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The implications of climate change for coastal habitats in the Uists, Outer Hebrides

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ABSTRACT

The low-lying, relatively flat landscape of the western seaboard of the Uists has a particular vulnerability to climate change, especially to rising sea levels. Winter water tables are high, and a high proportion of the area is permanent open water and marsh. Any changes in aquatic relationships could pose serious problems for the Uist environment, where the closely inter-connected habitats are internationally recognised for their conservation value. The uncertainty of most aspects of climate change is imposed upon an existing level of high climatic variability in the Western Isles, greatly complicating local habitat and land use scenarios, but rising sea level, possibly the most threatening aspect of climate change, is a certainty. Rising sea level alone has the potential to raise water levels within the islands by progressively reducing the effectiveness of an ageing drainage network, not only raising water levels, but possibly also facilitating saline infiltration of the water table. This raises problems for habitats, species, and for land users, in islands where habitat processes and human interaction with the environment have always been particularly closely linked.

1. Introduction

The islands of the Outer Hebrides of Scotland align north-south on the north-western seaboard of Europe, exposed on their western coasts to the open Atlantic Ocean. Within this archipelago, the islands from Bearnaraigh in the Sound of Harris to the southern end of South Uist, referred to here as 'the Uists' lie adjacent to an exceptionally wide continental shelf, with distances from the main islands to the 200 m shelf break of up to 120 km. The distance to the 50 m depth contour ranges from 17 to 28 km, while the 20 m contour generally lies some 5–8 km offshore, extending to 13 km off Heisgeir (as measured from North Uist/Baile Sear) (Cooper et al. 2012; Dawson et al. 2012). Much of the terrestrial coast has an altitude generally below 10 m and often below 5 m, as confirmed by LiDAR imagery (Fig. 1a and b). This platform supports 'machair', a habitat restricted globally to northern Scotland and NW Ireland, but reaching its finest development in the Uists (Angus, 2001). Within this machair platform, and over much of the area of North Uist, Benbecula and northern South Uist, there are myriad lochs (lakes), many with a surface close to sea level and often so low-lying that the sea enters the loch on at least some, and often all, high tides, creating brackish water bodies or 'saline lagoons'. The machair is generally alkaline because of its high shell content, while the landward blanket bogs are often highly acid. There is thus a highly complex gradient of pH and salinity, interacting with a water table that goes into winter surplus over significant areas of the machair, creating seasonal 'winter lochs'.

The gentle topographic gradient continues offshore, where a shallow, rocky seabed with minor pockets of sand supports a vast forest of kelp *Laminaria hyperborea*, extending some 6–8 km west of the islands, affording a considerable protective facility from wave action to the western beaches and their backing dune ridge and thus to the landward habitats (Angus and Rennie, this volume).

The landward habitat suite includes machair, a range of fresh water loch types, marshes, saltmarshes and saline lagoons, individually and in aggregate of outstanding value for nature conservation. This is reflected in an extensive network of Special Areas of Conservation (SAC) established under the EC Habitats Directive, and additional Sites of Special Scientific Interest (SSSI) established via UK and Scottish domestic legislation. This rich environment also supports very high numbers of breeding birds, notably waders, and these are protected by Special Protection Areas (SPA) via the EC Birds Directive. The combination of low gradients and fluctuating water tables means that transitional zones between habitats can be both extensive and dynamic, so that the distribution of habitats varies seasonally and inter-annually in response to relatively small changes in water regime.

