Chapter 11:
Coastal Margins

Coordinating Lead Author: Laurence Jones
Lead Authors: Stewart Angus, Andrew Cooper, Pat Doody, Mark Everard, Angus Garbutt, Paul Gilchrist, Jim Hansom, Robert Nicholls, Kenneth Pye, Neil Ravenscroft, Sue Rees, Peter Rhind and Andrew Whitehouse

Key Findings*

The six Coastal Margin habitats (Sand Dunes, Machair, Saltmarsh, Shingle, Sea Cliffs and Coastal Lagoons) make up only 0.6% of the UK's land area, but are far more important to society than their small area might suggest. The total value of the ecosystem services provided by the UK's coast is estimated at £48 billion (adjusted to 2003 values), equivalent to 3.46% of Global National Income (GNI). As an island nation, coastal landscapes are part of our cultural heritage and sense of identity. The Coastal Margins are an interface between land and sea, and directly provide ecosystem services to adjacent terrestrial and marine habitats. The ecosystem services of greatest financial value are tourism and leisure (cultural) and coastal defence (regulating), but the relative importance of these services differs according to location.

Sand Dunes, Saltmarsh and Machair make up the greatest area of Coastal Margin habitats: approximately 70,000 hectare (ha), 45,000 ha and 20,000 ha respectively. However, except for protected areas, basic data on the extent of these habitats is lacking; for some, estimates of their total area vary by up to 50%. Overall, Coastal Margin habitats have declined by an estimated 16% since 1945[2] due to development and coastal squeeze, but this is poorly quantified. All habitats have been affected by coastal development for industry, housing and tourism. Sand Dunes and Saltmarsh have also been affected by agricultural development (including forestry). Although the introduction of greater statutory protection in the 1980s has slowed the rate of loss and fragmentation of many sites, Coastal Margin habitats are still being lost today[2].

[2] *established but incomplete evidence*

Habitat losses due to sea-level rise have been relatively small so far, estimated at 2% over the past 20 years for Sand Dunes and 4.5% for Saltmarsh[2]. However, habitat losses are projected to reach 8% by 2060. Steepening of the intertidal coastal profile on soft coasts has been observed across the UK. Future losses will increase throughout the UK as storm erosion events increase in magnitude and sea-level rise further outstrips isostatic readjustment[2,b]; this issue is of particular concern where coastal squeeze operates, preventing land-ward migration of these habitats in response to sea-level rise.

[2] *established but incomplete evidence*

[b] *very likely*

The quality of Coastal Margin habitats has declined since 1945[2]. Sediment supply has fallen and natural dynamics have been reduced due to decreased availability of post-glacial sediment, widespread installation of artificial sea-defence structures, and increased armouring of soft cliffs[1]. The proportion of early successional habitats has fallen—by up to 90% in some dune systems—while scrub and grassland have increased. This reduces the Coastal Margins biological and conservation interest, and may indirectly alter ecosystem service provision. It also restricts their capacity to adapt to climate change and sea-level rise. The principal causes of these changes include a decline in traditional forms of management, such as grazing (particularly in the south and east), an increase in nitrogen deposition speeding up plant growth and soil development, and early conservation efforts which often focused on stabilising these naturally dynamic systems.

[1] *well established*
[2] *established but incomplete evidence*

* Each Key Finding has been assigned a level of scientific certainty, based on a 4-box model and complemented, where possible, with a likelihood scale. Superscript numbers and letters indicate the uncertainty term assigned to each finding. Full details of each term and how they were assigned are presented in Appendix 11.1.

Cultural ecosystem services provided by the coast are very important to the UK[2], with seaside tourism valued at £17 billion. The public values the coast highly: as living space; as a symbol of identity; for its scenery and wildlife; and for activities like walking, birdwatching, boating and outdoor sports. More than 250 million visits are made to the UK's coast per year, of which, around one-third are to natural habitats. Tourism patterns have changed in recent years, with day trips replacing overnight visits[1]. Overnight trips to the UK's seaside were worth £4.8 billion in 2009, while day visits were worth £3.9 billion in 2002. Moreover, overnight stays at the seaside exceed overnight stays in the rest of the UK's countryside and villages combined. These economic benefits are particularly significant in more remote areas. In Wales, in 2005, seaside tourism accounted for 42% of domestic tourism spend, supporting nearly 100,000 jobs and contributing £5 billion to income; the value of tourism to the Western Isles of Scotland is £49.9 million per year.

[1] *well established*
[2] *established but incomplete evidence*

Coastal defence is the most important regulating service provided by Coastal Margins[1]. All habitats contribute to coastal defence either directly by dissipating or attenuating wave energy or indirectly through regulating sediment. Sand Dunes and Shingle provide direct protection as a barrier, while Saltmarsh primarily attenuates wave energy. Up to 50% of wave energy is attenuated in the first 10–20 m of vegetated Saltmarsh, reducing the size needed for landward defences; 70% of Essex seawalls rely upon fronting Saltmarsh to maintain defence integrity[1]. Sand Dunes protect residential areas and high quality farmland, particularly in North West England and along the Norfolk Broads, while Shingle protects parts of the south and south-east coasts[2]. The soft coasts provide an estimated £3.1–£33.2 billion worth of capital savings in sea-defence costs in England alone.

[1] *well established*
[2] *established but incomplete evidence*

Carbon sequestration rates are high in Saltmarsh, Sand Dunes and Machair due to rapid soil development or sediment accumulation[2]. Sand Dunes on the west coast of the UK store 0.58 to 0.73 tonnes carbon/hectare/year (t C/ha/yr), while Saltmarsh stores 0.64 to 2.19 t C/ha/yr. However, the net benefit to the UK is small due to the low total area of these habitats. Carbon stocks in Coastal Margin habitats are (conservatively) estimated to be at least 6.8 megatonnes of carbon. Provisioning services generally play a minor role in Coastal Margins, although Saltmarsh-grazed lamb and beef are premium products.

[2] *established but incomplete evidence*

Coastal Margin habitats have high biodiversity and support a wide range of specialist and rare species[1]. This is reflected in the number of coastal sites designated for their biological importance. This diversity is partly dependent on natural dynamics forming a mosaic of habitats of different ages. This biological diversity contributes to the coast's cultural services and directly supports some regulating services; for example, Saltmarsh provides nursery grounds for many fish species including commercially important species such as sea bass (*Dicentrarchus labrax*) and herring (*Clupea harengus*). Coastal Margins provide important habitats for many bird species which provide a focus for nature-oriented visits to the coast[1]; at just four RSPB reserves, for example, such visits are worth £1.2 million. Sand Dunes, Machair, Saltmarsh, Shingle and Sea Cliffs support a wide range of natural pollinators, which, together with ground predators and parasitoids, may provide services of pollination and pest control to adjacent arable fields[4]. This may be of considerable local importance but, at the UK scale, the extent of this service is likely to be small.

[1] *well established*
[4] *speculative*

The principal conflicts in Coastal Margin habitats occur between services associated with disturbance and those associated with stability. In general, the disturbance resulting from processes such as erosion and sediment transport provide essential dynamics in natural coastal systems. However, pressure for land, fixed human assets, and management requirements to maintain coastal infrastructure, such as ports, mean that this natural dynamism is often deemed unacceptable. Conflicts can also occur between biodiversity interest and use of these habitats for leisure and recreation. Nonetheless, there is potential to identify 'win-win' combinations of services. Synergies are complex and may not occur in the same place or time, for example: sediment transport benefits coastal defence down the coast; pollination benefits other Broad Habitats; and erosion may cause serious short-term loss, but benefit habitat creation in the longer-term.

Sustainable management of Coastal Margin habitats must be holistic, taking into account physical, chemical and biological processes, spatial and temporal scales, drivers of change, and cultural elements. Most large Coastal Margin sites are designated as Special Areas of Conservation (SACs) under the Habitats Directive, or are Sites of Special Scientific Interest (SSSIs); therefore, the protection and maintenance of the biodiversity, natural processes and geomorphological interest remain primary objectives. However, appropriate management may enhance both biodiversity and other services. Sustainable management options include:

- Allowing Coastal Margin habitats room to migrate inland with rising sea levels in order to mitigate coastal squeeze ('managed realignment'). In Saltmarsh, this has shown additional ecosystem service benefits compared with a 'hold the line' strategy, but the principles can be applied to the other Coastal Margin habitats too.
- Managing sediment supply by allowing erosion to contribute new sediment to the coast, and allowing natural transport processes to proceed where possible.
- Maintaining or encouraging natural formation of early successional habitats where these are threatened or have disappeared.

Implications for policy include:

- The Coastal Margin habitats are of high financial and cultural value to the UK, yet they often fall into the policy no-man's land between marine and terrestrial interests.
- There remain major knowledge gaps for Coastal Margins, including basic data such as extent and trends, particularly in Scotland. This needs to be addressed by unified and strategic data gathering across the UK to detect change in coastal sediments and habitats in order to inform adaptation strategies. Coastal Margins face major threats in the coming decades, particularly from sea-level rise and climate change, as well as pollution and continuing development pressures. These threats are exacerbated by the linear nature of the habitat, with pressures on every edge and very little safe, core habitat, except on the largest sites. Threats from sea level rise will be most acute on coasts where habitats are constrained by artificial sea defences.
- Coastal Margins need to be managed holistically, maintaining natural dynamics where possible and acknowledging the interdependence with other habitats, including the Marine environment.

11.1 Introduction

The coastline of the UK is 32,086 km long with the inclusion of major islands (Frost 2010; Chapter 12). The coastline incorporates urban areas and a wide range of other natural and semi-natural habitats, but this chapter focuses on the six main habitats which are considered primarily coastal: Sand Dunes, Machair, Shingle, Saltmarsh, Sea Cliffs, and Coastal Lagoons (**Figure 11.1**). Small islands are considered within Sea Cliffs; sand and shingle beaches are included under Sand Dunes and Shingle respectively. The main linkages with other UK National Ecosystem Assessment (UK NEA) Broad Habitats are shown in **Table 11.1**, and the following habitats are considered elsewhere: coastal grasslands are included under Semi-natural Grassland (Chapter 6); mudflats, rocky shores and estuaries are covered under Marine (Chapter 12); and coastal urban areas are covered under Urban (Chapter 10). Within this Coastal Margin chapter, common issues across habitats are discussed first, followed by additional habitat-specific text where appropriate.

The habitats of the Coastal Margin provide some unique ecosystem services and drivers of change due to their location. Coastal Margin habitats generally form a transition zone between marine and terrestrial systems, with influences from both directions. Many are dependent on an active sediment supply (e.g. Sand Dunes, Machair, Saltmarsh, Shingle), and are governed to a large extent by marine-mediated geomorphological processes such as coastal erosion (of beaches, dunes and cliffs, for example) and alongshore sediment transport to down-drift shores and lagoons. Salt-spray, nutrient inputs and high wind speeds from the sea influence the vegetation of these habitats. Plant propagules arrive both from the sea and the land, while other natural and human influences occur from both directions and include succession, land use change, alterations in sediment supply and coastal development. Transitions and gradations also occur between Coastal Margin habitats.

The following text describes the properties of the main Coastal Margin habitats which underpin the goods and ecosystem services described later. **Figure 11.2** shows the UK distributions of these habitats.

