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Coastal Margin Habitats

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EXECUTIVE SUMMARY

Coastal margin habitats are varied and present around the UK in complex mosaics. They depend on the supply and movement of sediment by both marine and Aeolian processes as well as other processes including cycles of vegetation succession.

Most coastal habitats exhibit a degree of successional change and have the potential to re-establish after extreme events, hence in an unmodified state they could be relatively resilient to some elements of climate change. The legacy of past intervention has resulted in a reduced capacity for adaptation to coastal change without significant intervention in some places. In particular the reduction in sediment supply is critical as it underpins coastal form and function.

Most of the coastal habitats are not currently in favourable condition, with recent reporting on conservation status highlighting the poor future prospects for many habitats, especially sand dunes, largely in the light of climate change impacts.

Coastal habitats provide an important contribution to coastal risk management and other ecosystem services. Their importance is recognised by conservation and landscape designations.

There are close interactions with landward ecosystems and hydrology, with transitional habitats contributing to the overall value.

The changes in future are difficult to predict with certainty because of the presence of coastal management structures. Sea-level rise and climate change will impact on the extent, distribution and quality of coastal habitats, interactions with other impacts such as nutrient deposition may occur.

Social resistance to change is high and adaptation measures are difficult to implement. Long-term sustainable approaches to risk management are needed, with some indication that this is increasingly recognised at a policy level. In addition, protected/designated habitats at the coast need more adaptable approaches in order to move from a 'preservation' ethic to a more dynamic means of conservation of form and function which will contribute to adaptation measures, and knowledge gaps in this area need to be addressed.

FULL REVIEW

1. What is already happening?

Habitats covered

Coastal margin habitats occur in the supralittoral zone above the spring high tide line, exposed to the splash/spray of sea water but only covered in sea water infrequently by storm waves. In their natural state they form a transition zone between marine and terrestrial systems, both of which influence the form and condition of coastal environments. Coastal margin habitats covered in this review are:

- **sand dunes**
- **machair**
- **shingle structures and beaches**
- **hard rock and soft rock maritime cliffs & slopes**

These habitats are strongly influenced by physical processes. The sedimentary habitats are the result of deposition of largely marine-transported shingle and sand. Many areas are still influenced by wind, waves or tides, while others are more stable where deposition has resulted in sediments left beyond the reach of waves under normal circumstances. All are naturally dynamic systems which exhibit episodic or gradual morphological and vegetation change depending on the availability and movement of sediment. For example, deposits of wind-blown sand can be reactivated by storm conditions, creating greater diversity as they introduce early successional stages into the system. Maritime cliffs are influenced by marine erosion, and in the case of boulder clay, groundwater drives rates of cliff recession.

There are specialised forms of **maritime grassland and heath** which occur in association with these habitats. These are often associated with cliff slopes such as the 'waved heath' on the exposed Cornish coastline, or on cliff tops above the zone of specialised ledge communities and beyond the most exposed spray-splashed zone. Other forms of coastal grassland occur on low-lying coasts as transitions from upper saltmarsh where there is some brackish influence but regular tidal inundation is infrequent.

Coastal grazing marsh is not included in this review as it is largely a product of human intervention in the coastal floodplain; however it may be affected by sea-level rise and managed realignment (see *MCCIP ARC Science Review 2010-11 Intertidal Habitats and Ecology* [Mieszkowska, 2010]). Saline lagoons are not covered as these are considered to be a marine habitat, although may be subject to similar impacts.

Coastal evolution and coastal processes

Coastal margin habitats are linked to the marine environment through coastal processes and maritime influence. They are shaped by waves (size and direction), tides, nearshore currents, wind, fronting beach width, sediment availability, extreme events, exposure, rainfall, groundwater and air temperature. Changes in sea level relative to the land and other climate change impacts will affect coastal evolution. Past or current human activities such as grazing, agriculture, coastal defence or industry are also factors that shape the present configuration and ongoing evolution of the coastal margins, often preventing change.

The present-day coast and its evolution is still strongly influenced by the effects of the last glaciation, through the distribution of sediment and its subsequent constant re-working over the last 10,000 years. Isostatic rebound is also causing both lowering and raising of land levels relative to the sea. The continuation of sea-level rise can either transport sediment towards the land or ‘strand’ the sediment offshore, making it unavailable to the coast through natural processes.

The interactions of the active physical processes of sediment movement by wind, waves and tides (accretion and erosion) and geological, biological, chemical and human influences give the coastal margins of the UK a unique and varied character, as a result of geology, climate, exposure and land-use history (May & Hansom, 2003). The importance of sediment transport by marine and aeolian processes is essential for shaping supralittoral coastal habitats and driving coastal change (Pye *et al.,* 2007). Low-lying coastal margin habitats will experience infrequent tidal inundation during storm events as well as salt spray and wave splash. Maritime exposure influences species composition of vegetation, with some communities only found in coastal environments. Saline intrusion through beach sediments can also occur, particularly shingle, as a result of increased water pressure during high tides, or as a result of sustained sea-level rise. In contrast, many coastal margin habitats have groundwater or surface systems that are sustained by rainfall or groundwater movement. These can be above a saline water table, with some mixing between them. Freshwater aquifers may be subject to saline intrusion, especially in shingle (Burnham & Cook, 2001).

Nature conservation importance

The variation within coastal habitats means that they support a high number of species relative to their extent. For example, in England, sand dune, maritime cliff and shingle coastal habitats, with an estimated total extent of 31,200ha, support 148 UK BAP species (Webb *et al.,* 2010) compared to coastal and flood plain grazing marsh, with an estimated 235,000 ha in England supporting 47 UK BAP species. Many of the coastal species are adapted to the extreme conditions at the coast and the cyclical processes of succession associated with erosion and accretion.

Most coastal habitats are represented in designated sites under national and international conservation legislation. There are several coastal Annex I habitats identified as priority habitats in the Habitats Directive (i.e. in danger of disappearance and whose natural range mainly falls within the territory of the EU). These are on the blown sand deposits and are: 21A0 Machair (Ireland only); H2130 Fixed coastal dunes with herbaceous vegetation; H2250 Coastal dunes with Juniper; H2140 decalcified dunes with *Empetrum nigrum* and H1250 Atlantic decalcified fixed dunes.

