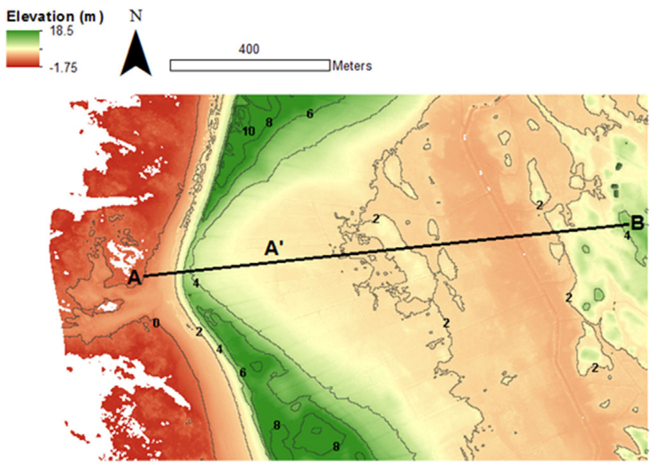

Fig. 2. LiDAR derived topographic map of Kilpheder. LiDAR data ©SNH on behalf of Western Isles Data Partnership.

findings of Wolf and Woolf (2006), who found no increase in storminess or maximum wave heights in the north-east Atlantic over this period. Some authors suggest that anthropogenic climate change may lead to increased storminess over the next century by influencing atmospheric circulation so that a more positive North Atlantic Oscillation (NAO) regime is favoured (e.g. Wang et al., 2004). However, even if the *status quo* is maintained it is possible that the adverse effects of storms will increase due to ongoing: i) erosion of the dunes, ii) lowering/narrowing of the dune crest or machair front, increasing the probability of over wash/breaching during storms, and iii) rising sea-levels, leading to a reduced shoaling effect and subsequently higher energy, larger waves, and higher water levels, which would also increase the probability of over wash, breaching, and flooding during storms. For example, at Kilpheder, it is unlikely that severe erosion experienced during the January 2005 storm will be recovered prior to the next extreme storm event.

Prior to the 'Great Storm' of January 2005 sea-level rise was considered to be the more pressing threat to the low-lying coastline of the Outer Hebrides, with local people being concerned that melting ice sheets would lead to flooding of much of the machair at Kilpheder. However, the rapid and dramatic changes associated with the January 2005 storm shifted community focus to the threat of flooding associated with a breach of the machair front during another extreme storm event. A comparison of the figures involved supports this opinion: current best predictions suggest a relative sea-level rise of somewhat less than a metre, occurring gradually over the next 85 years, while the January 2005 storm surge led to an instantaneous rise in sea level on the order of 2 m at Kilpheder (Dawson et al., 2007).

2.3. The 'Great Storm' of January 2005

On the 11th and 12th of January 2005 a severe storm highlighted the social and geomorphological sensitivity of the western coast of South Uist. The storm was caused by a northwest tracking cyclone with a central pressure of 944 mb (Angus and Rennie, 2008). The extremely low pressure and high wind speeds (max velocity ~170 km/h) coincided with high spring tides, causing a storm surge of up to 2 m (Dawson et al., 2007). The exposed Atlantic coastline of South Uist was particularly at risk as the predominant wind direction during the storm was from the south and west.

The morphological effects of the storm were varied, including: coastal change; erosion/breaching of the dune face and machair front; widespread deposition of storm debris; and severe flooding (Moore et al., 2005; Dawson et al., 2007). Local people described the storm as the "worst in living memory", and were adversely affected by widespread damage to infrastructure. Roads were damaged and covered with storm debris, and property was destroyed (Richards and Phipps, 2007). In addition to this, agricultural land was lost due to coastal change, and damaged by flooding and storm debris. At Kilpheder the machair retreated more than 5 m due to the storm and the coastline remains vulnerable to over wash and flooding. Tragically, the January 2005 storm also caused the loss of life when a family trying to escape the rising flood waters drowned.

2.4. ICZM at Kilpheder

In the immediate aftermath of the January 2005 storm coastal management was largely limited to clearing storm debris and repairing damaged infrastructure. Between 2005 and 2009 the local council, Comhairle nan Eilean Siar (CnES) obtained funding to undertake works at other locations damaged during the storm within South Uist, e.g. erecting a boulder wall to protect a road at Stoneybridge; relocating the school at Balivanich which had been damaged in the storm (Richards and Phipps, 2007). Under Scottish law, the landowner is the party responsible for providing coastal defences. There is no requirement for local councils to be involved unless public infrastructure is damaged or at risk. Additionally, CnES's approach to coastal management is one of managed realignment. As there was no anticipated risk to infrastructure or human life at Kilpheder, CnES had no plans to establish a coastal defence programme there.

