ABSTRACT

Climate change scenarios for NW Scotland and the Western Isles envisage a combination of rising sea level, increased winter precipitation, and increased frequency and severity of winter storms. The flat, low-lying machair lands of the Uists are thus particularly vulnerable, not only from marine overtopping of coastal dune ridges, but also from inland flooding and restricted drainage, which may enhance the duration and area of seasonal standing waters within the machair lands. The drainage network of the Uist machairs is a legacy of historic drainage of a more extensive loch network, which now forms an intricately balanced complex of linked water bodies exhibiting a wide range of pH and salinity. Any future change in water levels would impose significant environmental shifts. The conservation importance of machair is significantly augmented by a pattern of rotational cultivation that largely employs traditional methods and provides species-rich fallows. This tradition is already under economic threat, and increased flooding could have far-reaching consequences for both agriculture and wildlife. The Uist machair systems have a range of inter-dependent, multiple-interest international conservation designations and the vulnerability of these is examined in a context that incorporates the vital human dimension.

1. MACHAIR IN SCOTLAND

Machair is listed on Annex I of the EC Habitats and Species Directive. The machair plain tends to be very low-lying, behind a dune ridge, and often displaying a negative landward gradient, becoming increasingly wet, towards a network of marshes and lochs (lakes). In areas where the sea has access the marshes become saltmarshes and the lochs are brackish. Individual water bodies may display a wide range of water chemistry, being acid at their landward end and alkaline where they are influenced by blown shell sand; in some cases a salinity gradient is then super-imposed. The network of water bodies displays a wide range of water chemistry, highly dependent on a balance between fresh-water run-off and saline inflow, the latter determined by the height of the ‘sill’ separating the loch from the sea level.

The machair plain also has a vital local socio-economic importance. Much of the housing and transport network tends to be situated on the ‘blackland’ the transitional area between the machair grassland and the inland moorland, but there is also significant housing and infrastructure between this area and the sea, including schools and airports. The machair and blackland are the most productive areas for local agriculture, with arable cropping mainly confined to the machair areas. The cropping provides winter fodder for cattle, and cattle-rearing is regarded as vitally important to the maintenance of natural heritage interest. Often, the input of chemicals to the land and crop is limited, with most crofters (small farmers) applying storm-cast marine algae collected from the nearby beaches as fertiliser, thereby also helping bind the ploughed sand and prevent it blowing in the dry spring winds. Cropping of low-yielding grain crops
(rye and oats, with some bere, a primitive form of barley) tends to be confined to very small, unfenced patches, adjacent to fallows of 1-2 years, forming a small-scale patchwork of high botanical and invertebrate biodiversity (Figure 1). Some townships employ fencing, some have contiguous arable areas which themselves rotate, detracting from the small-scale patchwork, while overall there is a trend towards larger individual cultivation areas, reducing ‘edge’ habitats. With a trend away from arable, conservationists are now actively encouraging the retention of as many traditional methods as possible. Climate changes may further discourage a system of traditional cropping that is only just socially and economically viable.

The machairs of the Uists and Tiree are of international importance for their breeding waders and wildfowl, though numbers of the former have fallen in recent years due to predation from introduced hedgehogs *Erinaceus europaeus*. The most important breeding birds are dunlin *Calidris alpina*, ringed plover *Charadrius hiaticula*, oystercatcher *Haematopus ostralegus*, redshank *Tringa totanus*, snipe *Gallinago gallinago* and lapwing *Vanellus vanellus* (Angus 2001).

The machair grassland and its adjacent habitats are notified as Special Areas of Conservation (SAC) for machair, a range of sand dune types, saltmarsh, fresh waters, lagoons, and a range of species, some of these having Annex I priority status in their own right. There are Special Protection Areas (SPA) in support of the EC Birds Directive, and a range of domestic Sites of Special Scientific Interest (SSSI), National Scenic Areas and Scheduled Monuments. The SSSI include a range of Geological Conservation Review sites notified for Coastal Geomorphology, as well as several National Nature Reserves and sites listed under international conventions such as Ramsar. The machair of the Uists and Barra, and their satellite islands, and the Argyll Islands (including Tiree) are within Environmentally Sensitive Areas administered by the Scottish Executive Environment and Rural Affairs Department (SEERAD).