Nearly a third of England’s most important protected areas for wildlife (sites with an international designation) occur in the coastal zone. A high proportion is inter-tidal, but coastal grazing marsh and coastal wetlands are also significant. Almost 20% of all English SSSIs with geological features are at the coast. Over half of all Areas of Outstanding Natural Beauty have a coastal element; 6 out of 9 national parks in England have a coastline. Erosion is causing some features in SSSIs to effectively migrate beyond the boundaries of the designated site, particularly relevant for coastal soft cliffs with high recession rates.

Coastal sand dunes, machair, coastal vegetated shingle and maritime cliff and slope are UK BAP Priority Habitats, and forms of coastal grassland and heathland are covered by other BAP Priority Habitat definitions such as lowland heathland and lowland acidic grassland.

Ecosystem services

Coastal margin habitats are important for a range of ecosystem services, covered in more detail in the National Ecosystem Assessment. In summary, their greatest role is the regulating service of flood risk reduction, both directly by beaches, dunes and shingle ridges absorbing wave energy at the coast, and indirectly by the provision of sediment from coastal erosion, especially cliffs. The climate change impacts on the provision of these services needs to be addressed in the development of coastal management strategies. Other key services support tourist economies, recreation, ports, agriculture, water supplies and transport.

a) Sand dunes

Coastal sand dunes form where beach plains dry out between tides and sand grains are blown inland. Sand is deposited on the upper beach where wind speeds are reduced e.g. over tidal debris. Specialised plants colonise these deposits to form 'embryo dunes'. Grasses which can grow to keep pace with further Aeolian sand deposition colonise these low dunes and lead to higher dunes dominated by marram grass (*Ammophila arenaria*). With adequate sand supply, a series of dune ridges will form, with increasing levels of vegetation and stability as wind movement of sand is reduced by the resulting topography. Dune systems exhibit variation in successional stages, and will be in a constant state of flux, important for their diversity. Sand dunes support a range of species including the natterjack toad, which requires early-stage dune slacks and foraging areas, and the sand lizard, which requires open bare areas for basking and breeding burrows.

Sand dunes are important for both biological and geomorphological conservation. Many UK sites are notified as SSSI/ASSI for these interests and several are of international important for active coastal processes.

Sand dunes are a UK BAP Priority Habitat, with targets to maintain, restore and recover extent and condition. Of the Annex I coastal dune habitat types which occur in the UK there are 10 which occur in the UK (including machair). Of these, there are 4 priority habitats. One of these, H2250 'coastal dunes with Juniper', is extremely localised in Scotland. Other Annex I habitats are scarce across the UK, for example H2190 'Humid dune slacks' is estimated to cover less than 2000ha, with much of this concentrated in just a few sites. SACs for sand dune Annex I features are included in the Natura 2000 network.

Dune morphology in the UK is influenced by the balance between dune building processes, marine processes, including storm events and sea-level rise, and the sediment budget. Dunes release sediment to the beach plain during storm events, which is then later returned to the dune system by marine and aeolian transport. In addition, elements of the dune system (including water tables) are influenced by rainfall, temperature and nutrient status. Sea-level rise affects the position and condition of water tables through increased hydrostatic pressure. However, research to date based on analysis of dipwell and rainfall data demonstrates that the main factor influencing water tables in dune systems is effective rainfall (Jones *et al*., 2006; Clarke & Sanitwong Na Ayutthaya, in press). Soil development is influenced by climatic factors interacting with nutrient deposition (Jones *et al*., 2008). Long-term leaching of sandy soils can lead to acidic surface layers suitable for dune heath development.

Over the last 100 years it is estimated that Great Britain has lost 30-40% of its dune systems to a range of pressures (Doody, 2001) including development, afforestation, industry and golf course development. For example, the Tentsmuir system in

Scotland, the second-largest dune in Great Britain, is now almost completely planted with trees after over a century of forestry expansion (Doody, 2001), with only the more recently deposited dune ridges remaining in a natural state. The largest system, Culbin sands, has experienced equally extensive afforestation, initially in order to stabilise areas of active sand blow onto farmland. Both Wales and England have had some of the larger sites planted with extensive stands of conifers.

A study for Defra in relation to dunes and flood risk management in England and Wales (Pye *et al.,* 2007) characterised 158 localities into 112 'dune sites'. Of these studied, the best developed dune systems occur on the west coast (CP regions 4 & 5) , while dunes are least well developed on the south coast of England (CP region 3). The largest single dune system is located on the Sefton coast in north-west England (c. 20 km^2) in Region 5. More than 50% of the sites are smaller than 1 km^2, but from a flood risk management perspective many of these small sites, which often take the form of a relatively narrow fringing barrier, are of considerable significance. Examples are provided by dunes in Region 2 along the Dunwich to Sizewell frontage in Suffolk, which form part of the defence against tidal flooding of the Minsmere Levels and those along the Happisburgh to Winterton coast in Norfolk which contribute to the flood protection of an extensive low-lying area of northeast Norfolk which includes The Broads. Dunes are important for flood defence of several urban areas, for example parts of Pwllheli in Gwynedd (Region 5) and several settlements along the Lincolnshire coast (Region 2). In many of these places the frontal dunes have shown a trend for net erosion in recent decades, and a variety of dune protection works have been undertaken, not always successfully. Field surveys between 1999 and 2003 indicated that 35% of the total dune frontage in England and Wales showed significant evidence of net erosion or has been protected by defence works, while 35% showed evidence of net stability and 30% showed evidence of seawards accretion (Pye *et al*., 2007). The west coast sites showed the highest percentage of eroding and protected frontages (38%), while the south coast sites showed the lowest (7%). The largest percentage of protected dune frontage is found along the coastline of CP Region 2. At the great majority of dune localities only part of the dune frontage is protected ranging from < 20% of the total dune frontage at 112 of the 158 locations visited to two sites with > 80 % protected dune frontage.

Regional variations

Sand dunes occur widely on the UK coast, and exhibit different characteristics reflecting climatic and geological variations. The largest resource of sand dunes in the UK is in Scotland, with approximately 35,000 ha (UK BAP website). England has approximately 11,900ha and Wales 8,100 ha. Northern Ireland has a smaller resource of 1500ha, but contains some key sites. Hindshore dunes are more common in Wales and Scotland, with the most numerous type in England being bay dunes. Some of the largest systems are on the west coast in high energy environments where more sand can be blown inland. Barrier beach systems are more typical of the east coast, such as in North Norfolk. Sediments vary from calcareous sand derived from shell fragments, for example in north-west Scotland, to more acidic mineral sands as in parts of Northern Ireland.