However, the local community at Kilpheder felt that the site was at risk from further erosion in future storms and were concerned about the potential to lose agricultural land, and for parts of the machair to become permanently flooded. These concerns led to the local people becoming key instigators of – and participants in – the consultation and management programme subsequently adopted.

A period of research, consultation, and community engagement was undertaken between 2006 and 2011, which included: community meetings for local people to express their views; consultation with experts on coastal processes; community education workshops, question and answer sessions, and lectures on coastal processes and management approaches; the formation of a working group including representatives from CnES, the community, Scottish Natural Heritage (SNH), and Coast Adapt; the involvement of external charities; and consultations with potential funding bodies. Additionally a topographic analysis of the western coast of the southern Outer Hebrides (covering the Luib at Kilpheder) was undertaken using aerial photography and light detection and ranging (LiDAR) technology. The data produced was used to create a 3D digital terrain model (DTM) of the area, which facilitated a high-resolution analysis of the topography at Kilpheder.

The final decision for management was reached in February 2011 and was largely citizen driven. The major output of the ICZM process at Kilpheder is an artificial bund constructed from crushed rock overlain with a sand veneer. The bund directly overlies the pre-existing eroding machair front. Sand traps in the form of fishing nets and planting with marram have also been employed as complementary management strategies.

3. Coastal susceptibility to flooding

Several factors make Kilpheder particularly susceptible to flooding during storm events, including, the lack of a dune cordon, the exposed position of the headland, and the low topography inland from the headland.

Change in the position of the mean high-water mark of ordinary spring tides (MHWOST) between maps from the 1880s and 1970s suggests that there has been an ongoing landwards movement of the machair front at this site, with greater retreat at the centre of the headland (∼30 m, ≤0.3 m/yr), and lesser retreat to the north and south (Fig. 3). Historical maps are notoriously inaccurate; the difficulty of accurately identifying MHWOST in the field, distortions on paper and during scanning, and the width of the line used to plot a feature all contribute to an error that is often significant, and commonly as high as ∼15 m (Hooke and Kain, 1982; Baily, 2009). It is therefore necessary to interpret data with caution. However, consistency in the direction of change along the coast and local knowledge support the historical evidence for ongoing headland retreat in this area.

Both the machair front and the machair grasslands are very low lying at Kilpheder. Elevation decreases from the coast to the seasonally waterlogged area around the machair lochs. Although there are higher dunes to the north and south, the maximum natural elevation of the machair front at the centre of the headland is ∼4 m above OD. Elevation decreases gradually to a minimum elevation of ∼1 m OD about 900 m inland (Fig. 4). The low coastal topography makes Kilpheder particularly susceptible to breaching of the machair front or over-wash during storms.

In the storm of January 2005 a combination of high tide, extremely low atmospheric pressure, and adverse wind and wave conditions, led to a storm surge of 4.5 m above OD, about 2.75 m higher than the predicted water levels (Angus and Rennie, 2008). This level was observed in North Uist. Observations from South Uist and Benbecula suggest a surge of ∼2 m (Dawson et al., 2007).

Fig. 3. Positions of mean high water at ordinary spring tide (MHWOST) in 1881(solid line) and 1972 (dashed line), superimposed on 2005 aerial photography of Kilpheder. Aerial imagery ©SNH on behalf of Western Isles Data Partnership.

Although it is difficult to estimate water levels at Kilpheder during the January 2005 storm as levels would have varied considerably depending on local coastal and bathymetric configuration, Fig. 5 provides a visual indication of the susceptibility of the low-lying machair front to surges of this magnitude, and more typical storm surges of 0.5 m and 1 m.

4. Analysis of the ICZM process at Kilpheder

After the January 2005 storm events at Kilpheder generally followed the typical ICZM process: information on coastal processes was collated and presented at community meetings, experts were consulted on appropriate management approaches, a working group was formed from members of key stakeholder groups (summarised in Table 1), and local opinions were solicited through seminars, workshops, and question and answer sessions. The decision making stage was undertaken by the working group established to oversee coastal management at Kilpheder, with the approach adopted largely reflecting community opinion. The artificial crushed rock and shingle bund was installed in March 2011. Table 2 summarises the sequence of key events in the ICZM process.