11.1.1 Sand Dunes

Coastal Sand Dunes occur all around the UK (**Figure 11.2a**). They are formed from sand (0.2–2 mm grain size) that is blown inland from the beach, and are usually stabilised by vegetation (Packham & Willis 1997). Typically, phases of mobility and natural coastal dynamics lead to a sequence of dune ridges, which increase in stability the further away from the sea they are. As environmental stresses, such as wind speed, sand mobility and salt-spray, decrease further

Figure 11.1 The Coastal Margin habitats. a) Sand Dunes*, b) Machair†, c) Saltmarsh*, d) Shingle†, e) Coastal Lagoons†, f) Sea Cliffs*. *Photos courtesy of L. Jones* and J.P. Doody†.*

inland, pioneer plant species are replaced by more diverse vegetation communities and soil development advances. In the wake of migrating dunes, or on accreting coasts, wind can scour bare sand down to the water table; the exposed damp sand is colonised by a different set of plant species, creating low-lying dune slacks: a (usually) seasonal wetland, flooded in winter and often with high botanical diversity. The main vegetation types are dry dune grassland and dune slacks, with dune heath on some acidic sites; all have the potential for succession to woodland over time (Provoost *et al.* 2010). Therefore, Sand Dunes provide a highly diverse mix of habitats and services—often on the same site—due

Table 11.1 Linkages between Coastal Margin and other UK National Ecosystem Assessment (UK NEA) habitats.
✓ denotes a link; relevant habitat components are listed; - indicates not applicable.

	Other UK NEA Broad Habitats						
Coastal Margin habitat	**Mountains, Moorlands & Heaths**	**Semi-natural Grassland**	**Enclosed Farmland**	**Woodlands**	**Freshwaters – Open waters, Wetlands and Floodplains**	**Urban**	**Marine ***
Sand Dunes	✓ dune heath	✓ dune grassland	-	✓ afforested dunes	✓ dune slacks	✓ sandy beaches	✓ sediment
Machair	-	✓ machair grassland	✓ cultivated machair	-	✓ machair lochs	-	✓ sediment
Saltmarsh	-	✓ saltmarsh grassland	✓ enclosed saltmarsh	-	-	-	✓ sediment & water
Shingle	-	-	-	-	-	✓ shingle beaches	✓ sediment
Sea Cliffs	-	-	-	-	-	✓ soft cliffs	✓ sediment
Coastal lagoons	-	-	-	-	✓ lagoon water bodies	✓ lagoons	✓ sediment & water

* There are many links, principal exchanges are listed here but all are described in the text.

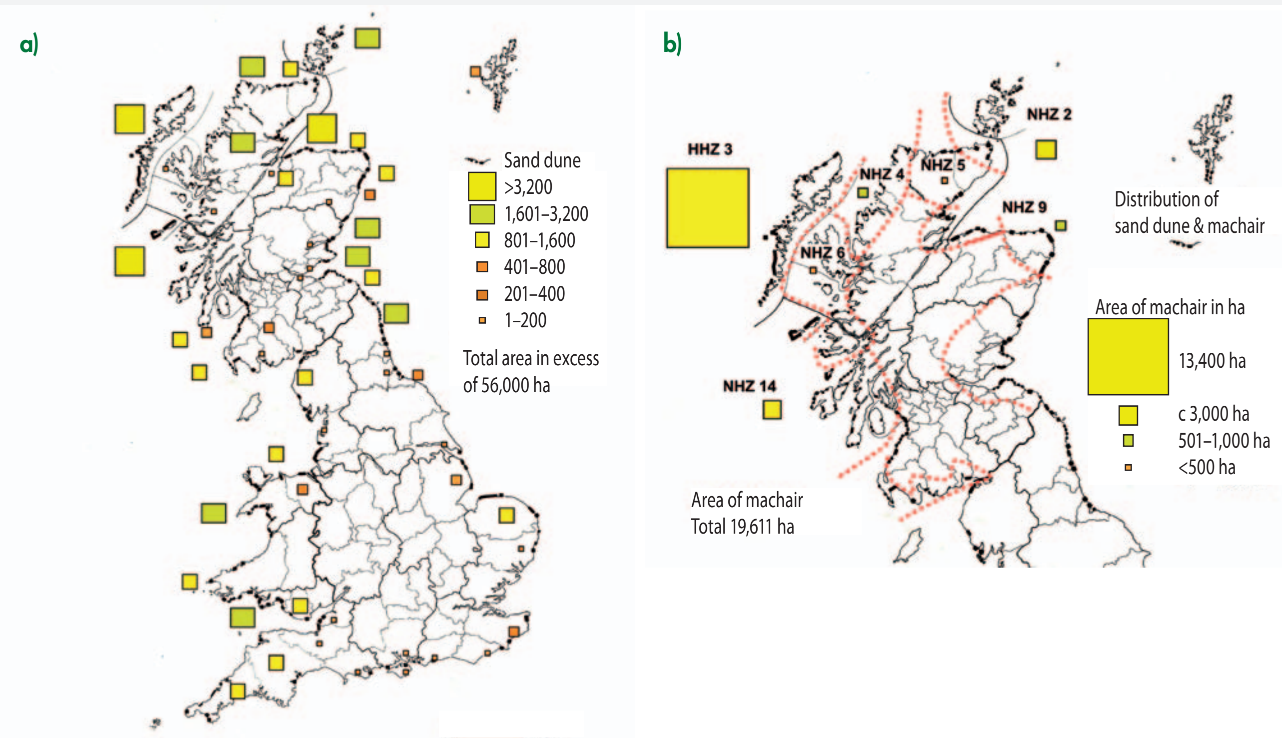


Figure 11.2 Distributions and approximate extent of Coastal Margin habitats in GB, by county based on JNCC data circa 1990: a) Sand Dunes, b) Machair in Scotland, c) Saltmarsh, d) Shingle, e) Sea Cliffs (more than 20 m high), f) Coastal Lagoons. Note: figures (ha and km) are based on 1:50,000 maps and are meant to facilitate comparisons. Field surveys since they were drawn up have greatly increased our knowledge of the resource which is bigger than indicated by the figures. Source: all maps provided by J.P. Doody; Coastal Lagoons map includes data from Barne *et al.* (1995–1998).

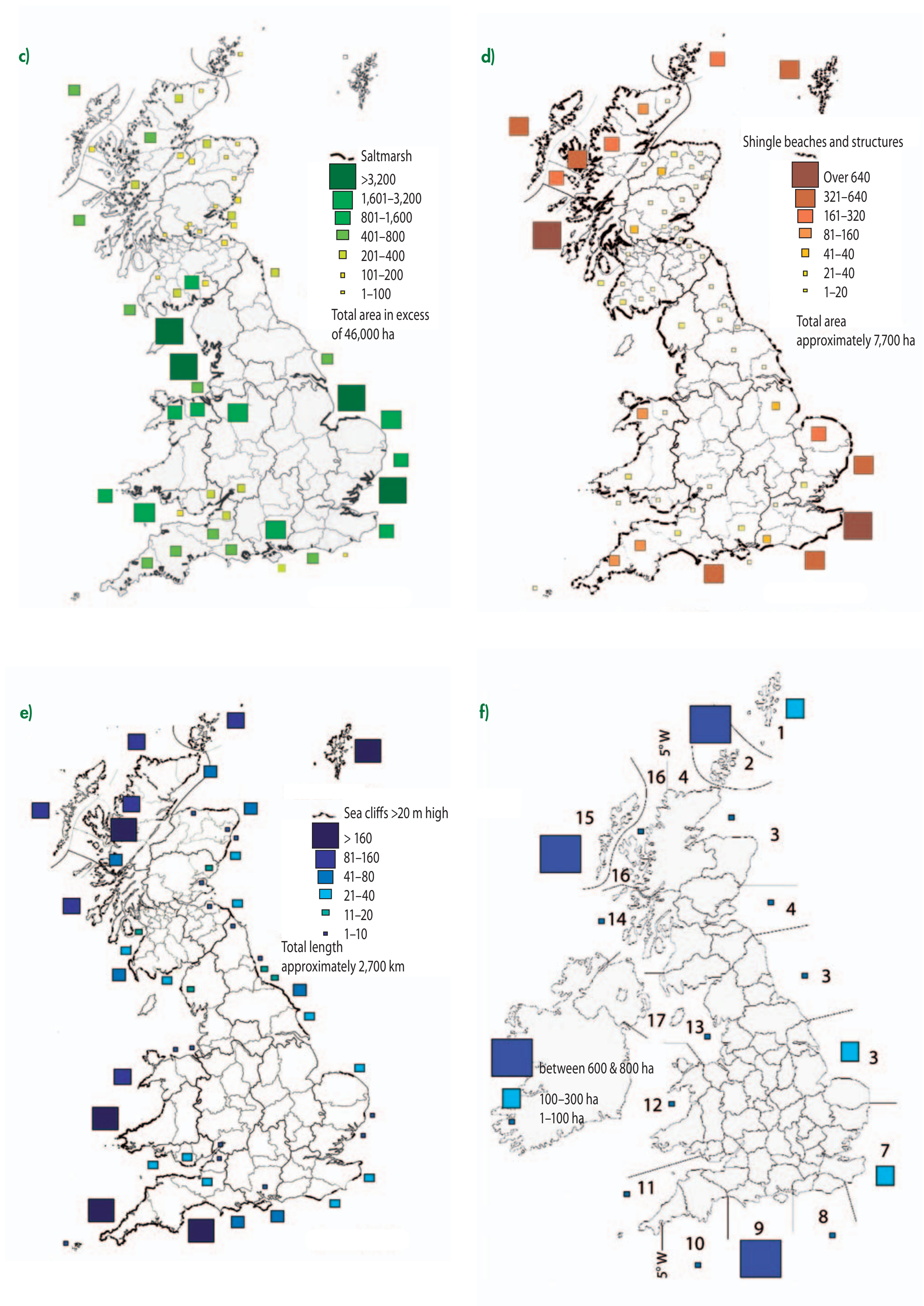


Figure 11.2 continued.

to differences in successional age, soil pH, local disturbance, management history, the steepness and aspect of slopes, groundwater chemistry and the hydrological regime in dune slacks (Everard *et al.* 2010).

11.1.2 Machair

Sharing many of the characteristics and processes found in Sand Dunes, Machair is a unique form of dune system, found nowhere else on Earth other than on the north-western seaboards of Scotland and Ireland (**Figure 11.2b**). Machair is a gently sloping and undulating (often inland-sloping) coastal dune-plain formed by depositional recycling of wind-blown calcareous shell-sand from the beach. There is usually a dune cordon seaward and species-rich grassland (managed by traditional low-intensity agriculture in the Uists Islands, Scotland), wetland, loch and peatland (with sand/peat admixtures) to the landward. Machair is characteristically lime-rich, subject to strong, moist, oceanic winds, and affected by current or historic human interference via grazing, cultivation, the addition of seaweed fertiliser and artificial drainage. The term 'machair' has both geomorphological and cultural meaning, much of its spatial extent mapping with Gaelic language and culture (Hansom & Angus 2001). All machair habitats have similarities in their land use history and their present distribution owes as much to cultural factors as it does to biotic and abiotic influences.

11.1.3 Saltmarsh

Saltmarsh is widely distributed around the UK (**Figure 11.2c**). The most extensive areas occur along estuaries in the counties of Hampshire, north Kent, Essex, Norfolk, Lincolnshire and Lancashire (May & Hansom 2003). Saltmarshes generally occur between mean high water spring tides and mean high water neap tides at temperate latitudes. The development of saltmarshes is largely controlled by physiography: fine sediments accumulate in relatively low-energy environments where wave action is limited. Consequently, salt tolerant vegetation develops where there is an accumulation of mud in estuaries, inlets, behind barrier islands or spits, and occasionally via marine inundation of low-lying ground. Four physical factors, sediment supply, tidal regime, wind-wave climate, and the movement of relative sea-level, primarily govern the character and dynamic behaviour of saltmarshes (Boorman 2003). The composition of saltmarsh flora and fauna is determined by complex interactions between the frequency of tidal inundation, salinity, suspended sediment content and particle size, slope, and herbivory. In general, total species-richness increases with elevation, leading to a characteristic zonation of the vegetation (Doody 2008). Transitions to mudflat occur at the seaward limit, while in the upper elevations of saltmarshes there may be further transitions to brackish, freshwater marsh, dune vegetation or vegetation overlying shingle structures.