Humans have used dunes extensively in the past, although current use of the remaining resource is now largely for conservation, tourism/ recreation (including golf courses) and low-intensity agriculture

b) Machair

Machair is a distinctive type of coastal grassland found in the north and west of Scotland, and in western Ireland. It is associated with calcareous sand, blown inland by very strong prevailing winds from beaches and mobile dunes. In its strict sense, 'machair' refers to a relatively flat and low lying sand plain formed by dry and wet (seasonally waterlogged) short-turf grasslands above impermeable bedrock, a habitat termed 'machair grassland'. However, the '*machair* system' includes the beach zone, mobile and semi-fixed foredunes, dune slacks, fens, swamps, lochs (some of them brackish), saltmarsh, and sand blanketing adjacent hillslopes. It is also often associated with an inland transition to heath and mire which can include sand-affected peatland. It is estimated that global 'machair grassland' extent is 25,000 ha, with 17,500 ha in Scotland and the remainder in western Ireland. The largest extents in Scotland are in the Western Isles (10,000 ha, mainly in the Uists), Tiree and Coll (4000 ha), Orkney (2300 ha) western Scottish mainland (1000 ha) and Shetland (180 ha). The full geographical extent of the wider 'machair systems' is believed to be in the region of 40,000 ha, with some 30,000 ha in Scotland and 10,000 ha in Ireland.

Machair grassland plains are complex features in terms of origin, development, processes, local habitat types and management. They are formed from sand blown inland following the periodic breakdown of foredunes above the beach and contain a mosaic of wet and dry grassland communities. These are related to grazing and tillage history superimposed upon gradients of surface stabilisation, soil acidity, and salinity which are controlled by local sand blow, water-table fluctuation and micro-topography, giving rise to highly complex habitat mosaics. Some plant communities are largely restricted to western and northern Scotland.

Machair has a very long history of management by people over several millennia. Recently this has involved a mix of seasonal extensive winter cattle grazing and low-input low-output rotational cropping of potatoes, oats and rye, and a small amount of beer barley. This traditional mixed management sustains varied dune, fallow and arable weed communities which provide expansive displays of flowering colour in summer. The periodic ground disturbance and seasonal absence of stock supports very important breeding bird populations. The wider machair system has a rich invertebrate fauna. This traditional agriculture is associated mainly with the Uists and Tiree; outside these areas there has been a marked decline in such land management with a corresponding decline in wildlife.

c) Maritime cliff and slope

Maritime cliffs and slopes comprise sloping to vertical faces on the coastline where a break in slope is formed by slippage and/or coastal erosion. On the seaward side, the cliff slope extends to the limit of the supralittoral zone and so includes the splash zone lichens and other species occupying this habitat. Approximately 4000 km of the UK coastline has been classified as cliff, with an estimated 1100 km in England, 2372 km in Scotland and 522 km in Wales.

Cliff profiles vary with the nature of the rocks forming them and with the geomorphology of the adjoining land. Marine erosion of exposures is critical to their function, although other processes such as the movement of groundwater are also important for landslips to occur in softer geology.

Maritime cliffs can broadly be classified as 'hard cliffs' or 'soft cliffs'. Hard cliffs are vertical or steeply sloping, formed of rocks resistant to weathering, such as granite, sandstone and limestone, but also softer rocks, such as chalk, which erode to a vertical profile. Hard cliffs support specialised higher plants largely on ledges and in crevices. Soft cliffs are formed in less resistant rocks such as shales or in unconsolidated materials such as boulder clay, forming less steep slopes and are therefore more easily colonised by vegetation. Soft cliffs experience frequent slumping and landslips, driven by groundwater.

The vegetation of maritime cliff and slopes varies according the extent of exposure to wind and salt spray, the chemistry of the underlying rock, the water content and stability of the substrate and, on soft cliffs, the time elapsed since the last movement event.

Strictly maritime vegetation occurs with the greatest exposure to the waves and winds. In the UK, such conditions occur on the northern and south-western coasts (Regions 4, 5, 6, 7). In extreme conditions, such as on the Isle of Lewis, saltmarsh vegetation can occur on cliff-tops. In other areas, where cliffs occur adjacent to sand dunes, sufficient windblown sand can accumulate on the cliff-slopes and tops to allow cliff-top dune vegetation to develop (climbing and perched dunes). On exposed hard cliffs lichens are often the predominant vegetation, especially at the lower levels in the wave splash zone. Ledges on such cliffs support a specialised maritime flora.

Hard cliffs are widely distributed around the more exposed coasts of the UK, occurring principally in south-west and south-east England (the latter area having the bulk of the 'hard' chalk cliffs), in north-west and south-west Wales, in western and northern Scotland and on the north coast of Northern Ireland. Soft cliffs are more restricted, occurring mainly on the east and central south coasts of England and in Cardigan Bay and north-west Wales. There are also examples on the coasts of Fife and Skye in Scotland and Antrim in Northern Ireland. Hard cliffs erode relatively slowly, although will experience mass movement at intervals.

Soft rock cliffs with no artificial coast protection are a rare resource in the British Isles and in Western Europe as a whole. Their geology has little resistance to erosion. Frequent slumps and land slips occur, caused by erosion by the sea, rain, storms, and groundwater percolating through the cliff. Soft cliffs erode more quickly than hard cliffs and often have shallower gradients which allow far greater colonisation of vegetation and development of a wider range of habitats.

The UK holds a significant proportion of soft cliff in north-western Europe (Whitehouse, 2007). England and Wales are estimated to have lengths of 255 km and 101 km respectively. Shorter lengths of soft rock cliffs occur in Scotland and Northern Ireland. England has the largest proportion of the UK resource with only 255 km of unprotected soft rock cliffs representing just 2.4% of the total coastal length. Of the 255 km 80% of this is found in the seven counties Devon, Dorset (Region 4), Humberside, Norfolk, Suffolk (Region 2), Isle of Wight (Region 3), and Yorkshire (Region 1) (Howe, 2003).