Perhaps the most noteworthy feature of the process at Kilpheder is that it was citizen initiated, and largely citizen driven throughout. The local council has adopted a policy of managed realignment apart from where council-owned infrastructure is at risk. Applied to Kilpheder, this policy would have allowed natural coastal realignment to occur. Evidently, the course taken at Kilpheder is a clear divergence from this, with the end result of a crushed rock and shingle bund representing the desired outcome of the community rather than institutional stakeholders.

Many aspects of the ICZM process were successful, and there were several positive outcomes. The ability of the community to initiate and maintain a high level of involvement in the process over a period of several years indicates that the South Uist community is capable of facilitating a 'bottom–up' approach to coastal management. Meetings, workshops, and seminars were well attended, reflecting the importance of coastal issues to the local population, and the willingness of local people to be involved in both the decision making and implementation stages of ICZM. Despite pre-existing tensions between some of the stakeholders, the ICZM process at Kilpheder was highly inclusive, with all stakeholders participating. For example, all of the stakeholders listed in Table 1 were involved in community meetings. Additionally, the working group was formed from stakeholders with markedly differing interests, (e.g. Storas Uibhist represented the views of the crofters and local community, preferring a management response of 'hold the line', while CnES's ICZM policy and CoastAdapt's environmental interests supported a management response of 'managed realignment'), ensuring that all potential management options were considered.

The high involvement of a number of different stakeholders made it possible to draw on the various strengths and abilities of each group during both the consultation and implementation stages, promoting cooperation between stakeholders. This is illustrated by the provision by CnES of the services of their ICZM Coordinator to advise and provide access to expert opinion, the acquirement of funding by SNH, the role of Oxfam Scotland in providing community support, and the involvement of local volunteers in carrying out some initial coastal protection works. Furthermore, the educational nature of workshops and lectures given by the CoastAdapt project led to several favourable outcomes in the coastal zone at Kilpheder including the agreement by local people to the cessation of sand and shingle extraction, and the promotion and adoption of soft coastal defence methods (in this case the erection of fishing net sand traps and marram planting).

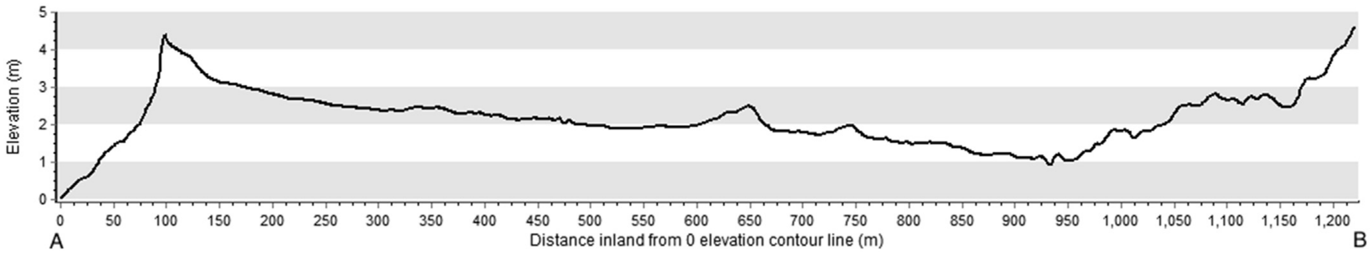

Fig. 4. Graph showing elevation along profile A-B from Fig. 2. Vertical exaggeration ×30. LiDAR data ©SNH on behalf of Western Isles Data Partnership.