11.1.4 Shingle

Shingle beaches and structures occur around the whole of the UK's coastline (**Figure 11.2d**). The most extensive are in the south-east where sediment of a suitable size is abundant, or has been in the past, and where there are rising sea levels. The more exposed and storm prone areas of north-west Scotland also have, mainly small, shingle beaches, including those raised above high water by isostatic uplift.

The term 'shingle' applies to any sediment with a mean grain size of between 2 and 200 mm (Randall 1977), which define thresholds for wind and wave transport. Sediment availability is crucial and comes from three sources. In order of importance these are:

1. Offshore Pleistocene glacial sediments reworked by storms and rising sea levels;
2. Rivers transporting shingle to the coast; and
3. Active erosion of existing 'soft rock' coastal cliffs and bluffs.

The first two of these sources are much reduced from former levels of supply in the UK, but although minor, the third is increasing in importance due to enhanced erosion, particularly in the south and east of England.

Shingle habitats most often occur as fringing beaches deposited at, or near, the limit of high tide. In exposed areas with abundant sediment they can develop into more permanent stony banks (shingle structures), often occurring as sequences of ridges which reflect the prevailing direction of alongshore drift and storms (Pye 2001). Vegetated shingle communities are uncommon and depend on substrate stability, moisture and nutrient availability. Two broad communities occur:

1. On dynamic beaches where species survive periodic disturbance and salt-spray; and
2. Away from the shore, in more stable conditions, allowing mature grassland, lowland heath, moss and lichen communities, or scrub to develop.

11.1.5 Sea Cliffs

Hard cliffs are widely distributed along the UK's exposed coasts, occurring principally in the north and west, but also in the south-west and south-east of England as 'hard' chalk cliffs. Soft cliffs are more restricted, occurring mainly on the east and central south coasts of England and in Cardigan Bay, Wales (**Figure 11.2e**). The UK Biodiversity Action Plan (UKBAP) for maritime cliffs and slopes (www.ukbap.org.uk/UKPlans.aspx?ID=27) defines them as "sloping to vertical faces on the coastline where a break in slope is formed by slippage and/or coastal erosion". The cliff-top zone can extend landward to at least the limit of maritime influence (i.e. the limit of salt-spray deposition), which in some exposed situations may continue for up to 500 m inland. Under this definition, cliffs may comprise entire islands or headlands, depending on their size. On the seaward side, they extend to the limit of the supralittoral zone (Chapter 12), and so, include splash zone lichens and other species occupying this habitat. Where the underlying geology of the cliffs is predominately soft rocks, such as clays, they are classified as soft cliffs. Such cliffs are often characterised by slips or areas of slumped cliff face that gradually become vegetated. Hard and soft cliffs under pressure from erosion behave differently and provide different functions: hard cliffs provide little sediment, while soft cliffs are major sources of sediment to sand and shingle beaches and to fine-grained habitats such as saltmarsh.

11.1.6 Coastal Lagoons

'Saline lagoon' (**Figure 11.2f**) is a term that is applied loosely in the UK to cover a wide range of coastal water bodies of varying salinity from nearly freshwater to fully marine (www.ukbap.org.uk/ukplans.aspx?id=42#8). The key characteristics of saline lagoons are that they are shallow, quiet water bodies, adjacent to the sea but sheltered from its direct effects. They exhibit great diversity of form (Barnes 1988; 1989a,b), ranging from fully natural water bodies enclosed by gravel or sandy barriers, or rock outcrops, through systems exhibiting varying degrees of human alteration, to wholly artificial water bodies impounded by human structures (Conlan *et al.* 1992). There is a broad geographical variation in their form, with rock basins dominant in western Scotland, natural bar-built lagoons in England, Wales, Orkney and Shetland, and artificial impoundments dominant in Northern Ireland (NIHAP 2003). They are categorised according to the mechanism of water exchange with the sea (Smith & Laffoley 1992; Downie 1996; Bamber *et al.* 2001).

Coastal Lagoons exhibit great diversity in substrate (bedrock, sand, gravel, mud), salinity, depth and stratification, and marginal habitats. They range in size from over 800 hectares (ha), such as the Loch of Stenness in Orkney, to less than 1 ha. They exchange water with the sea via seepage through barriers, overtopping, and direct discharge through permanent or temporary surface water connections that may be artificial or natural.

Depending on salinity, the dominant fringing vegetation type ranges from reeds (e.g. *Phragmites* species) to saltmarsh species (e.g. *Puccinellia maritima*). There is often a diverse submerged aquatic plant community as well, ranging from water lilies to seagrasses (e.g. *Ruppia maritima*); macrophytes can root on lagoon floors because of low current speeds. The fauna tends to reflect the species pool in neighbouring waters (Bamber *et al.* 2001), but lagoon specialists can occur (Ivell 1979; Barnes 1989b).

11.2 Trends and Changes in Coastal Margins

Coastal Margin habitats are naturally dynamic, as are the coastal environments in which they sit. They have responded to climate change and long-term geomorphological trends as the coast has adjusted to the higher sea levels of the Holocene Period. Human influences, such as land-claim, harbour construction and the expansion of coastal towns, have also been shaping the coast for the last 2,000 years. Since the 1960s, protective legislation has reduced many of the direct human pressures on Coastal Margin habitats. However, important drivers of change remain, and some, such as climate change and sea-level rise, are expected to intensify significantly during the coming decades. The text here describes some of the drivers common to Coastal Margins as a whole, followed by habitat-specific sections detailing changes in extent and quality of habitats over time, and the drivers that influence these.

11.2.1 Sediment Supply

Sedimentary coastal habitats are built from a supply of mobile sediment of varying grain size (Chapter 12). The natural supply of sediment was much larger in the early Holocene when sea levels were rising rapidly, and the erosion and reworking of sediment was widespread (Hansom 2001). Under the more stable sea levels of the late Holocene this supply has declined. Cliff erosion is a locally important source of sediment, such as on the southern and eastern coasts between the Exe and the Tees, while elsewhere, reworking of existing sediments dominates. In the last century, sediment supply has declined dramatically due to cliff protection and other armouring of the shore (Clayton 1989; Dickson *et al.* 2007), while dredging for navigation has reconfigured many estuaries and has often led to the significant export of sediment via spoil disposal. An important indicator of sediment loss is the widespread occurrence of intertidal steepening in the UK, with low water marks migrating landward faster than high water marks (Taylor *et al.* 2004; Hansom 2010). The loss of sediment supply to beaches causes beach-lowering and frontal erosion, and reduces their protective function, allowing erosion and reworking of backshore sediments. For other sedimentary environments, these effects are less well quantified, but in qualitative terms, the loss of sediment supply will have similar effects, although compare with Nicholls *et al.* (2000).

Looking to the future, sea-level rise and climate change are expected to promote erosion and sediment reworking (Pye & Saye 2005). However, without new supplies of sediment, these changes are expected to be adverse and cause significant reconfiguration, relocation and decline of coastal sedimentary intertidal and supratidal habitats (Orford *et al.* 2007).

Coastal engineering often causes a decline in sediment supply, for example, due to cliff protection. However, it can also locally, and even regionally, cause large increases in supply as sediment is imported for beach nourishment (Hanson *et al.* 2002); the largest scheme to date is the Lincshore project which covers beaches from Mablethorpe to Skegness. The beneficial use of dredge spoil may see similar trends for finer-grained sediments. In future, the development of offshore renewable energy may also alter sediment supply. Hence, sediment supply is increasingly linked to certain policy drivers, such as shoreline management, described in Section 11.2.7.

11.2.2 Climate Change

Climate change will have a range of impacts on Coastal Margins, which are discussed by habitat in Section 11.2.8. Changing temperature and rainfall patterns may lead to shifts in distributions of coastal species (Harrison *et al.* 2001; Berry *et al.* 2005), with local extinctions of species that are unable to disperse to suitable habitat or compete with incoming species. Changing rainfall will have big impacts on water table dependent habitats. Changing storm climates will impact on the rate of erosion (Lozano *et al.* 2004), and on the quantity and frequency of sediment exchanges between habitats. Increasing storminess may deepen the wave-base, remobilising sediment previously out of circulation, and altering threshold-dependent processes such as sea-defence functions in saltmarsh (Möller *et al.* 1999; Möller 2006).

11.2.3 Sea-level Rise

Predicted rates of eustatic sea-level rise will greatly exceed isostatic readjustment on all UK coasts (**Box 11.1**) and will impact all Coastal Margin habitats. The most recent UKCP09 sea-level rise projections for the UK (Lowe *et al.* 2009) (incorporating the results of the Fourth IPCC Scientific Assessment) provide 'central estimate' increases in mean sea level by 2095 that range from 23.4 cm (Edinburgh, low emissions scenario) to 53.1 cm (London and Cardiff, high emissions scenario). A maximum increase of 1.9 m under a high plus emissions scenario is considered possible. Tide gauge trends over the last 15 years in Scotland suggest that present rates are now equivalent to the high plus emissions scenario of UKCP09 (Rennie & Hansom 2011). The UK NEA Scenarios analyses (Chapter 25) have also incorporated the effects of sea-level rise on different habitats, including Coastal Margins.

The main implications will be inundation of low-lying coastal areas and islands, accelerated erosion of beaches, dunes and soft cliffs exposed to significant wave action, more frequent coastal flooding and saline intrusion (both surface and sub-surface). Coastal squeeze will occur where natural habitats, such as dunes and saltmarshes, are constrained by steeply rising ground or coastal defences on their landward side, preventing natural landward translation (coastal plain or estuary 'rollover') (Pethick 2001; Halcrow 2002; Pye *et al.* 2007; Saye & Pye 2007). Sea-level rise will also cumulatively disengage the wave base from the seabed, so that waves impact with more of their energy (Angus *et al.* 2011). Therefore, sea-level rise will put increased pressure on the sea-defence role of Coastal Margin habitats, making careful consideration of shoreline planning essential.

11.2.4 Air Pollution

Atmospheric pollution from nitrogen, sulphur and ozone influences the vegetation and soils of Coastal Margin habitats. To date, their influence has generally been greater on southern and eastern UK coasts due to the location of pollution sources and the prevailing south-westerly winds. Sulphur deposition has declined dramatically since the 1970s (NEGTAP 2001; RoTAP 2011), but nitrogen deposition increased rapidly between 1940 and 1990 (Fowler *et al.* 2004), and remains high today (RoTAP 2011). Both nitrogen and sulphur contribute to soil acidification which negatively affects biological and conservation interest on acidic or weakly buffered soils, and has caused a decline in base-loving dune slack species in the Netherlands, for example (Sival & Strijkstra-Kalk 1999). However, soil acidification has limited influence on other ecosystem services.

In addition to its acidifying effect, nitrogen causes eutrophication, resulting in declines in species-richness and increasing rates of vegetation succession and soil development in dunes (Jones *et al.* 2004, 2008; Remke *et al.* 2009). Nitrogen deposition enhances productivity for

Box 11.1 Rates of sea-level rise and isostatic adjustment.

Analysis of sedimentary sea-level index points (Shennan *et al.* 2009) and results of geophysical modelling (Lambeck 1995) show that different parts of the UK have experienced very different sea-level histories during the Holocene, reflecting spatially varying patterns of isostatic and hydro-isostatic readjustment following melting of the last British ice sheet. At many locations, the tide gauge records indicate that high waters have been rising faster than low waters and mean sea level, with a resulting slight increase in tidal range (Woodworth *et al.* 1991; Pugh 2004).

Changes in the level and frequency of high waters are potentially of greater significance than changes in mean sea level, as it is extreme events that are mainly responsible for episodes of rapid coastal erosion, barrier-breaching and coastal flooding (Pye & Blott 2008, 2009).