Soft rock cliffs have long been known to support rare and notable invertebrates, particularly bees and wasps, beetles and flies. The ecological requirements of these species relate to the successional phases of cliff habitats dependent on varying degrees of stability from open bare ground to sheltered scrubby patches.

Recession rates of soft cliffs are important to the processes of coastal change. They are largely episodic and driven by both weather patterns that influence surface and groundwater as well as marine erosion from wave attack at the toe.

Soft cliff erosion is an important source of sediment. The areas with the most rapid rates of recession are on the south and east coasts of England (Regions 2 & 3). For example, Holderness cliff erosion is estimated to supply 3M m^3 a year of fine sediment into the marine system, most of which is transported to the Lincolnshire coast and the Humber (HR Wallingford, 2002).

Coastal erosion risk management leads to stabilisation. It is estimated that in the 100 years up to the 1990s, 860km of coast protection works have been constructed to reduce erosion (Lee, 2001), reducing sediment input by an estimated 50%. Schemes to extend or replace coast protection are still being proposed, often in response to reactivation of landslides. Recently, high levels of rain have reactivated landslides on the Dorset coast at Lyme Regis, Dorset (Region 4) and Cayton Bay, Yorkshire (Region 1).

d) Coastal shingle

Shingle is defined as sediment with particle sizes in the range 2-200 mm. It is a globally restricted coastal sediment type. Shingle beaches are widely distributed round the coast of the UK, where they develop in high energy environments. In England and Wales it is estimated that 30% of the coastline is fringed by shingle. However most of this length consists of simple fringing beaches within the reach of storm waves, where the shingle remains mobile and vegetation is restricted to ephemeral strandline communities able to grow and set seed in one growing season and making use of nutrients from decaying seaweed and other debris.

Shingle structures take the form either of spits, barriers or barrier islands formed by longshore drift, or of cuspate forelands where a series of parallel ridges piles up against the coastline. Some shingle bars formed in early post-glacial times are now partly covered by sand dunes as a result of rising sea levels leading to increased deposition of sand.

The origin of coastal shingle varies according to location. In southern England, much of it is composed of flint eroded out of chalk cliffs. Shingle deposits of Ice Age origin lying on the sea bed may be reworked by wave action and re-deposited or moved by longshore drift along the coast. In northern and western Britain, shingle may derive from deposits transported to the coast by rivers or glacial outwash. Shingle structures are of significant geomorphological interest and contribute to flood risk management especially in the south of England.

The vegetation communities of shingle features depend on the amount of finer materials mixed in with the shingle, and on the hydrological regime. The classic pioneer species on the seaward edge include sea kale *Crambe maritima*, sea pea, *Lathyrus japonicus,* Babington's orache*, Atriplex glabriuscula,* sea beet, *Beta vulgaris,* and sea campion *Silene uniflora*; such species can withstand exposure to salt spray and some degree of burial by sediment. Further from the shore, where conditions are more stable, more mixed plant communities develop, leading to mature grassland, lowland heath, moss and lichen communities, or even scrub. Some of these communities appear to be specific to shingle, and some are only known from Dungeness. On the parallel ridges of cuspate forelands, patterned vegetation develops, due to the differing particle size and hydrology. Some shingle sites contain natural hollows which develop wetland communities, and similar vegetation may develop as a result of gravel extraction.

Shingle structures may support breeding birds including gulls, waders and terns. Diverse invertebrate communities are found on coastal shingle, with some species restricted to shingle habitats.

Regional Variation

Shingle structures sufficiently stable to support perennial vegetation are a comparatively rare feature even in the UK. The major vegetated shingle structures surveyed in 1987-1991 by Sneddon and Randall (1993a,b; 1994a,b) totalled some 5000 ha in England, 700 ha in Scotland and 100 ha in Wales. Recent assessment from air photos in England (exeGesIS & Doody, 2008) has indicated that this is likely to be an underestimate ,with only 3596 ha in England in the 1990s. Further work is underway to provide an update based on analysis of 2006-2009 photos. Dungeness, in southern England, is by far the largest site, with over 2000 ha of shingle, and there are only five other structures over 100 ha in extent in the UK. The main concentrations of vegetated shingle occur in East Anglia and on the English Channel coast, in north-east Scotland, and in north-west England and south-west Scotland. The Welsh coast has a number of small sites. This habitat is poorly represented in Northern Ireland, where the key site is Ballyquintin in County Down.

e) Coastal grassland and heath

The extent of the associated cliff-top coastal grassland or heathland will extend landward to at least the limit of maritime influence (i.e. limit of salt spray deposition), which in some exposed situations may continue for up to 500 m inland, this is particularly relevant to exposed Scottish coasts. On cliffs and slopes which are more sheltered from the prevailing winds and salt spray, the vegetation communities are more similar to those found inland, and are increasingly influenced by the chemistry of the substrate. Calcareous grassland communities with a few maritime specialist species occur on sheltered chalk or limestone cliffs. The upper sections and cliff-tops of hard cliffs on acidic rocks may support maritime heaths characterised by heather *Calluna vulgaris*. The coastal heaths of the Sclliy Isles and Cornwall are distinctive in form and species composition. Mobile soft cliffs support a wide range of vegetation from pioneer communities on freshly exposed faces through ruderal and grassland communities to scrub and woodland. Maritime grasslands occur on cliffs and slopes in less severely exposed locations; a maritime form of red fescue *Festuca rubra* is a constant component, together with maritime species such as thrift *Armeria maritima*, sea plantain *Plantago maritima*, buck's-horn plantain *P. coronopus* and sea carrot *Daucus carota* ssp *gummifer*.

Low-intensity agricultural management of these maritime grasslands is an essential factor for the survival of some species which also make use of the adjacent coastal habitats. For example, the cliff-nesting chough feeds on invertebrates in grazed grasslands on cliff tops (Brown and Grice, 2005).

Regional variation

Key sites are found in Wales, within the Pembrokeshire Coast National Park and the Gower Peninsula. In England key sites are in the south west region, especially Cornwall, Scilly Isles, Exmoor, Isle of Wight and Dorset, with smaller areas elsewhere on the coast. Scotland has extensive cliff top habitats with a maritime influence. The resource is not quantified separately from other coastal and non-coastal habitats. Few areas support natural transitions from saltmarsh to grassland: in England these are now largely confined to sea walls.