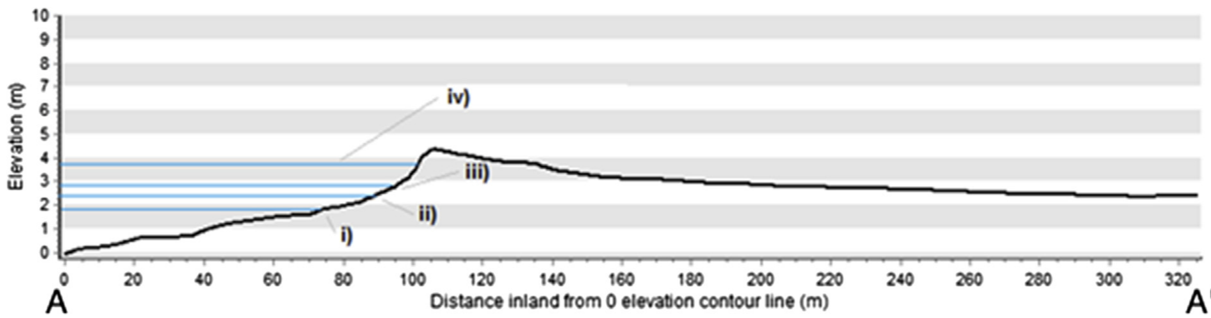

Fig. 5. Profile A–A′ from Fig. 2 shown with water levels for: i) 2012 highest tide (1.86 m O.D., Balivanich tide table, 2012), ii) highest tide combined with a 0.5 m storm surge; iii) highest tide combined with a 1 m storm surge; iv) highest tide combined with a 2 m storm surge. Chart datum-ordnance datum conversion of −2.59 m (Lochmaddy, Dawson et al., 2007) used. Vertical exaggeration ×8. LiDAR data ©SNH on behalf of Western Isles Data Partnership.

However, the management strategy adopted at Kilpheder also reflects a disconnect between coastal science and practice at this site. Although coastal geomorphologists were consulted and CnES's ICZM Coordinator was involved in the decision making process, the artificial bund erected was considered to be 'the least favoured and most damaging option' of those considered by experts in terms of coastal geomorphology and maintaining the environmental character of the site. While several alternative management strategies to the 'do-nothing' approach were suggested by the scientists consulted – all of which were considered preferable to the crushed rock bund – these were not deemed practicable at Kilpheder due to the strong local desire to 'hold the line'. Evidently despite the inclusion of numerous stakeholders in the consultation process the final decision was made in significant favour of the social and cultural demands on the site, with little regard given to environmental considerations. A further shortcoming of the approach adopted appears to be the lack of a rigorous maintenance and monitoring programme. Since the defence was erected in March 2011 visual inspections have been made only on an *ad hoc* basis after storms, while there is no indication that any form of maintenance has been undertaken despite evidence for damage to fencing, cuspate erosion of the bund, exposure of buried shingle, and damaged sand traps (discussed further in Section 5).

Table 1
Groups and organisations involved in the ICZM process at Kilpheder. (*working group formed during ICZM process).

Stakeholder	Acronym	Type	Responsibilities (related to Kilpheder)
CoastAdapt	–	Transnational project	Facilitate community adaptation to coastal change
Comhairle nan Eilean Siar	CnES	Local government	Governance, ICZM
Crofters Commission	–	Public body	Crofting regulation
Kilpheder Grazings Committee	–	Community/agricultural	Management of common grazing land
Lochboisdale Community Council	–	Community	Community care issues
Oxfam Scotland	–	Charitable organisation	Community support
Scottish Natural Heritage	SNH	Public body	Natural heritage and diversity, conservation designations
Storas Uibhist	–	Community landowner	Land management
Working group*	–	Working group with members from CnES, Storas Uibhist, CoastAdapt, and SNH	Determine management approach

The above shortcomings of ICZM at Kilpheder appear to be largely attributable to a lack of integrative instruments in the institutional framework. Specifically, there appears to have been failure to: i) integrate the environmental assessment of the site with the policy adopted; ii) convincingly communicate the scientific case for a 'do nothing' or soft defence approach to the local community; and iii) either identify the need for ongoing maintenance of the bund and/or determine where the responsibility for maintenance lies. There are a range of possible causes for these failures, including the delay in obtaining expert opinion (while consultation for protection works started in summer 2006, coastal experts were not contacted until 2010 (see Table 2), time-pressure exerted by constraints on funding obtained, and pre-existing tensions and lack of trust between stakeholders. Additionally, it was noted by CnES that in the wake of the 2005 storm the community felt that '…they were left to cope with and to recover from the damage on their own. Despite appeals to the authorities they did not receive assistance in repairing storm damage.' This lack of support from the authorities may have fuelled the desire to prevent future storm damage rather than adapt to coastal change.

Table 2
Timeline of events related to the ICZM process at Kilpheder. Acronyms for ICZM stages are: information collecting (IC), consultation (C), implementation (I), decision making (DM), management (M).