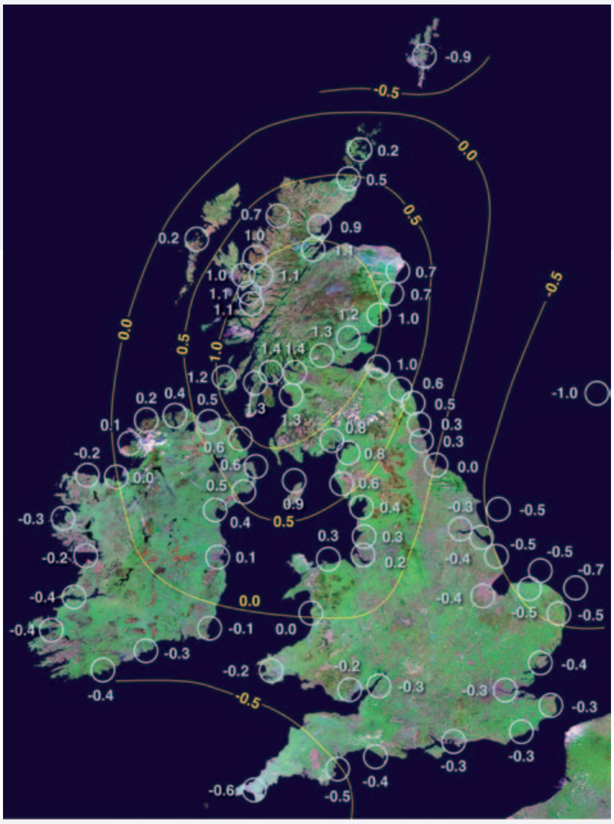


Table 1 Central estimates of relative sea-level changes (cm) with respect to 1990, under high, medium and low emissions scenarios. Source: extracted from Lowe *et al.* (2009).

	London			Cardiff		
Year	High	Medium	Low	High	Medium	Low
2000	3.5	3.9	2.5	3.5	2.9	2.5
2030	16.0	13.5	11.4	15.9	13.4	11.4
2060	31.4	26.3	22.2	31.4	26.3	22.2
2095	53.1	44.4	37.3	53.1	44.4	37.3
	Edinburgh			**Belfast**		
Year	High	Medium	Low	High	Medium	Low
2000	2.2	1.6	1.2	2.3	1.7	1.3
2030	10.7	8.2	6.1	11.1	8.6	6.6
2060	22.1	71.1	13.0	22.9	17.8	13.7
2095	39.2	30.5	23.4	40.3	31.6	24.5

marginal agriculture and contributes to ecosystem services which benefit from stabilisation, but acts to the detriment of services dependent on early successional systems which are particularly sensitive to eutrophication due to their nutrient- and organic-poor soils. Saltmarsh is highly productive but is still regarded as nitrogen-limited and, therefore, susceptible to the impacts of nitrogen deposition (van Wijnen & Bakker 1999), with similar effects on vegetation growth and rates of succession. Direct deposition of atmospheric nitrogen to Coastal Lagoons is low, but runoff, groundwater and surface waters contribute to eutrophication issues in both Coastal Lagoons and Saltmarsh. The eutrophication impacts of nitrogen may be lower where other nutrients, such as phosphorus, become limiting.

11.2.5 Tourism

Tourism is both a driver of change and a beneficiary of social, cultural and biodiversity services (Section 11.3.3). Almost all of the population of the UK lives within 100 km of the coast (Cooper 2009), so tourism has been a major driver of change at the coast. Tourism patterns and their impact have changed over the last 60 years. Resort tourism dominated from the 1940s to the 1960s (Walton 2000), resulting in high visitor pressure at relatively few coastal locations, primarily located near beaches. As long seaside holidays have declined due to increasing overseas travel (Cooper 1997; Williams & Shaw 1997), and car ownership has increased, coastal tourism is increasingly dominated by day trips (Williams & Shaw 2009), dispersing visitor pressure more widely along coasts within a few hours' drive of major urban areas. More recently, interest in nature- and outdoor-oriented attractions and specialist sports have further dispersed visitor pressure to more remote locations and a wider range of coastal habitats. At low to moderate levels, tourism benefits Coastal Margin economies. However, excessive tourism levels can put pressure on resources, such as water or waste treatment, increase land-claim for infrastructure development, damage sensitive ecosystems, cause pollution, and have adverse social impacts, particularly when tourist numbers are strongly seasonal or greatly exceed the local population. Current trends indicate that long-stays at the coast will remain static or decline slightly in the future, while day visits and short-stays will continue to increase (VisitWales 2008; Williams & Shaw 2009). Trends in tourism as a cultural ecosystem service are discussed in more detail in Section 11.3.4 and Chapter 16.

11.2.6 Coastal Development

Development pressure is high at the coast. Historically, land-claim, harbour construction and the expansion of coastal towns and infrastructure have all been taking place for the last 2,000 years, but have intensified greatly since the mid-19th Century (French 1997; May & Hansom 2003). Seaside resorts were the fastest growing British towns in the first half of the 19th Century, and their expansion for tourism continued until after the Second World War (WWII) (Walton 1983, 2000). Fourteen seaside resorts trebled their census population between 1881 and 1911 (Walton 1983), with further growth in many resorts between 1911 and 1951, bringing the resort population in England and Wales from 1.6 million in 1911 to nearly 2.5 million in 1951 (Walton 1997). Development pressures since 1945 have differed by habitat, with industrial and agricultural expansion the most common pressure on Saltmarsh, while housing and tourism infrastructure were the dominant pressure on Sand Dunes and Shingle (Section 11.2.8.1 and 11.2.8.4, respectively).

Demographics and residential preference also drive coastal development. There is strong net in-migration to coastal towns of people of working age and people choosing to retire by the sea (Beatty & Fothergill 2003; Chapter 3).

11.2.7 Policy Drivers

Policy influences all the major drivers affecting Coastal Margins. Devolution has resulted in different coastal policy approaches across the UK, although all are influenced by European legislation, such as the Habitats Directive, the Water Framework Directive and the Floods Directive, as well as the EU Recommendation on Integrated Coastal Zone Management (ICZM) (McKenna *et al.* 2008).

11.2.7.1 Sea defence and shoreline management planning

Historically, the response to flooding and erosion has been sea defence and coastal protection respectively. While these measures deal with the immediate and local problem, they often have adverse consequences down-drift, and into the future, as they may export problems of erosion and hence degrade natural defences. They may also reduce the natural capacity of the coast to respond to changing conditions.

The current policy for coastal management in England and Wales is based on Shoreline Management Plans (SMPs) (Leafe *et al.* 1998; MAFF *et al.* 1995; Defra 2006), with some limited application of SMPs in Scotland (Hansom *et al.* 2004). Northern Ireland lacks a strategic approach to shoreline management. The emphasis of SMPs is on reducing the risk of flood and coastal erosion through an integrated portfolio of measures which work more closely with natural processes and include a move from hard defences to soft protection, beach nourishment and managed realignment (Klein *et al.* 2001). With current knowledge there is a greater appreciation of the relationship between cliff erosion and sediment supply to beaches and intertidal zones, and, as a consequence, we have a better understanding of erosion and flood risk (Dawson *et al.* 2009). In particular, the English coastline currently has the greatest rates of relative sea-level rise in the UK, so initiatives in the last decade have moved away from simple cost-benefit considerations to a multi-criteria approach that takes account of environmental, social and technological elements.

Shoreline Management Plans take a strategic perspective over a 100-year timeframe. Essentially, they choose between four options:

- Advance the line
- Hold the line
- Managed realignment (adaptive management)
- No active intervention

The SMP process explicitly considers the full range of options, including managed realignment at sites that have previously been defended. Managed realignment is becoming a key tool in coastal management, providing sustainable flood risk management, potential long-term economic benefits and possible climate change mitigation (**Box 11.2**; Section 11.5.1.2). Addressing a series of 'epochs', SMPs may move from one policy to another over time in recognition of the fact that a particular policy may not be sustainable over the full 100-year period. Many plans currently adopt a 'hold the line' policy, which is due, in part, to the possibility of a managed realignment option being locally unpopular, but also suggests that the full economic and ecosystem benefits that can be obtained from managed realignment are not well appreciated or understood (Andrews *et al.* 2006; Turner *et al.* 2007).

Box 11.2 Alkborough Flats: a managed realignment case study highlighting multiple benefits across all ecosystem service categories. Source: Everard (2009).

Figure 1 Alkborough Flats. *Photo courtesy of M. Everard.*

Managed realignment was one of the options at Alkborough Flats (**Figure 1**) on the Humber, England, setting back the defence and allowing 400 hectares of 'reclaimed' arable land to flood and to form saltmarsh, mudflat, reedbed and other intertidal habitat. It addressed multiple objectives including reducing flood risk, as well as providing compensation for habitat lost elsewhere in the estuary. The Environment Agency case study sought to evaluate benefits across the full suite of ecosystem services in the Millennium Ecosystem Assessment classification (i.e. provisioning, regulating, cultural and supporting services; MA 2005).

The biggest surprise was evidence overturning an unstated assumption that 'provisioning services' were being traded-off to boost 'regulatory services' (particularly flood risk) and 'supporting services' (habitat for wildlife). The annual loss of food production (£28,075 calculated by the loss of arable production partly offset by livestock-grazing), was compensated by the higher value of fibre (£26,820 greater value from wool production relative to prior straw production) and the sale of rare breed genetic stock sheep and cattle (£3,000). The recruitment of fish of commercial and recreational importance was acknowledged as a research gap with potentially significant value.

Regulatory services were enhanced by an estimated annual value of £14,553 from carbon sequestration, in addition to a total flood risk management benefit (over 100 years) of £12.26 million. Research gaps thwarted valuation of the regulation of air quality, microclimate and erosion.

Enhancements to cultural services included an estimated £164,830 uplift to (formal) recreation and tourism, and £5,000 from protection of navigation. The supporting services were understandably harder to value, but included a significant annual benefit of £749,438 from habitat for wildlife and a further £8,160 estimated for enhanced primary productivity. Care was taken not to double-count services.

Cumulatively, and relative to the initial £10.2 million investment, the net lifetime benefit-to-cost ratio was 3.22. This confirms that ecosystem restoration, rather than technological solutions, can offer substantial value across the full range of ecosystem services. It also demonstrates that environmentally sensitive innovations can result in win-win solutions, and need not be a trade-off between benefit types and beneficiaries. The managed realignment scheme was officially opened in September 2006.

11.2.7.2 Conservation policy

Conservation policy affects the degree of statutory protection for coastal sites, how that protection is enforced and, at a local scale, how individual sites are managed. While the majority of large sites are protected under Special Area of Conservation (SAC) designations, a number only have Area/Site of Special Scientific Interest (ASSI/SSSI) or National Nature Reserve (NNR)/Local Nature Reserve (LNR) status, and, therefore, a lower level of legal protection. In terms of area protected, only around 20% of Sand Dunes and Machair, 50% of Saltmarsh and Coastal Lagoons, and 58% of Shingle are under SAC protection (calculated from area under SAC (JNCC 2007) and habitat area in **Table 11.2**). The statutory protection of sites of biological, geological or other interest (for example, Everard *et al.* 2010) has been a major factor in slowing land-claim or agricultural intensification of Coastal Margin habitats. At the regional scale, a smaller proportion of sites have statutory protection in Scotland and in Northern Ireland. Piecemeal development continues on unprotected sites, but even sites protected by SSSI status are not immune, for example, the sand dunes at Menie in Aberdeenshire, Scotland, partly within the Foveran Links SSSI, were recently purchased for golf and leisure development.