The Scottish machairs thus have a very high value for a wide range of heritage interests, as well as a very high importance to local people, on whom the maintenance of the heritage interest ultimately depends. The very high inter-dependency between the various habitats and people is critical to all interests, and if climate change is a threat to any of these, it affects the others.

2. MACHAIR LOCHS

The present drainage network of the Uists has been substantially influenced by a complex network of canals and drains established in the late 18\textsuperscript{th} Century (Figure 2), lowering water tables and reducing the extent of a network of...
lochs that had been sufficiently large to permit intra-island navigation by boats (Anderson 1758). No records remain
of the main part of the drainage works, but the area involved has very little gradient, and the designers must have been
remarkably skilled. Today, large areas of machair grassland on the latest large-scale Ordnance Survey maps contain
no contours.

Attempts to prevent sea water flooding the machair at the north end of South Uist date back to at least the 16th Century,
but it was not until 1842 that effective sluice gates were established at the west end of Loch Bee (Waterston & Lyster
1979). Although there are also sluice gates on some of the other lagoons, most of the outflow from the wider drainage
network is via pressure-operated flap valves that allow egress of fresh water while preventing the ingress of saline
water. For the most part the drains are well-maintained but locally, as at the south end of South Uist, the channels are
becoming choked.

The stability of the present loch network of the Uists is dependent on the maintenance of the artificial drains. Evidence
of this is provided by the island of Boreray off North Uist, where lack of drain maintenance has permitted the saline
lagoon to recover some of its former area (Angus 1997).

No information on the pre-drainage natural history of the loch network survives, but it is clear that the present net-
work has a very high biodiversity value, including a range of obligate brackish water species (Covey et al 1998).
Although any redistribution of saline and fresh water would very probably conserve and possibly even enhance the
chemical diversity of the loch network, the ability of many of the species to adjust to any change is poorly understood,
and sudden changes are not only possible, but more problematic in respect of biota adjustment.

3. CLIMATE CHANGE SCENARIOS

The UK Climate Impacts Programme (Hulme et al. 2002, usually referred to as UKCIP02) identified and mapped a
range of climate attributes for four emission scenarios for the UK and Ireland at a resolution of 50km. However, this
resolution was not sufficiently high to show effects on even the larger offshore islands, and as a result the British-Irish
Council (BIC) commissioned a Regional Climate Model (RCM) from the UK Hadley Centre with a resolution of about 25km (Jenkins et al. 2003). Both scenarios use three time periods (2011-2040, 2041-2070, 2071-2100), referred to for convenience as the 2020s, 2050s and 2080s, respectively.

Global mean sea level is predicted to rise by between 9cm and 69cm by the 2080s (Jenkins et al. 2003). Mainland Scotland still displays isostatic uplift, but Scotland’s outlying islands did not have a thick ice cover during the last glaciation(s) and display negligible isostatic change (Shennan & Horton 2002) and so the BIC study estimates a relative sea level rise of between 9cm and 69cm by the 2080s for both the Western Isles and Orkney.

Changes in climate can also enhance coastal erosion and also impact on sediment redistribution, as reviewed in respect of machair by Hansom and Angus (2001).

4. RISING SEA LEVEL

The machair coasts of Scotland tend to be low-lying, and they are thus particularly vulnerable to rising relative sea level, causing marine incursions, or to flooding with brackish or fresh water, resulting from impoundment by redistributed sediment and/or increased water surpluses. Any marine flooding of areas that have not been subject to such flooding for at least several centuries will result in salt deposition and osmotic stress to most organisms in the flooded areas, possibly at fatal levels, jeopardising the survival of vulnerable species in affected areas.