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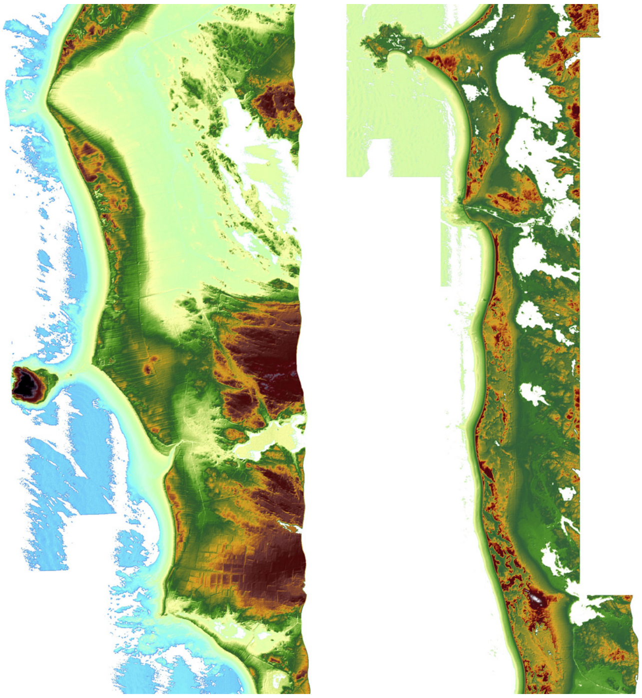

Fig. 1. 1 m LiDAR imagery of western South Uist showing ramped relative altitude from Cille Pheadair southwards (left) and from Rubha Aird a'Mhuile southwards (right). Lowest ground pale blue-pale green, highest dark red; open water is blank. Note the narrow, frontal low dune ridge in the north of the left image and the low-lying ground landwards of the main dune ridge in both images, believed to represent old loch basins. LiDAR image captured November 2005 by Western Isles Data Partnership© SNH for WIDP. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Historic maps that predate the first triangulated terrestrial map of Bald (1805) indicate more extensive loch networks in the interiors of South Uist and Benbecula, while numerous historical accounts tell of their use for navigation, to the extent that during the 18th Century, they enabled "communication by water, in boats, from the east sea, to almost every single farm on the island" (Anderson, 1785, Ritchie, 2006). Anderson's 1785 report also tells of the construction of a canal between a former inland Loch Dalbrog and Loch Boisdale in South Uist (a marine inlet on the east coast), excavated to facilitate this communication, but also drained large areas of land. This may have been the start of a long period of drainage, though there are few historic accounts of the works of this period. Canals for navigation within South Uist may date as far back as the 14th Century (Rev. Michael Macdonald, pers. comm.).

Bald's (1805) map shows a drainage network that is more restricted than the older [indicative] maps, but significantly larger than today's network. Over a period of around 200 years, a drainage programme was undertaken and successively improved. The resulting network is an extensive interlinked system that for the most part can discharge water only during low tides due to the very small altitudinal differences involved, with gradients as low as 1%. Some of the drains are valved, so that sea water is prevented from entering at high tide, but the large 'Roe Glas' drain at Cill Donnain (NF722276) has only a grid to prevent the entry of debris, allowing sea water to enter Loch Chill Donnain during spring tides, over a distance of 1.4 km. On the NW side of Loch Bi (NF769463), the valves have been lost, while more modern floodgates built at Strom Dearg (NF762197) leak sea water into the seaward end of the old canal that now drains much of the machair lands and lochs of southern South Uist.

The current internationally recognised nature conservation value of machair and its assoacited habitats, which in turn has a very strong and largely positive relationship with people, has been artificially established and is artificially maintained. Though it is possible that the natural situation was even finer in terms of conservation value, it is beyond doubt that the current habitat quality is very high indeed, and that aspects of this are threatened by climate change. Ultimately the future environmental functionality of the Uists, including its habitats and its land use, is dependent on the behaviour of water, whether from storm waves, or from gradual sea level rise causing increased marine flooding, raising loch levels or leading to saline infiltration of the water table.

2. Climate change scenarios and predictions for the Uists

Jones et al. (2009) and Murphy et al. (2009) envisage warmer summers and wetter winters for north-west Scotland, including the Western Isles. Uist agriculture is largely cattle-based, with winter fodder crops grown on the machair; crops usually support a rich biodiversity of wild flowers, insects and birds (Angus, 2009). Warmer summers could improve yields, and expand the range of crops (currently mainly rye and oats, with limited use of bere barley). However, earlier harvests could have a negative impact on biodiversity unless wild flowers and ground-nesting birds are also able to complete the most vulnerable parts of their fruiting/breeding cycle earlier. However, this probable advantage could be hampered by the machair remaining wetter for longer in winter, preventing ploughing until later in the spring, offsetting any gains in summer and autumn. These aspects have a high level of uncertainty, and storminess is arguably even more uncertain, and with seasonal and annual variation in sunshine, precipitation and storminess already very high, any trend might be difficult to confirm or even detect.