11.2.7.3 Coastal access

The length and accessibility of coastal paths is increasing all the time, but the issue in England and Wales of legal access to Coastal Margin habitats, many of which are in private ownership, remains. Scotland has its own access legislation which allows responsible public access to all land except Ministry of Defence land and private dwellings and their curtilages. Through its 'Enterprise Neptune' programme, the National Trust has acquired approximately one-third of the coast of England and Wales, and has been instrumental (often in partnership with local authorities) in developing coastal paths that allow people to view and experience these habitats without causing damage. A new legal right of access to all the coast of England has been created by the Marine and Coastal Access Act 2009, which will provide a linear route along the coast, with access from this route to the water or cliff edge. For the first time, this will allow people direct access to many coastal habitats that were previously forbidden lands. Saltmarshes have been excluded from the provisions of the Act, largely on the grounds of public health and safety.

11.2.7.4 The Coastal and Marine Access Act

Under this act, the Marine Management Organisation (MMO) was created. The MMO will prepare marine plans on behalf of the marine planning authorities in UK territorial waters, and be the regulator of most activities in the marine environment including new development. A number of the activities the MMO regulates have direct relevance to Coastal Margins, including coastal dredging, aggregate extraction and the laying of submarine cables. The MMO will also be a key advisor on marine issues to other bodies taking decisions affecting the marine area. The Act requires the designation of Marine Conservation Zones (MCZs) as part of a wider UK network of Marine Protected Areas (MPAs). Some MPAs will be based on existing national and international nature conservation designations such as SSSIs and Special Protection Areas (SPAs).

11.2.8 Overview of Trends and Changes in Coastal Margin Habitats

The Coastal Margin habitats described in this chapter (excluding Sea Cliffs) have declined in area by an estimated 16.8% over the last 60 years, mainly through development pressures for residential, tourism and industrial use, and agricultural intensification; habitat quality has also deteriorated (Williams 2006). **Table 11.2** summarises the areal extent and trends over the last 10 years for each habitat, and the changes in habitat quality. In the future, habitat loss due to coastal erosion, compounded by sea-level rise and reduced sediment supply, will increase, with a total loss of a further 8% of current habitat projected. These trends are discussed in detail for each habitat in Section 11.2.8.1 and 11.2.8.6. The trends in habitat area from 1945 to the present day, and future projections up to 2060 (estimated from the literature), are summarised in **Figure 11.3**.

11.2.8.1 Sand Dunes

In the UK there are more than 70,000 ha of Sand Dunes (excluding Machair), the greatest resource of which is in Scotland (**Table 11.2a**), and more than a fifth of which (around 15,000 ha) falls within protected SACs (**Table 11.2b**) (JNCC 2007). Although estimates differ depending on survey methodology and scope, it is thought that the UK has lost 30% of its dune area since 1900 (Delbaere 1998; **Figure 11.4a**). After the 1960s, the rate of loss slowed due to statutory protection of most of the larger, high quality sites. However, habitat loss or deterioration from development pressures, such as caravan parks, industry, residential homes and golf courses, will continue to occur on those sand dunes lacking full legal protection (Packham & Willis 1997). Sympathetic management of links golf courses where the dunes have SSSI status can benefit conservation (Simpson *et al.* 2001), but this is by no means the case at every site. Future losses

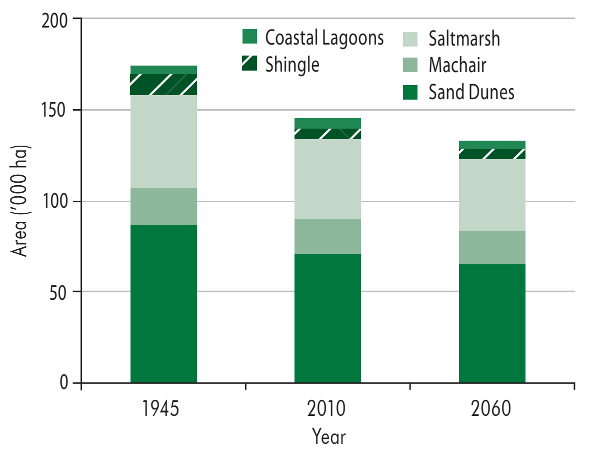


Figure 11.3 Past, present and projected future area of Coastal Margin habitats (excluding Sea Cliffs). Data sources discussed by habitat in Section 11.2.8. Estimated declines: 1945 to 2010 (16.8%); 2010 to 2060 (8.1%).

Table 11.2 Extent, trends and condition in Coastal Margin habitats. There remains considerable uncertainty about some of these estimates of area, primarily as most reporting focuses on sites with statutory protection (Special Area of Conservation, SAC; Site/Area of Special Scientific Interest, SSSI/ASSI) and ignores the smaller sites, but also due to the variety of habitat definitions and mapping protocols/techniques used. Two tables are shown: **a) Extent data deemed most reliable, together with reported trends.** Trends: = stable, ↓ weak decline, ↓↓ strong decline, ↔ trend equivocal, ? trend unknown. Source: JNCC (www.jncc.gov.uk), except Sand Dune and Machair for Scotland (Dargie 2000), Shingle and Sea Cliffs for Northern Ireland (NIEA; www.doeni.gov.uk/niea/). 'Sea Cliffs' are assumed to be comparable to JNCC habitat class 'Maritime Cliffs and Slopes', and 'Coastal Lagoons' comparable to JNCC 'Saline Lagoons'. Note: totals may not match sum of country estimates due to different update years. **b) Area and trends in area from Article 17 of the Habitat Directive reporting on habitats within SAC and SSSI.** Limited extrapolation to UK resources; UK-level data only. Trends: = stable, ↓ weak decline, ↓↓ strong decline, ↔ trend equivocal, ? trend unknown. Source: JNCC (2007). Current condition based on condition monitoring of SACs and SSSI/ASSIs, reported by Natura 2000 habitat types. Note, these are not easily summarised to Coastal Margin habitats for Sand Dunes or Saltmarsh. For an explanation of Natura 2000 codes, see JNCC (2007).

a)

	Sand Dune (ha) Good quality survey data, 1980s to 1990s, 2000		Machair (ha)		Saltmarsh (ha) Old survey data		Shingle (ha) Only vegetated shingle		Sea Cliffs (km) Incomplete data, 1990s		Coastal Lagoons (ha) Mostly recent data up to 2005	
England	11,897	↓	0	n/a	32,462	↓↓	5,023	↓	1,082	?	1,205	=
Northern Ireland	1,571	↓	0	n/a	250	=	50 n/a	n/a	500	?	42	=
Scotland	50,000	?	19,698	↔	6,000	↔	670	?	2,450	?	3,900	=
Wales	8,101	↓	0	n/a	5,800	↓	109	↓	522	↓	37	=
UK	71,569	?	19,698	↔	44,512	↓↓	5,852	?	4,554	?	5,184	=

b)

	Sand Dune (ha)*		Machair (ha)		Saltmarsh (ha)†		Shingle (ha)‡		Sea Cliffs (ha)¶		Coastal Lagoons (ha)	
Trend period	1950/1994–2006		1994–2006		1973/1987–1998/1999		1994–2006		1994–2006		1994–2006	
Area (ha) and trend	28,762	↔	13,300	=	31,805	↓ (1% p.a.)	5,160	↓ (1% p.a.)	22,000	=	5,480	=
Current condition of SACs which were assessed (% of those assessed), 1998–2006												
Unfavourable	66		70		57		76		50		7§	
Favourable	34		30		43		24		50		93§	
Current condition of strongly indicative SSSI/ASSIs (% of those assessed)												
Unfavourable	-		53		-		46		34		-	
Favourable	-		47		-		54		66		-	

* Covers Natura 2000 habitats: H2110, H2120, H2130, H2140, H2150, H2160, H2170, H2190, H2250. Current condition summarised for H2120, H2130, H2190 only (92% of UK resource).
† Covers Natura 2000 habitats: H1310, H1320, H1330, H1420. Current condition summarised for H1310, H1330 only (99% of UK resource).
‡ Covers Natura 2000 habitats: H1210, H1220. Current condition reported only for H1220.
¶ Area assumes 50 m width x 4,066 km length.
§ Trend period 1998–2005 only.

will also occur through sea-level rise and increased coastal erosion, which are predicted to contribute a further 2% loss in area between 1999 and 2020 at the UK scale (www.ukbap.org.uk/ukplans.aspx?ID=28). Impacts will vary by region depending on the rate of sea-level rise and local sediment supply, as well as exposure to storm wave activity (Saye & Pye 2007). Many large dune sites in England, Wales and Scotland have shown steepening of the beach profile over the last 100 years, which will cause further losses in area (May & Hansom 2003; Saye & Pye 2007).

The character of the UK's Sand Dunes has changed markedly over the last 60 years. In the mid-1940s, many UK dune systems had a high proportion of bare sand (Dargie 2000); for example, bare sand at Newborough Warren in Anglesey declined from 75% to just 6% today, which is a decrease of more than 90% of its original extent (Rhind *et al.* 2001, 2008; Jones *et al.* 2010a). Although successional development from bare sand to full vegetation cover and soil development is a natural process, its rate is slowed by disturbance (both natural and man-made), but hastened by artificial stabilisation, reduced sediment supply, eutrophication and climate change (Jones *et al.* 2004, 2008; Provoost *et al.* 2010). In a minority of sites, large-scale disturbance due to military activity during WWII (e.g. Braunton Burrows) or tourism pressure (Ranwell & Boar 1986) temporarily kept succession at bay. However, there has been a consistent trend towards increased vegetation cover and over-stabilisation in the UK, and across north-west Europe (Jones *et al.* 2010a; Provoost *et al.* 2010), resulting in the loss of specialised species (Howe *et al.* 2010) and loss of the dynamic and open character of dunescapes. A few sites have managed to buck this trend, and continue to show considerable mobility (e.g. Sands of Forvie, Scotland and Morfa Dyffryn, Wales), but this is mainly where sediment supply remains high.

Climate change may shift species distributions northwards, but this is unlikely to impact much on ecosystem service provision in the Coastal Margin habitat. However, future decreases in rainfall and altered seasonality of rainfall are predicted to lower dune water tables by up to 1 m by 2080 (Clarke & Sanitwong 2010). The associated drying out of dune slacks will result in a loss of many rare species, and may cause release of stored soil carbon due to faster decomposition. Furthermore, dune soils develop faster in the wetter regions of the UK, but warmer temperatures due to climate change may speed up soil development in other areas too (Sevink 1991; Jones *et al.* 2008), leading to successional change.

Invasive species, such as sea buckthorn (*Hippophae rhamnoides*) which is considered non-native around most of the UK, except in some sites in Lincolnshire and Norfolk where it is classed as native, and garden escapees, such as Japanse Rose (*Rosa rugosa*), can change the character of dune vegetation and significantly impact on native species, causing a decline in dune biodiversity (Binggeli *et al.* 1992; Edmondson 2009).

The intensity of grazing by managed stock and by natural grazers is important in governing the balance between stability and mobility, and therefore impacts on the ecosystem services provided. Since WWII, managed grazing of dunes has declined, particularly in the south and east (Section 11.3.1).