Year	Month/Season	ICZM stage	Event	Notes
2005	January	–	Storm	~5 m of crest retreat occur at Kilpheder
2006	Summer	IC/C	Coastal change seminar	Community education and discussion
2007	Winter	IC/C	Coastal care meeting	Community education and discussion
2010	Spring	–	Oxfam Scotland initiates project focused on communities in South Uist	
2010	June	C	Community meeting	Work at Kilpheder prioritised, community participation agreed, Oxfam Scotland becomes involved and encourages community to apply pressure on authorities to 'take action'
2010	Summer	I	Cessation of sand and gravel extraction in the coastal zone	
2010	September	DM	Community meeting	Nature of coastal defence discussed
2010	October	DM	Working group formed	Group's purpose is to agree and find finance for a management plan, and to consult experts
2010	Autumn	I	Fishing net sand traps erected	Work carried out by community
2010	Winter	IC	Coastal experts contacted for advice	
2011	January	–	Funding secured by SNH	
2011	February	DM	Coastal protection meeting	Management options recommended by coastal experts rejected by local residents
2011	March	DM	Climate adaptation meeting	Decisions for management at Kilpheder communicated to community
2011	March	–	Deadline for project completion	Deadline stipulated by funding body
2011	March	M	Crushed rock, shingle, and sand bund erected	

Despite the comprehensive programme of community consultation and education, the need to 'take action' at Kilpheder was not overcome during the decision making process. While the involvement and ingenuity of the local community in initiating and driving the ICZM process are desirable outcomes in their own right, the end result at Kilpheder suggests that promoting entirely citizen based decision making may not always result in appropriate management strategies. The public preference for the 'hold the line' management option is a common feature where communities are involved in ICZM in the UK (Tunstall and Penning-Roswell, 1998), and is frequently a barrier to adopting more environmentally sustainable approaches to coastal management (e.g. McFadden, 2008). In this case, the social and cultural demands on this site have taken precedence, resulting in a

Fig. 6. Photos of the ridge at Kilpheder showing clockwise from top right: eroded scarps on the sea-ward side of bund (March, 2012); the top of the ridge, partly re-vegetated following over-topping during winter 2012–2013 (March, 2013); damaged sand traps made from fishing nets, located to the south of the ridge (March, 2012); sand accumulation in the eroded scarps at the base of the seaward side of the bund (June, 2012).

management strategy which neglects environmental considerations.

It is noteworthy that the ICZM process at Kilpheder has been almost entirely reactive, i.e. the process was initiated in response to an extreme event. Since the January 2005 storm several measures have been put into place to enhance community resilience, including improving communication between local communities and authorities, community education on coastal processes, putting support networks in place to protect vulnerable individuals in future storms, and enhancing the capabilities of emergency services (Ritchie and Kingham, 2007). Further improvements to the ICZM process at Kilpheder would result from enhancing communication pathways between experts and the community, employing a more balanced approach to decision-making, and increased focus on the continuous nature of ICZM which would promote ongoing monitoring and maintenance of the site, and emphasise that the construction of defences is not the ‘end point’ of coastal management.

5. Design, monitoring, and maintenance of the bund

As discussed in Section 4, the selection of an artificial shingle and crushed rock bund as the defence for Kilpheder was largely based on the views of the community. The coastal experts consulted suggested several possible defence approaches for the site, and their assessments of the environmental and geomorphological suitability of each approach. In decreasing order of suitability, the approaches included: i) no intervention; ii) the creation of a secondary dune inland from, and at a shallower angle than, the existing machair front; and, iii) the creation of an artificial dune along the existing machair front. The use of shingle and crushed rock was strongly advised against due to potential environmental impacts on transport dynamics and coastal character. The selection of the coastal defence approach to be used was made by the working group. They elected to implement an artificial shingle and crushed rock ridge against the advice of coastal experts as past experience in the Outer Hebrides indicated that a non-interventionist stance would be unacceptable to local residents. Storas Uibhist, the community landowner, indicated that crofters who rely on the land at Kilpheder for their livelihood “would not wear the loss of land” associated with anything other than a ‘hold the line’ approach. Furthermore, the acquisition of funding from SNH created a “strong public relations drive to ‘do something’”. These factors led to the selection of a highly visible and environmentally unsuitable defence, which minimised disruption to human activities.