2. What could happen in the future?

General

A review by Hopkins (2007) recognised that sea-level rise is the most serious threat to wildlife at the coast. There will be specific impacts for individual coastal habitat types, but it is important that the mosaic of habitats at the coast is considered as a whole In addition there will be different levels of impact depending on geographic location, topography of the land behind, existing and previous human interventions. This makes detailed predictions of change difficult. In particular the following issues will need to be considered for the coastal margin as a whole:

- Relative sea-level rise will alter the mosaic of habitats. There will be complex morphodynamic responses over different spatial and temporal scales, including impacts on longshore drift.
- Coastal cells will respond differently dependingon types of coast, legacy of past human intervention/current practices.
- Impacts will be greater where there is a sediment deficit particularly relevant to rate at which estuaries will infill to reach an 'equilibrium' form
- Storm surges will also affect the potential of systems to adjust to new equilibrium states
- Land drainage may be affected as sea levels rise, thus reducing the 'fall' available and with implications for low-lying land behind the coast. In addition, sediment movement can block outfalls

The impacts of coastal change have been investigated by the National Trust for its land holdings in England, Wales and Northern Ireland, using the UKCIP02 projections. These studies have led to development of the coastal policy of the National Trust in these countries, where they are significant landowners at the coast. A landscape scale study of climate change impacts on the Broads, using the UKCIP02 projections (Natural England, 2009) also highlighted the issue of addressing these in relation to freshwater habitats.

The 'Futurecoast' study in England and Wales for Defra to inform Shoreline Management Plans, provides a qualitative assessment of the evolution of the open coast over the next century, including the magnitude of shoreline change. There are now a number of tools available to improve understanding of risk to human assets from flooding and erosion and the potential shoreline management needs. The need for planning for change was also highlighted in the 'Future Flooding' report. Understanding how these integrate with conservation management of the coast in the light of climate change is essential. Defra projections for sea-level rise are used for planning for flood risk management, and may be higher in some areas than others.

Predictions to date have been based on previous climate projections, although the general principles are similar. A range of factors need to be considered based on recent updates from the UK Climate Impact Programme (UKCIP) as follows:

- Sea-level rise relative to land levels will have impacts on all coastal habitats. The predicted ranges (adjusted for land movement) of sea-level rise are 21-68 cm for London and 7-54cm for Edinburgh over the next century, with potentially greater increases after that.

- Storm surges may have more frequent 1 in 50 storm surge events, the largest trends in the Bristol Channel and Severn estuary. If these coincide with high tide events these could result in extensive flooding.
- Significant wave height: projected increases in mean and extreme winter wave height in south and south west of the UK
- Annual average temperature is predicted to rise by 1 to 3 °C or more during the century, with the largest increases in the south and east of England.
- Warming is likely to be greater in autumn and winter than in spring and summer.
- In winter, minimum temperatures are predicted to rise more rapidly than maximum temperatures, reducing the diurnal temperature range, while in summer, maximum temperatures will rise more rapidly than minimum temperatures, increasing the diurnal range.
- Variability of winter temperature between years is likely to decrease with cold winters becoming rare and fewer days with frost.
- Variability of summer temperatures is likely to increase, with very hot summers becoming more common.
- Annual precipitation will probably increase by 3-5% by 2050, with greater increases in winter and autumn and no change or a decrease in summer.
- Year-to-year variability of seasonal precipitation will likely show changes, such that the frequency of dry summers will double and wet winters treble by 2080.
- More of the increased precipitation is likely to occur in intense storm events than at present, especially in winter.
- Evapotranspiration is likely to increase year round but particularly in autumn and summer. Windstorms are likely to be more frequent than in the last few decades

Of less direct relevance to coastal margin habitats are sea surface temperature increases, near bottom surface temperature and stratification as these could affect sediment transfer processes

The need for making space for the natural development of coastal habitats and rivers is recognised in England Biodiversity Strategy adaptation principles (Smithers *et al.*, 2008).

a) Sand dunes

Sea-level rise is important for sand dune management not least because of the flood defence role, which they play. Pye & Saye (2005), using an assumed sea-level rise of 0.41 m by 2100 (the median value based on IPCC predictions), have predicted that several sites in Wales are likely to experience significant net loss of dune area/habitat over the course of the next century, notably Morfa Dyffryn, Newborough Warren, Whiteford Burrows and Kenfig. However, at some sites where sediment supply rates are expected to remain high there is likely to be continued net gain, notably at Laugharne-Pendine, Morfa Harlech and Ynyslas. Due to past morphological changes, these sites appear to be experiencing sand accumulation and possibly represent exceptions to the rule. Even at sites likely to experience a net gain, there will still be erosion, with shoreline retreat on sections of exposed coastal frontage, especially at the up-drift ends of sediment transport cells, while accretion is likely to occur down-drift where sediments can accumulate, for example, in spit and ebb-tidal delta complexes at the mouths of estuaries. At the remaining sites there is likely to be little net change, with some sites (e.g. Aberffraw) continuing to show fairly uniform slow progradation and others (e.g. Merthyr Mawr) showing spatially variable but balanced loss and gain. However, the Defra estimates for sea-level rise used in this study may underestimate medium to long-term changes suggesting even higher levels of habitat loss in the longer-term. Another possibility, if vegetation is either absent or poorly developed, is that sea-level rise could lead to the evolution of trangressive dune fields (Carter, 1991) but under the current high levels of stability this is probably unlikely. Management of over-stabilized dune systems in the context of sea-level rise will depend largely on the level of local impact. Rollback is one possible solution (i.e. allowing dunes to migrate landward). However, as most dune systems in Wales are highly stabilized by vegetation, this could restrict the likelihood of landward migration. Even where this might be possible, it is often constrained by coastal assets such as golf courses.