Rising sea level is most likely to affect areas in the lower courses of streams and rivers. The Howmore River in South Uist is one of the largest rivers in the Western Isles, with its own saline lagoon, while its basin includes the brackish Loch Roag. The basin also includes a range of fresh-water lochs of conservation importance, notably Loch Altabrug and Loch Fada at almost the same altitude as Loch Roag. The salinity of some or all of these water bodies will increase during saline incursions. Larger lochs such as Loch Bee (S Uist) are often sluice-controlled at their outflows and these may help protect such areas on the highest tides.

Some particularly low-lying machair grasslands give way ‘inland’ not to marshes and lochs, but to saltmarshes and sand flats accessed by the tide laterally. These tidal flats provide an additional route for tidal incursions onto machair land (Figure 1).

Any saline flooding of arable land will present a greater challenge to arable crofters than does fresh water flooding.

5. PRECIPITATION

Under a medium-high emissions scenario, the British-Irish Council RCM envisages an increase in December-February precipitation of up to 8% in the Western Isles and 10% in Orkney by the 2080s. The uncertainty margins range from +24% to –12% for the Western Isles and +23% to –1% for Orkney.

There is already a perception within the Western Isles that seasonal winter water on the machair now covers a greater area and takes longer to disperse than previously. The BIC study suggests that spring (March-May) and summer (June-August) temperatures would increase by 1.8°C and 1.5°C, respectively, by the 2080s in the medium-high emissions scenario, which could offset any increase in surface water by increasing evapo-transpiration.

However, the relative roles of surface drainage, percolation and evapo-transpiration in the dispersal of this water are unknown, and it is possible that even a slight change in precipitation could have serious implications for seasonal
standing water, especially if combined with lower soil temperatures and/or higher relative humidity. Summer (June-August) precipitation in the Western Isles could decrease by 22%, so that flooding early in the season could be replaced by later drought problems.

Any increase in flooding area, or prolonging of duration, could inhibit or even prevent ploughing of much of the present area of machair arable area. Although it would be possible to move to drier areas, this has not yet happened in wet spring seasons, and higher areas would be more subject to drought. Areas that have not been ploughed in the past tend to support a range of species absent from arable/fallow areas (Angus 2001). The arable and fallow areas have botanical interest on account of the range of agricultural ‘weeds’ they support, often of species that have largely succumbed to herbicides elsewhere. However, increasing herbicide use and enlargement of individual cultivation patches are now combining to reduce biodiversity. Additionally, whole-crop silage is tending to reduce the number of sources of seed, further reducing biodiversity and increasing the vulnerability of the traditional arable habitat.

Many invertebrates rely on the small-scale patchwork of crop and fallow, notably the nationally important (and protected) great yellow bumblebee *Bombus distinguendus* (Hughes 1998). However, the loss of arable land to flooding may provide some bonuses in the form of more breeding territory for species such as dunlin that prefer wetland, albeit at the expense of species such as ringed plover that prefer cultivation.

6. STORMINESS

The nature of future storminess is particularly uncertain, but the BIC report suggests that the number of deep atmospheric depressions passing across the UK will increase by 40% by the 2080s. Using data provided by the Proudman Oceanographic Laboratory, the BIC report suggests a likely increase in storm surges, reflected in higher wave height. That this may already be under way is suggested by increases in North Atlantic maximum wave heights of 2.5-7.5 m m⁻¹ over the period 1955-94 (Gunther *et al.* 1998). A maximum surge of 0.89 m was recorded from Stornoway in the Outer Hebrides in February 1990 (Hickey 1997, as cited in Dawson *et al.* 2001). Dawson *et al.* (2001) suggested that surge elevations above 0.5 m “would have a serious impact … capable of outstripping the rise in sea level predicted from sea surface change and land level changes”.

Depressions tend to add amplitude to astronomical tides, the worst case scenario being a deep depression storm surge with strong onshore winds coinciding with an exceptionally high astronomical tide.