There is less uncertainty about sea level rise, however, and measurements have established that recent (1992–2007) annual relative mean sea level rise in the Western Isles is of the order of 5.7 mm yr^{-1}. Measurements also confirm a lower but significant rate for the 100 years prior to this. There is no way of knowing if the recent increase is temporary or likely to continue into the future (Rennie and Hansom, 2011). At current rates, mean sea level in the Western Isles will have risen by 57 cm by the year 2100, relative to its level in 2000.

The drainage network has thus been progressively losing efficiency for a long period, possibly since its construction. As the altitude of low tides progressively rises, it reduces the hydraulic gradient between loch and sea, and thus the ability of the drainage network to perform. Terrestrial water tables and loch levels will thus rise progressively. The behaviour of the machair water table is complex and poorly understood, but more prolonged winter water surpluses must be regarded as a strong possibility, while slowly rising loch levels will flood land that has been used for agriculture, both adversely affecting the cropping that is so important to the local economy and to wildlife.

In addition to poorer drainage of surface water, there will be a cumulative rise in sea water inflow to inland lochs and thus, to varying degrees, into the water table, though this will vary depending on the presence or absence of valves at the outfalls.

Climate change, imposed on an already variable and vulnerable environment, augments this vulnerability on the coastal edge via the possibility of major sediment re-alignment, and via rising water levels inland, probably with higher salinity. LiDAR imagery has revealed potential vulnerability to marine flooding via the eastern coasts of Baile Sear, via the lower reaches of the Howmore River, and via a breach in the dune ridge at Cille Pheadair (Fig. 1). Marine incursions via the latter two locations would enable sea water to flood extensive low-lying areas to the north and south of the incursions.

Mobilisation of sand also has the potential to block fresh water flows, notably the Howmore River, leading to fresh water flooding, though human intervention could ensure that such flooding is short-lived.

3. Landward coastal migration (coastal roll back)

Annual sea level rise rates above 3–4 mm yr^{-1} are believed to be capable of triggering significant changes to soft coasts (Carter et al., 1989; Rennie and Hansom, 2011), and the Uists have been subject to higher annual sea level rises than this for at least 15 years, without significant coastal change, even in the extreme storm event of January 2005 (Angus and Rennie, this volume). That is not to say significant changes will not happen, and the reef of Sgeir Husabost, at low water mark on the west coast of Baile Sear, testifies to the capacity of this coast for significant change: the reef is all that remains of the township of Hussabost, mentioned in the papal Charter of Inchaffrey of 1389 (Angus, 1997).

Geomorphologically, progressive landward movement of beaches, sediments and habitats, a response to rising sea level, is known as landward coastal migration or roll back, as is well known from the migration of barrier island coasts world wide (Oertel, 1985). In the Uists it is clear that the current distribution of coastal habitat and the coastline itself, form the current manifestation of a process that has never been stable and recent research has suggested that the machair coastline of the Uists is a particular form of barrier island system with sandy sediment sitting on top of an undulating bedrock surface (Cooper et al. 2012). If this is the case then it is likely that dunes will increasingly roll landward over the machair, and the machair in turn will advance eastwards under the influence of the mobilised sediments. Fresh water lochs will then be pushed inland by advancing sand (Fig. 2), and invaded by sea water as the sea level rises, perhaps compensating for the loss of at least parts of the current lagoon suite to fully marine habitat. Such events are not only highly possible, but probable …if left to develop naturally.

However, it is unlikely that this process will be allowed to proceed without intervention. Sediments and habitats have the capability of rolling back, albeit at the expense of landward habitats. But land tenure is fixed to a line on a map, now verifiable by GPS and GIS, and landholding cannot roll back, at least on its landward boundary. There is currently no facility or even responsibility for addressing this issue. Some crofters will thus lose land, to the extent that they are likely to intervene in an attempt to halt or at least slow the loss. If coast protection is truly justifiable, it is in the interests of the wider community that there should be a mandatory consultation procedure analogous to planning consent, administered by the Local Authority.