The likely results of projected climate change factors in terms of sand dune stabilisation are difficult to predict. The predicted rise in temperature is unlikely to have a major impact where dune species, particularly plants and invertebrates, have a southern distribution and tend to be thermophilic ,as in Wales,. There are exceptions, such as the dune grass *Leymus arenarius*, which is close to its southern limit in Wales. Some dune plant communities with a northern distribution such as the semi-fixed dune grassland *Ammophila arenaria-Festuca rubra-Hypnum cupressiforme* subcommunity may shift their range. Also most dune plant species in this part of the world use the C3 pathway in photosynthesis enabling them to better utilize any increase in CO2 levels. It is possible that dune grasses will grow more rapidly as temperatures rise (Carter, 1991). Warmer, wetter conditions as evidenced from the Holocene stratigraphic record dune are also likely to favour further stabilization and soil development, but this may be offset or even reversed by a higher incidence of summer droughts and intense storm events. Rates of recent soil development in dunes have been linked to climatic variation over the last 60 years, with faster soil development associated with warmer periods (Jones *et al.,* 2008).

More stable parts of some Scottish mainland dune systems could remobilise as relative sea-level rises, especially on the outer Firths (Pethick, 1999) but these systems are part of wider functional systems that often include saltmarsh. Scottish saltmarsh is often very firmly rooted and such modelling as has been conducted tends to regard sediments as readily mobile. The likely 'lag' in mobilisation of saltmarsh will have a 'knock-on' effect in how the wider sedimentary system mobilises, so that it is very difficult to anticipate how these systems will behave. The Firths' outer dunes are often developed as golf courses, as yet with limited plans for adaptation of courses, so that protection is preferred over relocation. If golf courses do not adapt, existing or future coast protection will affect sediment movement patterns, preventing sand exchange with beaches and potentially lowering beach levels. The outcome of this is that the risk of erosion is increased, not only for the golf course but within the sediment cell as a whole. Dune slack communities are strongly dependent on hydrological regime and recent modelling work predicts drastic falls in water table of over 1 m by 2100 under UKCIP02 medium range climate predictions for a site in north west England (Clarke & Sanitwong Na Ayutthaya, in press). The climate change impacts on dune slacks remain a major knowledge gap.

In summary the following impacts are important for sand dunes:

- Dune slacks will be influenced by rainfall patterns
- Dune mobility affected by blown sand: wetter beach plains due to sea-level rise may reduce amount of blown sand
- Sea-level rise is key factor, but temperature, precipitation, wind speed/direction, and rainfall patterns will affect quality and functionality of dune habitats
- Climate impacts may exacerbate effects of nutrient deposition, dunes will become more stable, densely vegetated and less diverse
- Loss of open sand affects species such as natterjack toad and sand lizard which need open areas to bask and hunt

b) Machair

The potential impacts of climate change on Scottish machair are related to three elements of climate change: accelerating relative sea-level rise, temperature changes, and changes in storminess. These have different levels of probability, and this is further complicated by two or more of these factors acting together. Ongoing studies by SNH have concentrated on two main fields: sea level change and habitat vulnerability. The former involves research by Rennie & Hansom (in prep.) and a commissioned study, 'Shorelook'. This is a wider research programme that includes historical analyses with time lapse Digital terrain Models from a network of representative sites, and a project on coastal steepening. Shorelook 1 will translate UKCP09 scenarios into geomorphological and ecological changes into the future by reviewing a range of Relative Sea-level rise situations around the Scottish coast, as well as possible impacts of storm events, that are believed to be more significant drivers of change than storm trends.

SNH studies of the impact and causes of the severe storm of 2005 (a single event that could not be directly linked to climate change) have revealed a number of hitherto unknown issues regarding the vulnerability of the low-lying coastal plains of the Hebrides which support machair. Angus & Rennie (in prep., storm study) suggested that the severity of the storm of 2005 was due in part to the combined effects of atmospheric pressure-related sea level elevation, wind-driven storm surge and high tide raising the wave base to the extent that it substantially disengaged from most of the seabed. Normally, the extensive shallow seabed off the Uists, which supports dense forests of 'tangle' *Laminaria hyperborea* significantly reduces wave energy, but in the 2005 event, higher than normal sea levels and waves impacted the coast retaining a higher proportion of their energy than would normally be the case, resulting in extensive marine flooding.

Remote sensing investigations using LiDAR and air photography, have indicated that the Uists were more vulnerable than previously thought. Narrow and low dune ridges were identified in this work. If marine erosion continues to lower the coastal edge, this vulnerability will increase. This information is being used for contingency planning for extreme events and climate change.

There is limited knowledge of the impacts of more frequent flooding on the seasonal lochs of the machair: while recovery after the 2005 event was quicker than expected, the understanding of water table processes in such low-lying areas needs to be improved to predict future impacts in scenarios of longer or more frequent saline flooding. Drainage is complex due to artificial systems constructed around 1800.

Rising sea levels will reduce the fall available, and in the 200 years since installation, these drainage systems have lost an estimated 10% of their fall 10%.

The integration of the machair system with the dune ridge is also important. The dunes give protection from flooding, but if they are displaced landward as sea levels rise, they will overwhelm the machair plain. If they are breached

c) Maritime Cliff and Slope

- Increased marine erosion at cliff toes with higher sea levels/more frequent storms
- Hard cliffs: rocky shore platforms may have more marine scour/wave attack at cliff foot due to beach lowering, may be lost with sea-level rise (can't accrete unlike beaches)
- Headlands form natural hard points and may promote changes in shape of intervening bays and beaches
- High levels of winter rainfall may promote greater risk of landslides, leading to more demands for coast protection
- Old landslide complexes likely to reactivate more rapidly than expected as groundwater pressure increases
- Warmer temperatures may favour invasive species e.g. Hottentot fig, but may also promote suitable conditions for thermophilic species.
- Balance of bare ground to successional vegetation may be altered on soft cliffs, with potential loss of mosaics important for scarce invertebrates
- Changes in intensity of land use of cliff top land may reduce potential for colonisation of eroding slopes by semi-natural vegetation

d) Coastal Shingle

Sea-level rise will impact on shingle beaches and structures. Because many key sites are found in areas with greatest projected sea-level rise (Regions 2 & 3) there could be a disproportionate impact. There will be complex morphodynamic responses over different spatial and temporal scales. Increased levels of wave and tidal energy and subsequent erosion will cause some features in protected sites to migrate beyond the designated boundaries. This has already been recorded on a shingle foreland at Kessingland in Suffolk (region 2), in response to longshore drift (Doody, 2004; Rees 2006). This process is likely to continue and accelerate in the face of sea-level rise, here and elsewhere in the south and east.