11.2.8.2 Machair

The world extent of Machair is about 30,000–40,000 ha, of which, around 67% is found in Scotland and 33% in the Republic of Ireland. The UK total is estimated at 19,698 ha (**Table 11.2**). Of the Scottish Machair, around 4,000 ha are covered by SAC protection and around 6,300 ha are SSSIs (Hansom & Angus 2001). In general, Machair sand budgets have been negative for a substantial period of time (Hansom 2010) and Machair erosion losses are not balanced by Machair gains. The most extensive Machair occur in the Uists, where the average recession rates over the past 100 years have been about 0.5 m per year: this represents a loss of 1.2 ha/km of coast over the period 1945 to 2010 (Hansom 2010). Over the past 15 years, rates of sea-level rise in the

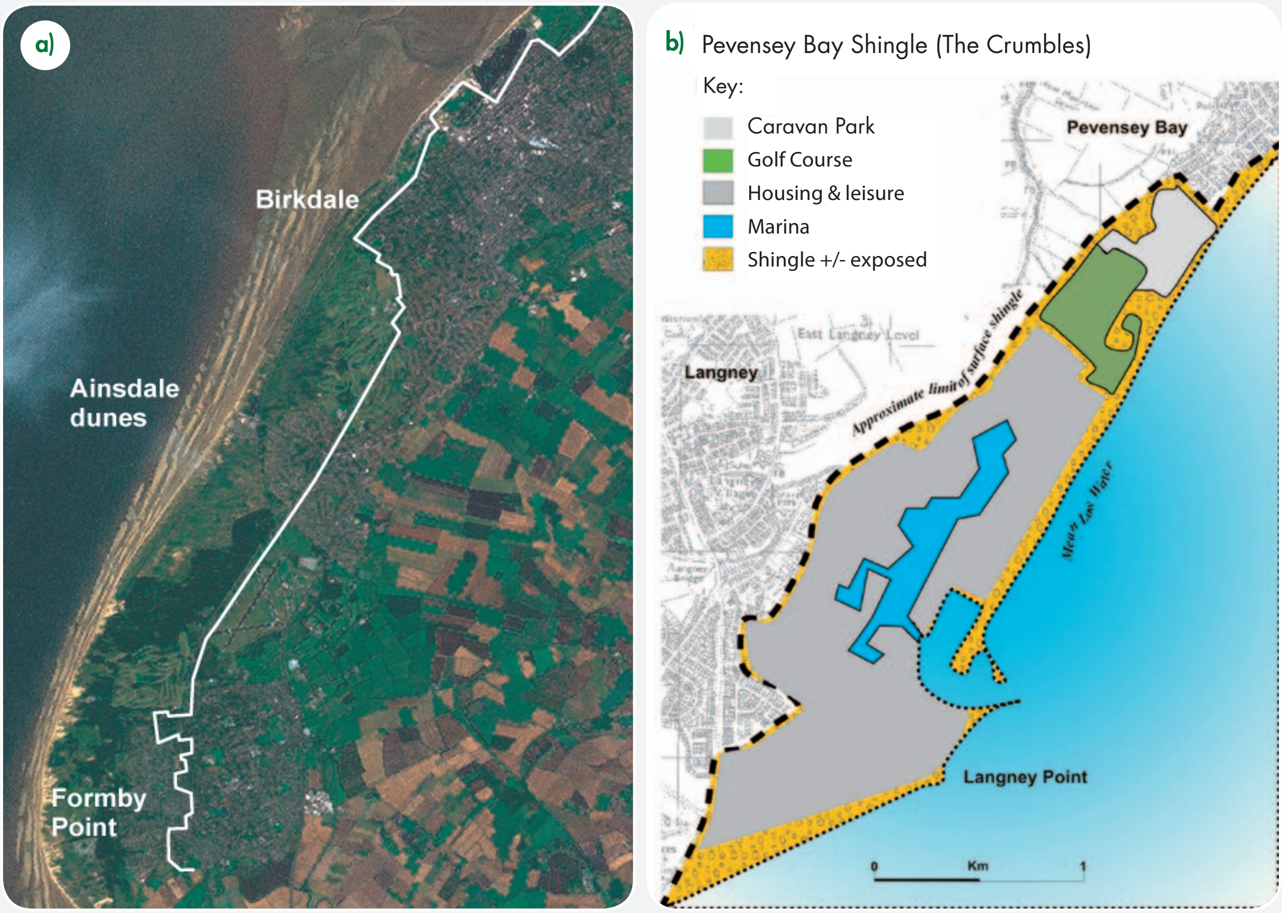


Figure 11.4 Examples of habitat loss: a) Sand Dunes on the Sefton coast, north-west England, lost to urbanisation, forestry and golf courses; and b) almost complete loss of Shingle due to development pressures at The Crumbles, East Sussex. The white line shows seaward limit of urban extent in 1945. Note the subsequent development at Ainsdale and Formby. Golf courses and afforestation of dunes pre-date 1945. Source: a) ArcGIS World Imagery Map: ESRI, i-cubed, USDA FSA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGP; urban extent courtesy of Sefton Borough Council. b) Map courtesy of J.P. Doody.

Western Isles have almost tripled from 2.2 mm/yr (before 1992) to 5.7 mm/yr. This is due to land subsidence (not emergence), faster global sea-level rise (Rennie & Hansom 2011), increased storm wave activity and reductions in sediment supply over the last century because of coastal steepening (Taylor *et al.* 2004; Hansom 2010). Therefore, it is likely that future losses will exceed the rates predicted elsewhere in UK: 6% over the next 60 years. Nevertheless, the likely extent of future Machair loss is unknown.

Given the remoteness of most Machair, development pressures are reduced, yet much of the transport infrastructure of the Scottish islands (roads, airports and bridges/causeways), military land and many crofting townships are located on Machair. There have been recent disputes over the extent of traditional grazing rights between Machair crofters and golf course developers in the Uists.

Changes in the character of Machair occur both naturally and through anthropogenic influences. Machair development relies upon exhumed and recycled sands eroded from older dunes or Machair, so ongoing aeolian activity is essential to the future health of the system. At present, aeolian erosion of Machair is minimal, and Machair surfaces are now more stable than they have been in the past (Angus & Elliott 1992). Machair supports much of the transport infrastructure in the outer Isles, so human responses to erosion events are a driver in themselves as decisions can often exacerbate erosion on site and/or export the erosion elsewhere.

Agricultural practices have changed over time in Machair areas; from the mid-1970s to 2009, there has been a 60% reduction in arable land use across five townships on the Uists and Benbecula, for instance. In Lewis and Harris, sheep have gradually replaced cattle over the past 50 years, with negative impacts on Machair biodiversity (Hansom & Angus 2001).

An additional grazing pressure on almost all the Machair islands comes from rabbits that were introduced in the Outer Hebrides in the late 18th Century and are now widespread. Their grazing pressure has resulted in problems in areas already heavily grazed by livestock. Although less evidence exists to fully determine the effects of burrowing and scraping, it is thought that these actions may initiate erosion (Angus & Elliott 1992) and that, combined with grazing, they may also lead to significant changes in vegetation (Dargie 2000).

11.2.8.3 Saltmarsh

Saltmarsh in the UK covers about 45,000 ha (**Table 11.2**), with the five largest sites (Wash, Inner Solway, Morecambe Bay, Burry Estuary, Dee Estuary) accounting for one-third of the UK total (Burd 1989). Approximately 22,000 ha are in SACs, and Common Standards Monitoring shows that 58% of saltmarsh features assessed are in favourable condition (JNCC 2007).

Prior to the 1980s, major losses of Saltmarsh occurred due to widespread, large-scale reclamation of land for agriculture or development (Morris *et al.* 2004). In the Wash, 3,000 ha of marsh were reclaimed in the 20th Century alone (Doody 2008). Extensive marshes once existed in the Forth Estuary but, over the last 4,000 years, some 50% of the former intertidal area has been claimed for agriculture and development, 33% of this decline occurring during the past 150 years (Hansom *et al.* 2001). Currently, major losses in Saltmarsh extent are occurring in the south-east of England. Between 1973 and 1998, over 1,000 ha were lost (Cooper *et al.* 2001). In the Solent the total Saltmarsh resource declined from 1,700 to 1,080 ha between the 1970s and 2001 (Baily & Pearson 2001), with further losses in Poole Harbour (Born 2005). Losses also occur due to erosion, which takes a number of different forms, but most commonly includes the landward retreat of the seaward edge, either as a cliff or steep 'ramp', or as an expanding internal dissection of the marsh by the widening creeks. Erosion predominantly affects lower marsh communities which are more vulnerable to wave action.

There have been some gains in Saltmarsh extent, particularly on the larger, west-coast marshes (e.g. the Dee, Ribble, Solway Firth and Morecambe Bay), which is largely accounted for by the expansion of lower marsh transitional plant communities over intertidal mud and sand flats, and by the expansion of common cord-grass (*Spartina anglica*). Managed realignment also contributes to new habitat creation; nonetheless, Saltmarsh losses continue to exceed gains (Rupp-Armstrong & Nicholls 2007) and estimates of net losses vary in range from 4.5% over 20 years (French 1997) up to 2% per year (Nottage & Robertson 2005).

The non-native common cord-grass is the result of hybridisation between an introduced American cord-grass and a native British species. It was extensively planted along British coasts to stabilise mudflats, but became invasive. The expansion of common cord-grass onto previously bare upper mudflats is considered to have negative impacts on shorebird and wildfowl feeding areas, benthic invertebrate habitat and seagrass (*Zostera* species) populations (Doody 1984). Common cord-grass has expanded onto beaches at Southport (Ribble Estuary) and Cleethorpes (Humber Estuary) causing possible changes in their amenity value. However, in some areas, dieback of common cord-grass has occurred for unknown reasons, preventing the need for artificial control; in the late 19th and early 20th Centuries, for example, widespread dieback occurred on many southern sites (Lacambra *et al.* 2004).

Wind-wave climate has the most influence on the horizontal extent of Saltmarshes, while relative sea-level rise has a major influence on their vertical growth and on their medium- and long-term evolution (Allen & Pye 1992). Evidence from Holocene sedimentary sequences suggests that vertical saltmarsh accretion is able to keep pace with projected rates of mean sea-level rise, with the essential sediment supply being provided by the accelerated erosion of soft cliffs, beaches and the seaward edge of the marshes themselves (Pye & French 1992). However, in some larger estuaries there may be insufficient sediment available to maintain the areas of saltmarshes and tidal flats at current levels and, particularly where saltmarshes are backed by embankments for coastal defence, they may suffer coastal squeeze. Even where accretion is able to keep pace with sea-level rise, the loss of fronting saltmarsh will lessen coastal defence services.

Agricultural operations may cause unfavourable Saltmarsh condition. Cessation of grazing or over-grazing can lead to a loss of biodiversity. Over-grazing may reduce the wave attenuation function, but it may also raise erosion thresholds through soil compaction—although there is little evidence on the impacts of grazing to date.

11.2.8.4 Shingle

Vegetated Shingle covers approximately 5,800 ha in the UK (**Table 11.2**), mostly in England. Of this total, 3,382 ha are in SACs (JNCC 2007). Areas of undisturbed Shingle have declined dramatically over time, but this is not well quantified. The principle pressures have been infrastructure development; for instance, during the 1980s, almost all of the 160 ha of Shingle at 'The Crumbles', East Sussex, were lost to housing, gravel extraction, caravan sites and a new marina (**Figure 11.4b**). Dungeness is the largest shingle structure in Great Britain, with 1,700 ha of exposed Shingle. Yet gravel extraction has taken place there since the 1940s, affecting some 40% of its surface (Fuller 1985), although there is currently minimal shingle extraction from the main shingle structures as they are now mostly designated as an SSSI. At Rye Harbour, East Sussex, most of the 375 ha of Shingle are damaged through gravel extraction and disturbance. Losses of Shingle landforms in England were predicted to total 200 ha (1.6%) between 1992 and 2010 (French 1997), but are yet to be verified.

Infrastructure development has been a major driver of change for Shingle, particularly for facilities requiring remote locations (such as those for military uses) or a nearby source of cooling water, such as nuclear power stations (such as those in Dungeness). However, these developments have largely ceased, and in the recent Department of Energy and Climate Change (DECC) consultation relating to the provision of new nuclear power stations, Dungeness is specifically excluded because its development would impact adversely on its internationally important nature conservation sites. On the other hand, there is a continuing threat to the site from an extension to Lydd airport. Orford Ness, another large Shingle structure on the south-east coast, is now owned and managed by the National Trust, so is unlikely to be damaged further by large infrastructure developments.