Many machair systems are protected by a dune ridge, often with a gravel ridge fronting the dunes that serves to absorb sufficient wave energy to safeguard the machair in all but the most extreme storms. However, many machair systems have already lost their dune front, and are now being undercut by wave action (May & Hansom, 2003).

In addition to the physical threat of sediment removal posed by storm surges, there is the additional possibility of waves overtopping the dune ridge and flooding the machair grassland with sea water, augmenting the extent and salinity of any seasonal water behind the dunes (Hansom & Angus, 2001). Although overtopping of dunes is regarded as of low probability, some gravel ridges (for example at Stoneybridge in South Uist, Figure 3) have been overtopped in recent decades, affecting the hindshore surface (May & Hansom, 2003). Any serious overtopping of this ridge would flood the Howmore basin and its lochs with saline water, which would then affect a wide area of machair and its associated habitats.

The threats of marine undercutting and overtopping are increased by unregulated sediment removal. As this is non-commercial, used for agricultural purposes, it is outside planning control. Crofters already recognise that sediment removal is problematic; some townships (the committee-based management unit for land and rights held in common
by crofters) have already banned sediment extraction, while others have opted for sand removal from the beach instead of the machair or dune in a well-meaning attempt to mitigate impact, but unwittingly making a negative impact on the sediment budgets of almost all machair sites where this occurs.

Sediment-related changes combine with those outlined above to inflict an impact that is likely to be greater than the sum of its parts.

7. DISCUSSION

North-western Europe presently has one of the most variable year-to-year climates in the world (Jenkins et al 2003). The human input to the conservation importance of machair systems is very high, and it is not just climate change alone, super-imposed on existing uncertainty, that might affect the future of the habitat, but also the perceptions and motivation of local land users regarding this uncertainty. If local people believe that climate change will make any stage of their arable operation so difficult that it is no longer worth the considerable effort involved, then there will be wide-ranging impacts on machair and its associated habitats: not only might arable cropping cease, but cattle-rearing might also cease without the availability of locally-grown fodder.

Some climate change scenarios (e.g. sea level rise) have a greater probability than others (e.g. storminess). There is no doubt that changes are already being experienced in machair, and this is to be expected in a dynamic habitat whose very existence is dependent on climatic extremes. Perceptions regarding the impact of the various climate change scenarios on the habitat and its species, including the human inhabitants, vary according to standpoint, but the status of the scenarios supplied by UKCIP02 and the BIC report is such that it is incumbent on the appropriate authorities to begin planning for the ‘worst case scenario’, just as Emergency Planning provides for the unlikely but potentially devastating event. For example, the UK Civil Contingencies Bill (2004) now extends the legal definition of ‘emergency’ within the UK to include, in respect of ‘environment’, flooding, or disruption or destruction of plant life or animal life (Section 1 (3)).

Planning requires information, yet at present there is no accurate coastal baseline for the machair lands that can be used to accurately monitor changes now or in the future. The tools exist, however, and have already been applied systematically in England. Airborne radar (LiDAR) and CASI (Compact Airborne Spectographic Imagery)
are acquired together, with additional digital aerial photography, to provide high-definition Digital Terrain Models (DTMs). Subsequent data collection enables change to be measured with high precision, while the model(s) can be used to run a range of scenarios. Such modelling would be invaluable in machair environments to model flooding, and predict how the drainage network might be developed to mitigate the impacts of flooding. Successive DTMs would also identify significant sediment movements and associated trends to pinpoint areas of particular vulnerability. In Scotland such imagery has been collected only for parts of the Firth of Forth and small sections of Tiree and Coll. A full programme of acquisition of such baseline data is urgently required in Scotland to target the most vulnerable coasts: the machair lands.

The people who live and work on the machairs have a vital status in habitat planning. The socio-economic inter-relationships between people and machair are complex and poorly understood, but they are clearly very close indeed. Machair is arguably as much a cultural product as a geomorphological one, and the critical role played by people must be fully accommodated in any integrated approach to planning its future.

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