The bund was designed so that approximately one third of its volume was placed below the machair edge on the upper beach. The remaining two thirds of the crushed rock was placed on top of the machair. An artificial sand dune was constructed above the crushed rock. This was planted with marram grasses – with reference to the guidelines published by The Woods Hole Sea Grant and Cape Cod Cooperative Extension (2008) – and spread with seaweed to enhance stability. Additionally, sand-blow fences were erected to the north and south of the defence, and fishing nets were draped over sections of the dune.

Some aspects of the sustainability of the defence were considered, specifically those which promoted the stability of the defence. For example, the crushed rock placed on the upper beach was implanted to a depth of 1–2 m, and re-covered with the excavated sand to minimise settling and undermining. Additionally, it was recognised that the defence would need to be fenced off to exclude livestock which roam freely over the machair grasslands and beaches for much of the year. The defence is recognised as being unsustainable in terms of allowing pre-existing machair sediment transport processes to continue. In particular, it was recognised that aeolian transport of sand from the beach to the machair might be disrupted, and longshore transport of crushed rock clasts could potentially alter the character of the coast to the north and south of the defence. The working group acknowledged that during severe storms the ridge would be overtopped and eroded, and recognised that ongoing maintenance would be required to maintain the original form of the bund. In the view of coastal experts, the defence is unlikely to be sustainable in the long term due to ongoing processes of sea-level rise and shoreline retreat at this site.

Despite the acknowledged importance of monitoring and maintaining the ridge at Kilpheder, no official programme was put in place by the working group. Since its construction in spring 2011 no maintenance work has been undertaken.

Visual inspections of the ridge between May 2011 and November 2013 indicate that maintenance is now required on several aspects of the defence (Fig. 6). The fencing designed to exclude livestock from the bund was knocked down on the seaward side of the defence in winter 2011–2012, and has not been repaired since. On several site visits cattle were seen to be grazing on the bund. While there is some evidence for sand accumulation at the base of the ridge during the summer months, over the course of winter 2011–2012 and 2012–2013 deep cuspate scarps were

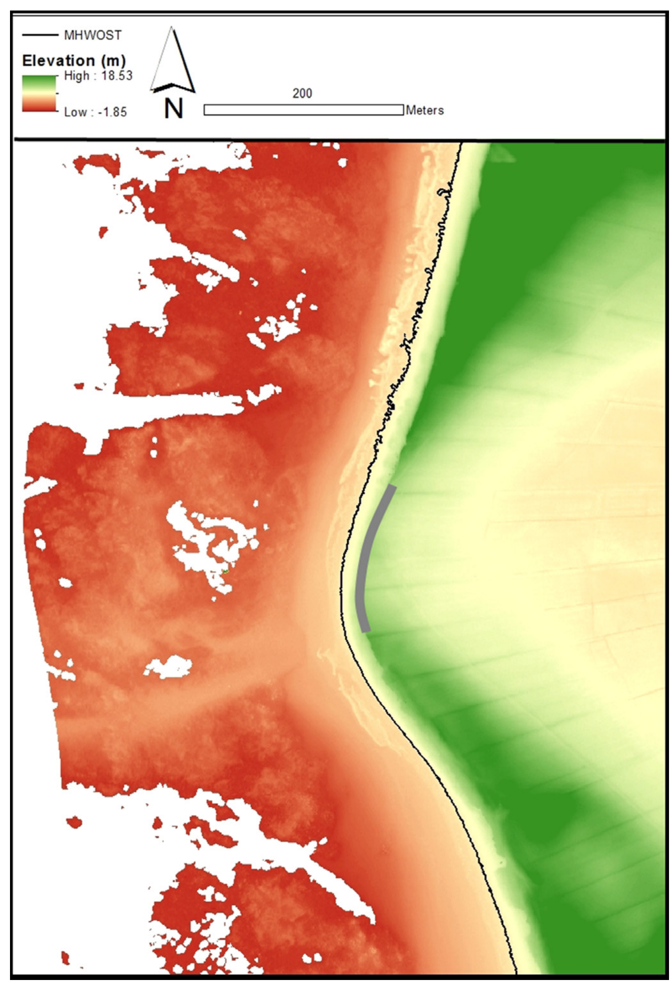

Fig. 7. Map of Kilpheder showing the position of the bund (marked in grey) relative to the position of MHWOST. LiDAR data ©SNH on behalf of Western Isles Data Partnership.

eroded on the seaward face of the bund (Fig. 6). This has exposed the buried crushed rock and shingle, which is now being transported away from the site by longshore drift. Fishing nets displaced during storms have not been repaired, and the sand trap fencing to the north and south of the ridge appears to be largely ineffective. Furthermore, the ridge was over-topped during winter 2012–2013, which caused erosion of the artificial sand dune above the ridge. Eroded areas had partially re-vegetated prior to the beginning of the winter 2013–2014 storm season.