Climate is the major variable affecting community distribution and species range of Shingle vegetation (Farrell & Randall 1992); for example, Oysterplant (*Mertensia maritima*), which has a northern distribution, has disappeared from several more southern localities in the UK and Republic of Ireland due to the warming climate (Randall 2004). Because of the skeletal soils, high porosity and low water-retention of shingle, predicted reductions in summer precipitation in the south and east will have a negative effect on plant survival. Warmer temperatures also favour invasive species, especially garden escapees, which threaten many native species (Doody & Randall 2003a).

Disturbance, both natural and human-induced, affects Shingle vegetation. A few specialised plants are able to survive periodic movement of shingle beaches, but increasing storm frequency and intensity will destroy most vegetation. This will be particularly significant for mature, stable vegetation on stony banks as re-establishment takes a long time (although restoration is possible) (Walmsley & Davy 1997, 2001). On the most mature shingle structures, even relatively small incursions, such as those made into the surface layer by vehicles, may remain visible for many years. Regular disturbance as a result of re-profiling for sea defence has significant adverse effects on vegetation at some sites. For example, at Cuckmere Haven, Sussex, the western part is highly managed and devoid of vegetation, whereas the eastern side is unmanaged and, despite high visitor numbers, shows good vegetation cover (Smith 2009).

11.2.8.5 Sea Cliffs

Approximately 4,500 km of the UK's coastline has been classified as Sea Cliff (**Table 11.2**). The Joint Nature Conservation Committee (JNCC) estimates the area of cliffs as 22,000 ha, of which, 8,482 ha are in SACs (JNCC 2007). There has been no national survey of maritime cliffs and slopes in the UK, but 'desktop' inventories exist for England and Wales (Hill 2002; Tantram & Dargie 2005) and the Department of the Environment (DOE) in Northern Ireland has an online Maritime Cliffs and Slopes Habitat Action Plan (HAP). Without a national survey, it is not possible to provide a meaningful account of the status of this habitat, or discuss national trends in terms of its conservation value. However, unpublished evidence suggests that large stretches of maritime cliff vegetation are in sub-optimal condition, with coastal slopes dominated by rank, coarse grasses, bramble, bracken and scrub (Oates 1999). Traditional grazing of cliff slopes is now far less prevalent than it was in the late 1800s, but it is still practised on a local scale in places such as north and west Wales (Oates 1999).

According to the JNCC (2007), the main pressures affecting maritime cliffs are:

- Modification of cultivation practices
- Over- and under-grazing
- Abandonment of pastoral systems
- Urbanised areas (human habitation)
- Continuous urbanisation
- Walking
- Horse riding and non-motorised vehicles
- Air pollution
- Sea defence and coast protection works
- Erosion
- Invasion by unwanted species.

A major concern has been the loss of habitat due to agricultural encroachment, urban or industrial development, and holiday accommodation. In some places, cliff-top vegetation has been reduced to a narrow strip with most of the natural zonation destroyed. This prevents cliff-top biological communities from retreating in response to cliff erosion, subjecting them to a form of coastal squeeze.

Erosion is a highly significant factor in soft cliffs. However, this does not imply a loss of the cliff resource, either in geological or biological terms, as erosion is vital for constantly renewing geological exposures and recycling the botanical succession of this habitat.

Coastal protection systems have been built on many soft cliff coasts in order to slow or stop the rate of erosion, and thus protect capital assets behind the cliff line. Cliff faces may also be drained, re-profiled and sown with hardy grasses of little value for nature conservation. All such works have the effect of stabilising the cliff face, resulting in geological exposures being obscured, bare soil and early pioneer stages being progressively overgrown, and wet flushes drying out. Additional effects of defences include accelerated erosion and sediment starvation at coastal sites down-drift of defended sites. Taking into account cliff protection works over the past 100 years, it has been estimated that sediment inputs may have declined by as much as 50% (Clayton 1989). In 1994, a Ministry of Agriculture, Fisheries and Food (MAFF; now Defra) survey identified more than 90 km of new cliff protection works likely to be needed in the following ten years, which was estimated at the time to incur a 36% loss of the remaining soft cliff resource. The actual loss from these works has yet to be quantified.

In the traditional low-intensity grazing systems that prevailed before WWII, livestock were grazed on cliff grasslands where they maintained open, maritime grassland vegetation. But post-war intensification of agriculture has led to maritime grassland on more level terrain being ploughed out, while that on sloping ground has been abandoned and, where not maintained by exposure, is frequently overgrown by scrub. In addition, localised eutrophication can be caused by fertiliser runoff from arable land nearby.

The siting of holiday accommodation on cliff-tops not only reduces the landscape value of a site, but can also cause heavy, localised erosion and disturbance to nesting birds. A rise in the number of walkers and dogs along some coastal footpaths has increased livestock-worrying and forced a number of farmers to remove their stock from these sites. Consequently, some of the sites are now suffering from a lack of appropriate grazing, and scrub encroachment is likely to become a problem.

Predators, such as rats, can have a significant impact on populations of cliff- or burrow-nesting seabirds, particularly on island sites. The spread of alien, invasive plants, such as hottentot fig (*Carpobrotus edulis*), can have a devastating impact through smothering indigenous maritime plant communities.

11.2.8.6 Coastal Lagoons

Saline lagoon habitat has been reported in terms of the number of individual systems and the areal extent of the lagoonal habitat. Due to the ongoing debate on the classification of lagoons, these figures are subject to revision. **Table 11.2** gives the areal extent of lagoons as an estimated 5,184 ha, of which, around 2,600 ha are in SACs (JNCC 2007). Symes and Robertson (2004) present tabulated data on the numbers of saline lagoons in Great Britain broken down according to type and country. The lagoons of Northern Ireland have not been categorised, but are few in number. Lagoons were indicated in a 2005 Biodiversity Action Plan (BAP) report to be stable in all UK regions. However, earlier work by Bamber *et al.* (2001) estimated that some 30–40 lagoons were lost in England alone during the 1980s. In 1992, it was estimated that about 120 ha of Coastal Lagoons in England (10% of the existing English resource) would be lost over the subsequent 20 years, mainly as a consequence of sea-level rise (Smith & Laffoley 1992), with an estimate of net loss of 500 ha from SAC/SSSI/Ramsar sites in England and Wales over a 50 year period (Lee 2001).

Many lagoons have been altered by coastal defences or infilling associated with waterfront development, and this threat will continue. Lagoons are also created artificially and extensive human interference in their geomorphology is often advocated to maintain habitat (Symes & Robertson 2004). In addition to direct impacts on natural barriers, the interruption of sediment supply through coastal engineering works can cause changes in barrier morphology and sedimentology, altering porosity, inlet persistence and dimensions.

Saline lagoons with natural barriers are likely to migrate landwards with rising sea levels by barrier 'over-washing' and the transfer of sediment from the front to the rear of the barrier. Associated with this, the landward margins of the lagoon will be flooded, and the marginal habitats will migrate over terrestrial environments. The patterns of barrier evolution are highly site-specific and dependent on the rate of sea-level rise, sediment supply, transport modes (along-shore/cross-shore) and the surrounding topography. The various scenarios for barrier evolution are outlined by Carter *et al.* (1987). Barriers may breach, accrete, break down, or migrate, according to local circumstances. There are obvious differences in the responses of the back-barrier lagoon to each of these changes. Natural lagoons with rock sills are likely to experience increased saline influence with rising sea levels and a landward shift in the marginal habitats. Artificial lagoons, however, are entirely dependent on continued human intervention.

Geomorphological evolution of natural lagoons is often inhibited by infrastructure and human activities. Many are likely to experience coastal squeeze as a result of defences on their landward margins: the barrier migrates landward, but the lagoon margins are fixed. Conversely, artificial lagoon habitats are likely to be maintained and may even increase in area. In addition, managed realignment schemes in SMPs often include provision for the creation of new artificial lagoons, which is likely to increase the extent of such habitat.

Increased summer temperatures as a result of climate change may lead to an increased level of desiccation in the intertidal area, restricting the distribution of intertidal species (NIHAP 2003), and increased water temperatures may affect lagoon specialists with limited dispersal ability. Changes in the volume and timing of freshwater discharge due to climate change have the potential to alter lagoon salinity regimes. The salinity regimes of lagoons are subject to natural change as succession leads to freshening of the water and eventually to vegetation such as fen carr. Thus some formerly saline sites are now freshwater lagoons. In contrast, the regime of Porlock lagoon in Somerset is shifting in the opposite direction since artificial maintenance of the gravel barrier halted. Since a breach of the barrier in 1998, it has transformed into a more saline system (Orford *et al.* 2001; **Figure 11.5**).

Pollution, in particular nutrient enrichment leading to eutrophication, can have major detrimental effects on lagoons, including species loss, although studies in the Fleet lagoon in Dorset demonstrate that a distinctive ecosystem can be maintained under such conditions (Weber *et al.* 2006). Regulation of freshwater inputs and artificial manipulation of seawater input through inlet/outlet control can impact on salinity, residence time and water quality.

Johnson & Gilliland (2000) list the following impacts on water quality of saline lagoons:

- nutrient enrichment: including direct metabolic effects on species (for example foxtail stonewort (*Lamprothamnium papulosum*), which most frequently occurs at sites where soluble reactive phosphate is below 10 micrograms per litre; an increase in growth of epiphytic, floating, ephemeral, benthic and phytoplanktonic algae and associated competition with lagoonal vegetation of conservation interest; and indirect effects on lagoonal fauna;
- turbidity: including an increase in light attenuation and smothering, or inhibition of feeding of lagoonal invertebrates;
- toxic contamination: suggested contaminants of concern from studies outside lagoons include heavy metals, herbicides/pesticides and chronic oil pollution. These potentially impact on the suitability of lagoons as habitats, and the exploitation of their living resources;
- organic enrichment: likely to be of limited concern given that lagoonal sediments are naturally high in organic material.

Coastal defence policy affects natural and artificial lagoons both directly and indirectly. Holding the line will require that the elevation of the barrier be raised, while allowing the barrier to migrate will mean flooding of adjacent land or, if that is defended, a reduction in lagoon area. Holding the line in an adjacent coastal area can reduce the sediment supply to a lagoon barrier. The main policy driver for Coastal Lagoons is the Water Framework Directive which requires water bodies to achieve at least 'good' ecological status. Those Coastal Lagoons fronted by shingle or sand barriers are subject to the implications of SMPs that affect the barrier.

11.3 Ecosystem Goods and Services Provided by Coastal Margins for Human Well-being

Ecosystem services provided by the UK's Coastal Margins are many and varied (**Figure 11.6**), and have substantial value, being estimated at £48 billion (adjusted 2003 values—3.46%

Figure 11.5 Porlock in Somerset: a Shingle ridge breached in a storm (at point arrowed) has become a tidal inlet with the grazing land behind reverting to Saltmarsh (Doody & Randall 2003b). *Photo courtesy of J.P. Doody (September 2005).*

of UK Global National Income—by a study which applied the ecosystem service economic values of Constanza *et al.* (1997) to coastal biomes in Europe (COREPOINT 2007; Firn Crichton Roberts 2000). This section discusses the main goods and ecosystem services provided by the Coastal Margin, using the set of services and definitions of the UK NEA Conceptual Framework (Chapter 2). Goods and benefits provided by the identified 'Final Ecosystem Services' for each Coastal Margin habitat, and an indication of their importance, are summarised in **Table 11.3**.

Goods relating to *provisioning services* in the Coastal Margins are relatively minor; the most important are meat and wool from Saltmarsh, and timber from afforested Sand Dunes, while seaweed-gathering from the beach, used as fertiliser, and fodder crops are both locally important on Machair. Non-food provisioning services include the use of easily engineered flat land for development, the use of cooling water for nuclear power stations, and the use of land for military exercises.