Sea-level rise is an important issue in shingle management because of the role shingle structures play in flood risk management. They reduce the risk of flooding on low-lying land behind, but may change in morphology as sea levels rise. At Porlock in Somerset (Region 4) a shingle beach, breached in a storm, has since developed a tidal inlet with the grazing land behind reverting to saltmarsh. This may not always be an option where there are important assets. Particularly important is Dungeness (Kent, Region 3) where the presence of nuclear electricity generation will require the beach in front of the power stations to continue to be replenished until they are decommissioned. Rising sea levels and greater storm frequency will increase erosion and the movement of material, making flood risk reduction more difficult. Planning for future flood risk management needs to take account of the response of the shoreline to climate change, and be more adaptive than has been practised in the past

In a global context, beaches are vanishing (Gribbin, 1984) with 70% eroding and only 10% accreting (Bird, 1985). Although sea-level rise is not the only factor, there is a consensus that beach erosion and loss will get worse (Bird 1996). Studies at two sites on the south coast of England (East Sussex, Region 3) also indicate the important of the condition of the sediment, where annual weight loss of flint shingle by attrition could be as high as 1.9% per year (Dornbusch *et al.,* 2002). The importance of new sediment input is critical to sustaining these beaches, but is often prevented by coastal defences.

The following are important and increase the likelihood of erosion as a result of sediment depletion:

- Reduced supply from offshore sources. As sea levels rise the beach profile changes from a concave to a convex profile or become too steep for sediment to move onshore through the action of waves or currents, as well as increasing the distance from offshore deposits. Offshore dredging for construction material may reduce an aggregate supply that could be used recharge of beaches;
- Reduced supply from eroding cliffs. Maintaining coastal protection features on glacial or other soft rock cliffs 'locks up' sediment depriving the shoreline of new material through alongshore drift.
- Damming of rivers or other riverine protective measures prevent the delivery of sediment to the coast from the hinterland;
- Loss of sediment offshore through marine transport
- Greater risk of breakdown of shingle ridges, especially on artificially profiled beaches

Increased erosion will occur because of:

- Increased wave attack resulting in undermining and cliffing along the seaward beach front;
- Storm surges affecting the potential of systems to adjust to new equilibrium states and preventing seaward expansion through build up of beach ridges;
- Landward migration of narrow beaches, which could disappear against rising ground, marshes or coastal defence structures;
- 'Coastal squeeze' as larger structures overwhelm habitats to landward as shingle ridges migrate inland.

Sea defence structures built at the rear of shingle beaches will be:

- More susceptible to undermining as beach levels drop;
- More difficult and costly to maintain as the availability of material for beach feeding is depleted;
- More susceptible to the breakdown especially artificially profiled shingle ridges.

Larger shingle structures supporting freshwater aquifers may:

- Become vulnerable to saline water intrusion (mainly Dungeness).

Climate is the major variable affecting community distribution and species range of shingle vegetation (Farrell and Randall, 1992). The northern Oysterplant, for example, has disappeared from several southern localities in both Great Britain and Ireland a process attributed to a warming climate (Randall, 2004). Because of the dynamic nature of shingle beaches, only a few species survive and storms can destroy the vegetation. Increasing storminess in the last two decades appears to have had a considerable effect on western British foreshore vegetation - particularly in 1967, 1988 and 1989. However long-term recovery is rarely monitored.

Direct climate change impacts, such as patterns of precipitation or temperature will affect vegetation composition. Water retention is difficult in these areas and evapotranspiration is likely to increase year round but particularly in autumn and summer. Due to the free drainage through shingle, even though winters may be wetter, summer droughts may have greater impact. This could increase the ratio of bare ground to vegetation. Warmer temperatures may also favour invasive species, especially garden escapes, thus threatening some native species.

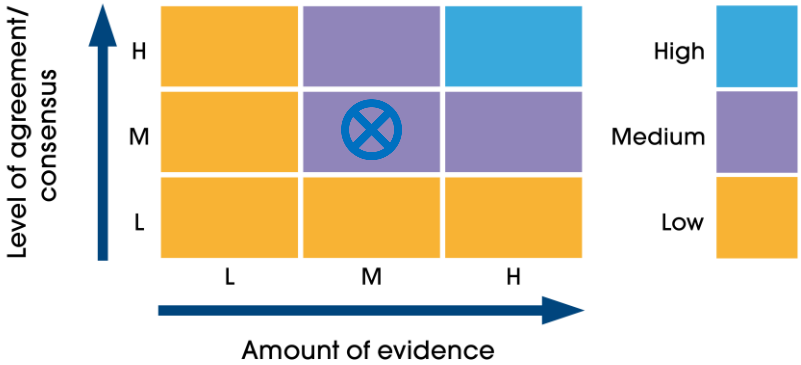
There is little research on the impact of climate change on shingle plants and animals. However, given the highly specialist nature of many of the species occurring in this hostile environment the effects are likely to more pronounced than for other habitats.

e) Coastal grassland and heath

One of the key factors is exposure, and it is unlikely that this will be reduced in future. As with many semi-natural habitats, coastal heaths or grasslands have been lost to development or agriculture, and the transitions are often truncated. This means that there is limited space to migrate into if the coast erodes. The main impacts will be related to any changes in the recession rates of cliffs or frequency of flooding on low-lying areas. This will not only potentially change species composition towards more halophytic species, but also reduce the extent of coastal grassland and heath. There may be soil chemistry changes if salt spray inputs change. Where these habitats are found above harder rock cliffs, there may be less impact on recession rates. However there have been limited studies on these particular habitats.

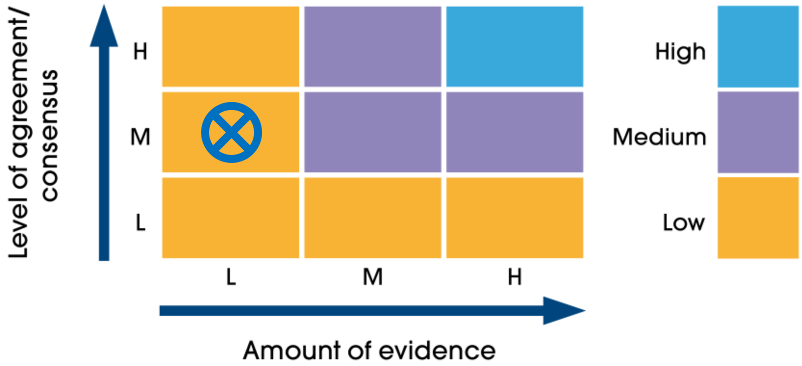
3. Confidence in the science

What is already happening: ***Medium***



Rationale: we are already observing some changes on coastal sites in terms of changes to sediment budgets and changes in composition. There has not been as much emphasis on supralittoral coastal habitats as there has been on littoral habitats, but increasing evidence on sand dune systems.