The performance of the bund highlights some of the issues associated with enforcing a 'hold the line' approach where it is not geomorphologically appropriate. For example, the bund is situated ~15–20 m inland from the position of MHWOST (Fig. 7). This is significantly lower than the minimum recommended distance for situating an artificial dune from MHWOST, which is ~30 m (100 ft) (The Woods Hole Sea Grant and Cape Cod Cooperative Extension, 2008). The proximity of the bund to MHWOST ensures that the seaward side of the ridge is frequently exposed to marine erosion, and reduces the chances of successful fixation by vegetation due to recurrent inundation of the base of the ridge. Additionally, the sand trap fencing appears to be ineffective in its current location with no evidence for sand accumulation between 2011 and 2013.

6. Conclusions

Although the coastline at Kilpheder is perceived as susceptible to erosion and inundation during storm events, shoreline change at this site is part of the natural process of realignment in response to rising sea-level and a depleted sediment supply. Given sufficient time, the coastline will re-stabilise further inland with rollback of associated habitats. The loss of land is unlikely to be significant in relation to the overall machair system, which is thought to be relatively resilient to the effects of storms in the long term (Angus and Rennie, 2008). However, it should be noted that at Kilpheder the amount of shoreline change associated with the January 2005 storm (~5 m) is significantly greater than long term annual erosion rates (~0.3 m/yr). The physical susceptibility of Kilpheder lies in the low-lying topography of the machair grasslands, and the susceptibility of this area to extensive flooding in the event of a breach of the machair front. Any future breach in this area is likely to be associated with a severe storm event, as opposed to ongoing gradual sea-level rise, or typical winter conditions.

Coastal science and advice on the best management policy (withdrawal from the coast) was presented to the community at several meetings. Despite this, the local community was unwilling to accept any loss of land at Kilpheder, and their views were the key factor in deciding to build an artificial crushed rock and sand bund along the existing headland. Although the land users are now fully aware that shoreline change is inevitable, there is a desire to delay any further loss of land, rather than adapt to it. The lack of assistance provided to crofters in the immediate aftermath of the storm may have contributed to this view.

The community response to storm damage at Kilpheder highlights the recognised social challenges associated with putting recommended policy for the coastal zone into practice. That land users are aware of the need to adapt to a retreating coastline is evident in their willingness to follow advice on the cessation of sand and gravel extraction, and to be involved in the consultation process. However a lack of integrative instruments in the ICZM process appears to have led to the adoption of a mitigative rather than adaptive approach to coastal change at Kilpheder. It is to be hoped that any additional time bought by construction of the bund can be used to address the underlying socio-economic issues which currently make withdrawal from the coast an unacceptable option for the crofting community.