Fig. 2. Roll back of machair sand into western section of machair loch, Loch Bhrusda, Bearnaraigh NF9182 August 1997.
Photograph by Stewart Angus.

Resistance could greatly complicate the environmental response, imposing an even greater level of uncertainty on how habitats and species might respond.

4. Habitat and species change

Rising water levels resulting from relative sea level rise and increasing precipitation will undoubtedly make cultivation more difficult, especially when preparing the land early in the season, though it is conceivable that warmer and drier summers could compensate for this. These impact the viability of cultivation and add to the existing pressures of declines in population in island communities.

Differing responses to seasonal change could cause ecological imbalances with unpredictable consequences, and perceptions of change could give rise to as much reduction in cropping as real change. It is feasible that some species might be separated seasonally from their food/host, while others may be unable to complete their reproduction due to earlier harvesting. A lowering of biodiversity levels due to a reduction in cultivation is thus envisaged, and with lower biodiversity within the remaining arable area. In addition, land loss to erosion will have an impact on the extent of good quality grazings, and arable land itself could be lost. The gradual reduction in effectiveness of the drainage network will lead to a rise in loch levels and their areal extents, further reducing the area of land available for agriculture. Sea water infiltration of the water table will lead to additional losses of arable land.

The distribution of dry and damp machair, marsh and saltmarsh will change at an increasing rate as water tables and saline impacts on water table change. Though distribution of individual habitats would change, extent of the overall habitat suite might be maintained except where there is a net loss to erosion or long-term flooding. Within the habitat complex, the loss of a habitat with a restricted distribution (machair) to a widespread habitat (saltmarsh) might be negatively viewed by conservationists. However, expansion of the area occupied by the highly distinctive machair marsh vegetation is not necessarily beneficial, if it contributes to an overall reduction in machair cultivation, since machair biodiversity requires all its current components in place to retain optimal biodiversity, of which cultivation is undeniably a part (Angus et al. 2011).

The habitat that might be most adversely affected by rising sea levels alone is saline lagoons. This habitat is Priority-rated on Annex I of the EC Habitats Directive, and the Uist lagoons tend to support higher numbers of species of distinctive lagoon organisms than lagoons elsewhere in Scotland. Thus far, the impact of climate change on lagoon habitats in southern Europe has concentrated on eutrophication (Lloret et al. 2008) and sedimentation/turbidity (Brito et al. 2012), with little mention of sea level rise, and none of increased salinity. Most of the lagoon organisms of the Uists have much in common with the Baltic, but studies there (Baltadapt, 2011) anticipate decreasing salinity due to an increase in river run-off. As sea levels rise in the Uists, existing lagoons will become more saline, and some will ultimately become marine habitats. Though specialist lagoon organisms may have wide salinity tolerances Bamber et al. 2001), they could become extinct in many of their existing sites as the water becomes increasingly saline, being out-competed by their marine relatives. Some of these organisms are rare because they have limited dispersal powers, and may not be able to make the geographical move to their 'roll back' analogue in time to prevent their extinction, so that there will be a net loss of biodiversity. Though translocations might assist the colonisation process (if they work), there would still be a need to identify the threatened site and a possible destination site, and neither is possible with the current level of monitoring and surveillance. There will also be a net loss of fresh water habitat, but from an area where such habitat is in plentiful supply.

Though the lagoons have a salinity higher than fresh water and lower than sea water, all but the shallowest lagoons tend to have a water column that is stratified, at least in summer, and there is also often a horizontal salinity gradient on the surface, sometimes accompanied by a pH gradient. The addition of tidal rhythms renders a complex hydrology more complex still, and it is essential to understand this before embarking on any measures designed to modify tidal exchange or identify suitable sites as destinations for translocation programmes. One of the most important lagoons, Loch Obisary in North Uist, has a northern basin that is 47 m deep, and there is no analogue loch available in the Uists of this depth, and the only option for retention of the high conservation value of this loch would be to raise the level of the channel connecting Loch Obisary to the sea, to keep pace with rising sea levels.