What could happen: ***Low***



Because coastal systems are highly complex and dynamic, with a legacy of intervention in many areas, there is likely to be lower confidence in predictions of future scenarios, there is also a lack of long-term data sets to indicate trends: more needs to be done on this across a wide range of coastal habitat types. This uncertainty requires careful consideration of the adaptation responses. What is certain is that the coast will change!

4. Knowledge Gaps

The top priority knowledge gaps that need to be addressed in the short term to provide better advice to be given to policy makers are:

General

- Coastal change needs to be fully evaluated at a coastal cell level against the UKCP09 predictions for a wide range of climatic factors to improve confidence in predictions and reduce uncertainty. This needs to include the responses of key species across a range of habitats.
- Successional processes in vegetation will be affected by climate and other factors such as nutrient deposition. The work in Wales on dunes indicates that there is a need for more information on the interaction of these factors, which is relevant to future management strategies.
- The studies in progress in Scotland indicate that the relationship between the coastal habitats and the landward areas is not fully understood. More work is needed to inform measures to restore the coastal flood plain in order to plan for and enable effective adaptation to climate change.

Shingle:

- Whilst there is reasonable knowledge of the status and evolution of the major shingle structures much less is known about the long lengths of shingle beaches. Assess the status of shingle beaches in relation to changing sea levels, human activities and determine their vulnerability.
- Impact of offshore dredging. There are differing views about the impact of offshore dredging on the coast. Given the importance of shingle foreshore to sea defence this issue needs research that is more active.
- Restoring shingle vegetation is difficult and there is only very limited research. Increase the effort on this aspect of management.

Machair

- Information needed for improved contingency and management planning is currently being developed via SNH commissioned and in-house research. Understanding a wide range of hydrological and topographical relationships will be important to inform the human response to both extreme events and longer-term trends.

Sand Dunes

- A number of knowledge gaps have been identified regarding the understanding of the hydrological, chemical and physical processes of dunes and how these could be managed in the context of climate change. More information is also needed on the restoration of processes and habitats to enable more effective adaptive measures to be implemented. It is unlikely that dune systems will be stable. Expanding the work in Wales of Pye & Saye (2005) to the rest of the UK will help understand where the greatest changes could occur.
- Guidelines for the ecohydrology of dune slacks have been produced by the Environment Agency in 2010 (Davy *et al*., 2010). Research gaps have been included in this guidance.

Maritime Cliffs

- Information is needed on the impacts of potential increased erosion on invertebrate communities on cliff slopes.
- The relationship between sediment supply from erosion of cliffs and transport to other coastal or marine habitats will become increasingly important to understand in the context of coastal management.
- A UK-wide vegetation survey of maritime cliffs ideally using Phase II (National Vegetation Classification) methodology is needed.

Coastal grassland and heath

- Particular areas where knowledge is missing is the extent and distribution of the habitat types; the impacts on species composition of climate change; management requirements and trends.

5. Socio-economic impacts

General

A review of the implications of sea-level rise for the UK (de la Vega-Leinhart & Nicholls, 2008) suggests that although the UK has the potential to adapt to sea-level rise, there are a number of barriers to implementation. For example, public acceptance of coastal change is still very low, and funding of innovative approaches is limited. The development of new Shoreline Management Plans in 2010 for England and Wales will help to direct the future public funding of coastal management, these plans are increasingly geared towards long-term sustainable solutions rather than a 'hold the line' approach. A number of 'pathfinder' projects in England have recently been announced by Defra which will explore a range of situations where coastal change is an issue for local communities.

Also in 2010, a revised beach management manual will be published to help guide engineers and other beach managers to more sustainable methods of managing flood risk on low-lying coasts.

The integration of coastal management with land-use and marine planning will become more important in future, under the broader context of Integrated Coastal Zone Management. The economic value of coastal habitats and coastal processes needs to be more widely understood and promoted: this is often difficult due to the public and political expectation that risk of flooding and erosion can and should be controlled.

There are a number of key researchers working on this issue of stakeholder dialogue and coastal change, for example the Tyndall Centre for Climate Change Research (Milligan *et al*., 2006)

Dune systems: The prospect of future morphological changes arising from climate / sea level change and changing patterns of coastal erosion and accretion, combined with changing attitudes away from fixed coast and flood protection towards coastal erosion and flood risk management, provides a significant opportunity to increase the geomorphological and ecological dynamism of dune systems. However, the evaluation of future management options needs to be carefully assessed on a site by site basis, taking into account the nature of local physical processes, sediment supply, likely long-term morphological evolution, and the present and possible future uses of the dunes themselves and the hinterland. Approaches to managing the landward movement of dune systems need to be developed (Pye *et al*., 2007). In view of the likelihood of increased beach steepening, rising sea levels and more frequent storm events in the coming decades, rates of frontal dune erosion are also likely to increase and 'hard' dune defences will become unsustainable in some areas. The future of dune golf courses will need to be addressed specifically in relation to this habitat.

Machair: The future of this habitat is totally interwoven with the role of traditional management. It appears to be very vulnerable to extreme events, and as is often the case, hard defences are called for after the event to reduce flood risk. This may not be sustainable in the long-term however.

Shingle: Flood and coastal erosion risk management relies largely on the ability of natural coastal processes to move and retain sediment within systems. In some areas there has been a decrease in shingle volume to sustain past flood risk management techniques, but new, more adaptive approaches which depend on natural processes are difficult for the public to accept.

Cliffs: it is estimated that on average, over the next 50 years 1 property per year will succumb to coastal erosion. Experience in places with rapid erosion form a focus for stakeholder dialogue on erosion risk management.

Coastal grassland and heath: Many of the key locations are within protected landscapes and as such play an important socio-economic role. Low- intensity agricultural management will play a key role in securing these habitats across their whole range, and needs to be addressed in agri-environment incentive schemes.

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