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References

Angus, S., Hansom, J.D., 2004. Tir a'mhachair, tir nan loch? Climate change scenarios for Scottish machair systems: a wet future?. In: Proceedings vol. 2, Littoral 2004. Delivering Sustainable Coasts: Connecting Science and Policy. Cambridge Publications, pp. 565–569.
Angus, S., Rennie, A.F., 2008. An Ataireachd Ard: the Great Sea Surge. The Natural Heritage Impact of the Storm of 11 January 2005 in the Uists and Barra, Outer Hebrides. Scottish Natural Heritage Commissioned Report. Scottish Natural Heritage, Inverness.
Baily, B., 2009. An analysis of old tide-line mapping for coastal zone management. In: Proceedings of the FIG Working Week. Eliat, Israel, 2009.
Cooper, J.A.G., Jackson, D.W.T., Dawson, A.G., Dawson, S., Bates, C.R., Ritchie, W., 2012. Barrier islands on bedrock: a new landform type demonstrating the role of antecedent topography on barrier form and evolution. Geology 40 (10), 923–926.
Dawson, S., Powell, V.A., 2012. Chapter 4. Relative sea level rise. In: Ghimire, S. (Ed.), Coastal Flooding in Scotland: a Guidance Document for Coastal Practitioners. CREW, pp. 27–31.
Dawson, A.G., Smith, D.E., Dawson, S., 2001. Potential Impacts of Climate Change on Sea Levels Around Scotland. Scottish Natural Heritage Research, Survey and Monitoring Report No. 178. Scottish Natural Heritage, Perth.
Dawson, A.G., Dawson, S., Ritchie, W., 2007. Historical climatology and coastal change associated with the 'Great Storm' of January 2005, South Uist and Benbecula, Scottish Outer Hebrides. Scott. Geogr. J. 123 (2), 135–149.
Dawson, A.G., Ritchie, W., Green, D., Wright, R., Gomez, C., Taylor, A., 2008. Assessment of the Rates and Causes of Change in Scotland's Beaches and Dunes. Phase 2: Commissioned report for Scottish Natural Heritage.
Hansom, J.D., Angus, S., 2001. Tir a'mhachair (land of the machair): sediment supply and climate change scenarios for the future of the Outer Hebrides machair. In: Gordon, J.E., Leys, K.F. (Eds.), Earth Science and Natural Heritage: Interactions and Integrated Management. The Stationary Office, Edinburgh, pp. 68–81.
Hooke, J.M., Kain, R.J.P., 1982. Historical Change in the Physical Environment: a Guide to Sources and Techniques. Butterworth Scientific, London, p. 236.
Hulme, M., Turnpenny, J., Jenkins, G., 2002. Climate Change Scenarios for the United Kingdom: the UKCIP02 Scientific Report. Tyndall Centre for Climate Change Research, p. 120.
IPCC, 2007. Climate Change 2007: Synthesis Report.
Mather, A.S., Ritchie, W., 1977. The Beaches of the Highlands and Islands of Scotland. Countryside Commission for Scotland, Battleby.
McFadden, L., 2008. Exploring the challenges of integrated coastal zone management and reflecting on contributions to 'integration' from geographical thought. Geogr. J. 174 (4), 299–314.
Moore, H., Wilson, G., Dawson, A., Dawson, S., 2005. Western Isles (South) Coastal Zone Assessment Survey: Grimsay, Benbecula, and South Uist. Commissioned Report for Historic Scotland and Scottish Archaeology and the Problem of Erosion. EASE Archaeological Consultants, Edinburgh, p. 31.
Nerem, R.S., Chambers, C., Choe, C., Mitchum, G.T., 2010. Estimating mean sea-level change from the TOPEX and Jason altimeter missions. Mar. Geod. 1 (Suppl. 1), 435–446.
Richards, L.A.R., Phipps, P.J., 2007. Managing the impact of climate change on vulnerable areas: a case study of the Western Isles, UK. In: McInnes, R., Jakeways, J., Fairbank, H., Mathie, E. (Eds.), Landslides and Climate Change: Challenges and Solutions, Proceedings of the International Conference on Landslides and Climate Change, Ventnor, Isle of Wight, UK, 21-24 May 2007, pp. 435–442.
Ritchie, W., 1979. Machair development and chronology in the Uists and adjacent islands. Proc. R. Soc. Edinb. 77 (B), 107–122.
Ritchie, W., Kingham, L., 2007. Assessment of Community Responses and Reactions to Serious Coastal Erosion and Flooding in January 2005 (CoPraNet case study).
The Woods Hole Sea Grant, Cape Cod Cooperative Extension, 2008. Coastal dune protection & restoration using 'cape' American beachgrass & fencing. Mar. Ext. Bull., Mass., 1–20.
Thorsen, M.K., Hopkins, D.W., Woodward, S., McKenzie, B.M., 2010. Resilience of microorganisms and aggregation of a sandy calcareous soil to amendment with organic and synthetic fertiliser. Soil. Use Manag. 26 (2), 149–157.
Tunstall, S., Penning-Roswell, E.C., 1998. The English beach: experiences and values. Geogr. J. 164, 319–332.
Wang, X.L., Zwiers, F.W., Swail, V.R., 2004. North Atlantic ocean wave climate change scenarios for the twenty-first century. J. Clim. 17 (12), 2368–2383.
Wolf, J., Woolf, D.K., 2006. Waves and climate change in the north-east Atlantic. Geophys. Res. Lett. 33 (6). http://dx.doi.org/10.1029/2005gl025113.
Woodworth, P.L., Teferle, F.N., Bingley, R.M., Shennan, I., Williams, S.D.P., 2009. Trends in UK mean sea level revisited. Geophys. J. Int. 176 (1), 19–30.