Though lagoons in the Uists lack the 'well-understood' criterion required for inclusion as 'sentinel systems' within the Global Observing Systems of the United Nations (Christian and Mazzilli, 2007), they nevertheless have considerable potential to serve as 'canaries in the cage' in respect of increasing salinity impacts on the wider low-lying environment of the Uists.

It is possible that adjustments to the drainage network such as the installation of variable valves on more of the outfalls and culverts could be made to limit adverse impacts of higher sea levels and of increased saline inflow, but this would have to be carefully designed to maintain environmental functionality and avoid incidental impacts. Where a loch currently receives limited saline inflow, cutting this off completely would have an economic impact as well as an ecological one, as there is an enhanced value to fishings of low loch salinity over fresh water (J. Steele, Storas Uibhist, pers. comm.).

There is a very strong culture of 'non-intervention' in coastal processes among coastal scientists, but here there is a recognition that the internal aquatic network of the Uists is already highly modified, as opposed to the largely unmodified outer coastline. Despite this distinction, there is a case for requiring similar consultative procedures for aquatic manipulation to those suggested for coastal manipulation. Indeed, it could be argued that any environmental manipulation driven by climate change that could be perceived as 'resistance' rather than 'adaptation' should be subject to a consultative approvals procedure.

5. Adaptive capacity

The habitats of the Uists have evolved in tandem with human settlement, at least since the Neolithic. The water table and loch network were significantly altered by the construction of an artificial drainage network from the mid eighteenth century onwards, and probably earlier to provide navigational links between lochs. Saline lagoons have been subject to sluice and culvert construction, and one – Loch Bi – has even had a major new connection to the sea constructed, and has been bisected by a large road causeway. Despite such significant changes, these systems, including Loch Bi, have retained a very high biodiversity, suggesting a high adaptive capacity.

Following the extensive storm-related marine inundation of January 2005 (Angus and Rennie, this volume), the seasonal lochs just inland of the dunes at Bornish, South Uist, were found to have a much lower salinity than sea water some four weeks after the storm, despite the absence of inflows and outflows, i.e. there was no obvious flushing. It is suggested that the interaction of this surface water with the subsoil water table acted to restore normal salinity. As an adaptation, this is a considerable advantage in respect of a one-off marine flood, but the advantage becomes a liability if marine flooding is sustained, allowing the water table over a large area (of unknown extent) to become saline. The volumes of lochs and water table in relation any marine inundation would also have a strong influence over salinity adjustments.

It is of interest that most of the physical impacts noted following the January 2005 storm were to hard structures. The beaches, dunes and saltmarshes that front much of the Uist coastline fall within the definition of 'soft coasts', lacking rigidity and having the capacity to move in response to wave action and currents, so that sediments can move along the coast, and also onshore or into the sounds between the islands. Though the soft coasts that constitute most of the western shorelines of the Uists thus have a considerable adaptive capacity in many locations, this is unlikely to be allowed to function freely because of fixed socio-economic aspects, notably infrastructure and land tenure. Roads and buildings can be relocated at a financial cost, but there is neither mechanism nor responsibility for adaptation of land holdings, even when (as in Benbecula and South Uist) the community owns most of the land as a single estate, including the intertidal.

Large-scale coastal changes, as have occurred in the past at Baile Sear, could have very significant impacts on lower-lying areas of the Uists, converting former loch basins that are currently arable land to intertidal sand, and covering extensive areas of coastal slopes with overwash deposits, locally including boulders as well as sand. This could mean that some crofts, and possibly even some townships, cease to be viable as agricultural management units.

The construction of sea walls can fix High Water Mark, giving a measure of protection to the land behind, but the considerable expense means that this will be feasible only when significant infrastructure is threatened, and fixed walls will give rise to foreshore steepening in front of the wall (Taylor et al. 2004), and will increase the rate of erosion at the ends of the wall (Pethick and Crooks, 2000). In communities where a high proportion of individuals have access to tractors and even earth-moving equipment, it is essential that the 'knock-on' consequences of intervention in coastal sediment processes are at least appreciated, if not fully understood. To discourage *ad hoc* intervention, there should be a formal approvals process for any such activity, a process that fully appreciates the principle of adaptation.

The very high levels of environmental connectivity between habitats, and between the natural environment and socio-economics are also evident in the aquatic environment, with the water table posing particular issues, in respect of its level and any saline infiltration. It is important to ascertain the level of adaptive capacity afforded by the water table, with a focus on the duration and geographical extent of any subsoil adjustment to high salinity surface water.

The existing drainage network and the sea-loch connections of the saline lagoons may offer considerable adaptive capacity for the management of water levels and the retention of existing lagoon habitats, but again the high levels of inter-connectivity dictate that careful, informed planning is required before embarking on any intervention.

The extensive inter-connectivity between habitats, and between habitats and people, requires the habitat suite to be addressed in its entirety. Monitoring and surveillance currently separate Annex I habitats, and inter-habitat turnover is poorly accommodated. Though the concept of habitat turnover has been extensively investigated (e.g. Van Teeffelen et al., 2012) this is almost invariably from the species perspective, albeit at the metapopulation level. In the Uists, it is necessary to address habitat turnover via the inter-connectivity of habitats and their collective functionality, by treating the habitat suite of the Uist shallow offshore, coastal lowlands, marshes, lochs and lagoons as a single ecosystem. It is also essential to accommodate socio-economic factors and human responses to change within any analyses, as these are integral aspects of inter-connectivity.

There are many aspects of the natural environment of the Uists with great adaptive capacity, and some where it is lacking, and habitat interconnectivity will undoubtedly bring the two together. Socio-economic aspects have lower adaptive capacity, with the critically important issue of land tenure having none, so that even where the community has the willingness and the knowledge to adapt, its capacity to do so may be absent or severely limited by statute. Because of the high level of connectivity, environmental and socio-economic adaptation, themselves inter-related, are in turn dependent on an adaptive capacity in governance that is currently lacking.

There is a strong convergence of objectives between local people and environmentalists, to the extent that pooled resources are in the interests of both. A lack of understanding of environmental functionality could lead to counter-productive measures by the community, just as poor understanding of socio-economics or agriculture could lead to a negative outcome for well-meaning environmental schemes. Mutual appreciation is thus essential, but even with this optimised, the problem of the relative inflexibility of administrative mechanisms threatens the viability of meaningful adaptation.

6. Conclusion

Uncertainties over future temperatures, precipitation and storminess could, in isolation, bring significant change to the western coasts of the Uists. Rates of relative sea level rise have already passed a threshold that is widely held to trigger significant coastal change (Rennie and Hansom, 2011), and the historic record strongly suggests that such change has occurred on this coast in the past. Inter-related, low-lying habitats are extensive, and vulnerable to this change, whether or not roll back will occur, with the possibility of loss of significant areas of land via coastal erosion and marine flooding.

Given the amount and value of infrastructure on or close to the coast, and the current inflexibility in land tenure, it is inevitable that there will be intense local pressure for fixed coastal protection works, to the extent that some of these will be constructed. If so, it must be accepted that there will be knock-on consequences for coastal process and their dependencies. This dependent impact could include additional erosional or flooding pressures on valued infrastructure or land, underlining the critical importance of a planning and approvals process that is well informed and able to consider wider and long-term impacts of resistance instead of adaptation.

Saline lagoons have a particular sensitivity, and it is anticipated that they will respond differently to their counterparts in southern Europe and the Baltic, becoming gradually more marine as sea level rises, and organisms reliant on this habitat may be unable to transfer to new lagoons created by roll back. Though a translocation programme could be developed to address this issue, it is reliant on feedback from surveillance that does not currently take place.

The complexity of coastal habitats, water regimes and land use requires early planning for change, and additional information and knowledge to inform this planning. The environment of the Uists is substantially a semi-natural one, where habitats and people have developed in tandem, in a relationship that has delivered high biodiversity with relatively high rural population density.

In a straitened financial climate, it becomes more necessary than ever to demonstrate the effectiveness of resource allocation (human and funding), and the continuing contribution of SNH and other conservation organisations to climate change studies in the Uists is dependent to a significant extent on the retention of high biodiversity in machair arable (crop and fallows) as well as the retention of natural coastal processes in this outstanding environment.

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