Sea defence is the most important *regulating service*, with all habitats contributing either directly by energy absorption or dissipation, or indirectly through sediment supply. Goods and benefits linked to wild species diversity are very important in these habitats, particularly fish nursery

Figure 11.6 Some of the ecosystem services provided by Coastal Margin habitats. a) sea defence*, b) leisure and amenity¶, c) crops†, d) meat and wool*, e) biodiversity (puffin‡; orchid†; moth†), f) military use*, g) personal space*, h) industry use*, i) sense of place*, j) education* and k) health and recreation*. *Photos courtesy of J.P. Doody*; L. Jones† and P. Jones‡; photo used under Creative Commons from J.D. Champion¶.*

grounds in Saltmarsh, and ecological niche provision for birds in all habitats.

Goods and benefits relating to *cultural services* are very numerous in Coastal Margins, and are primarily linked to tourism and recreation, but also to cultural, social, historical, artistic, and physical and mental health benefits to society. The specific services and how they provide these goods, together with their interactions are described in Sections 11.3.1 to 11.3.5. The inter-relationships between services provided by Coastal Margins are shown in **Figure 11.7**, and the text describes how the goods and benefits listed in **Table 11.3** are derived from these services.

11.3.1 Provisioning Services

11.3.1.1 Production livestock

Provision of wool and meat from livestock-grazing (sheep and cattle) occurs on the older, well-established grasslands of Sand Dunes and Machair, on cliff-tops and on the higher elevation Saltmarsh grasslands where the soils are sufficiently developed to support richer vegetation. Productive Saltmarsh-grazing produces distinctive-tasting, specialist products, such as saltmarsh lamb and beef, which are sold at a premium: on average 100% more than mass-produced meat. An evaluation of the benefits arising from

Table 11.3 Goods and benefits provided by final ecosystem services from Coastal Margin habitats. ◉ denotes high, and ⊙ denotes some importance of each good/benefit; superscript numbers indicate which goods/benefits are relevant to each habitat; * denotes locally important; † denotes historical use; P = Provisioning service, R = Regulating service, C = Cultural service, S = Supporting service.

Service Group	Final ecosystem service	Goods/Benefits	Sand Dunes ‡	Machair ¶	Saltmarsh	Shingle §	Sea Cliffs **	Coastal Lagoons
P	Crops, plants, livestock, fish, etc. (wild and domesticated)	Crops: vegetables, cereals, animal feed	-	⊙	-	-	-	-
		Meat: sheep/cattle[1], rabbits[2†], fish/shellfish[3]	◉ 1, 2 *	◉ 1	◉ 1 *	-	⊙ 1 *	⊙ 3 *
		Wild food: Mushrooms[4], Salicornia[5], other plants/berries[6], fish/shellfish[7], wildfowl[8]	⊙ 4, 6	⊙ 4, 6, 7	⊙ 5, 6, 8	⊙ 6	⊙ 6	⊙ 7
		Wool: sheep	⊙ *	◉ *	⊙ *	-	-	-
		Genetic resources of rare breeds[9], crops[10]	⊙ 9	⊙ 9, 10	⊙ 9	-	⊙ 9 *	-
P	Trees, standing vegetation & peat/other resources	Reed/grass for thatching[†], mats & basket weaving[†]	⊙	⊙	-	-	-	⊙
		Timber for wood pulp, furniture	⊙ *	-	-	-	-	-
		Turf/peat cutting	-	⊙	⊙ *	-	-	-
		Seaweed gathering for fertiliser	-	⊙	-	-	-	-
		Extraction of sand[11], gravel[12]	⊙ 11	⊙ 11	-	⊙ 12	-	-
		Military use	⊙	⊙	⊙	-	⊙	-
		Industrial use: pipeline landfall/energy generation	⊙	⊙	⊙	-	-	-
R	Climate regulation	Carbon sequestration	⊙	⊙	⊙	⊙	⊙	⊙
P R	Water quantity	Water for irrigation, drinking	⊙ *	⊙ *	-	⊙ *	-	-
R	Hazard regulation—vegetation & other habitats	Sea defence	◉	◉	◉	◉	◉ Indirect	⊙
		Preventing soil erosion	-	-	-	-	⊙	-
R	Waste breakdown & detoxification	Immobilisation of pollutants	-	-	◉	-	-	⊙
P	Wild species diversity including microbes	High diversity, or rare/unique plants, animals and birds, insects	◉	◉	◉	◉	◉	⊙
		Ecosystem-specific protected areas	◉	⊙	◉	◉	◉	⊙
		Nursery grounds for fish	-	◉	◉	-	-	◉
R		Breeding, over-wintering, feeding grounds for birds	◉ *	◉	◉	◉	◉	⊙

Table 11.3 continued. Goods and benefits provided by final ecosystem services from Coastal Margin habitats. ⦿ denotes high, and ⊙ denotes some importance of each good/benefit; superscript numbers indicate which goods/benefits are relevant to each habitat; * denotes locally important; † denotes historical use; P = Provisioning service, R = Regulating service, C = Cultural service, S = Supporting service.

Service Group	Final ecosystem service	Goods/Benefits	Sand Dunes ǂ	Machair¶	Saltmarsh	Shingle§	Sea Cliffs**	Coastal Lagoons
R	Purification	Water filtration: groundwater[13], surface flow[14], seawater[15]	⊙ 13	⊙ 13, 14, 15	⊙ 14	⊙ 13		⊙ 14, 15
C	Environmental Settings: Religious/spiritual + Cultural heritage & media	Sites of religious/cultural significance; World Heritage Sites; folklore; TV & Radio programmes & Films	⊙	⦿	⊙	⊙	⦿	⊙
C	Environmental Settings: Aesthetic/inspirational	Paintings, sculpture, books	⦿	⊙	⦿	⦿	⦿	⊙
C	Environmental Settings: *Enfranchisement + Neighbourhood development*	Beach cleaning/litter picking	⊙	⊙	-	⊙	⊙	⊙
C	Environmental Settings: *Recreation/tourism*	Many opportunities for recreation: incl. sunbathing, walking, camping, boating, fishing, birdwatching etc.	⦿	⦿	⦿	⦿	⦿	⦿
C	Environmental Settings: *Physical/mental health + Security and freedom*	Opportunities for exercise, local meaningful space, wilderness, personal space	⦿	⦿	⊙	⦿	⦿	⊙
C	Environmental Settings: *Education/ ecological knowledge*	Resource for teaching, public information, scientific study	⦿	⦿ *	⦿	⊙	⦿	⊙

ǂ Includes sandy beaches; ¶Includes fringing beaches, dunes, machair lochs; §Includes shingle beaches; **Includes small islands.

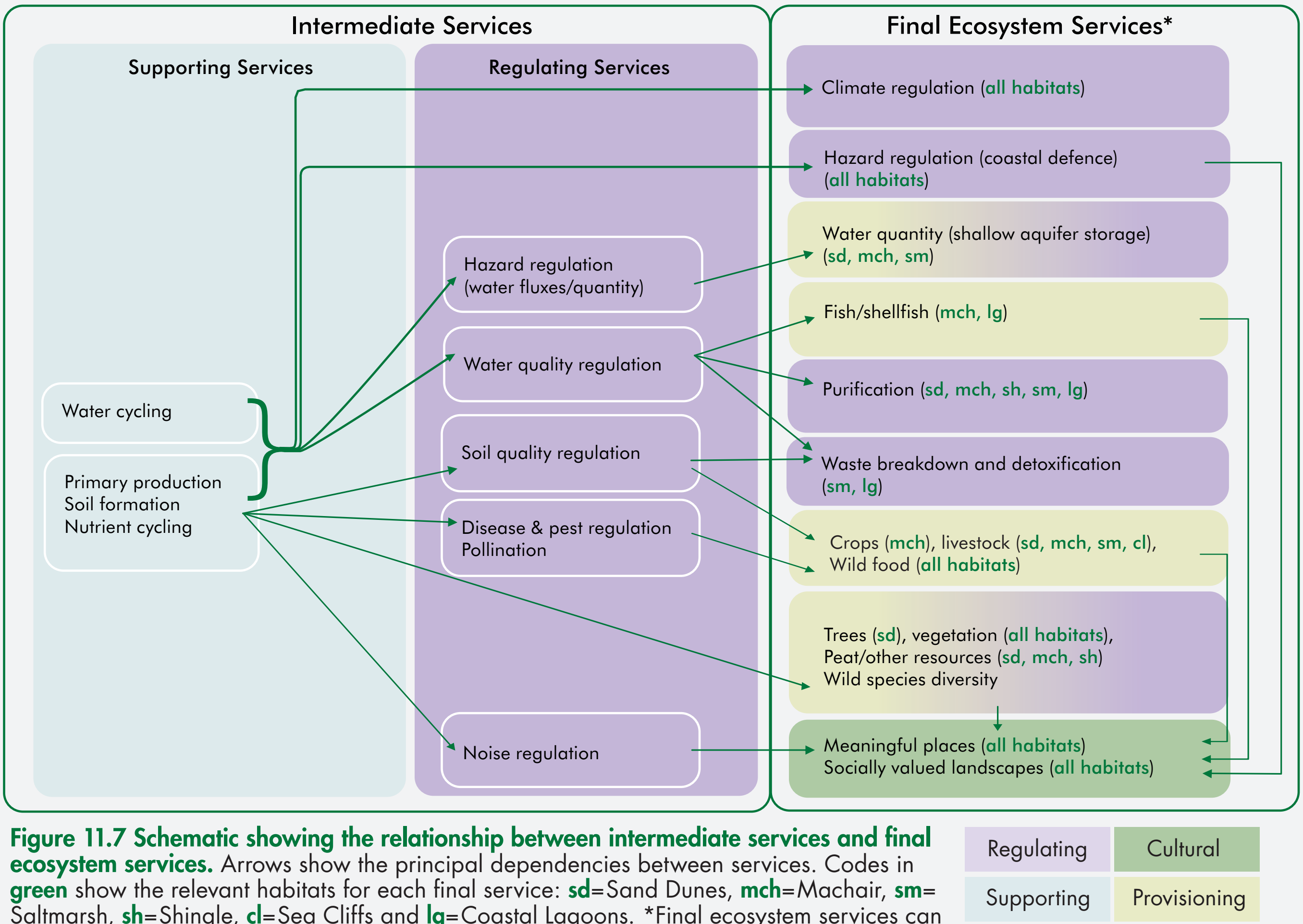


Figure 11.7 Schematic showing the relationship between intermediate services and final ecosystem services. Arrows show the principal dependencies between services. Codes in **green** show the relevant habitats for each final service: **sd**=Sand Dunes, **mch**=Machair, **sm**=Saltmarsh, **sh**=Shingle, **cl**=Sea Cliffs and **lg**=Coastal Lagoons. *Final ecosystem services can include those from the provisioning, regulating and cultural services.

the 440 ha Alkborough Flats Saltmarsh restoration project on the Humber estuary, England, estimated that an annual yield from sheep was £19,500 and from cattle was £21,000 (Everard 2009).

Apart from Saltmarsh, the herbage quality of Coastal Margin grasslands is poor, and most stock are hardy breeds or traditional varieties: cattle breeds include Welsh Black, Dexter, Galloway, Highland and North and South Devon; and sheep breeds include Herdwick, Scottish Blackface, Swaledale and White Welsh Mountain, as well as ancient breeds like Hebridean and Soay. Agricultural stock numbers on UK Sand Dunes have declined since 1945 and are now very low, with a rough estimate of 4,000 cattle and 13,000 sheep currently grazing this habitat (estimated from data in Boorman 1989; Boorman & Boorman 2001; Burton 2001), predominantly in north-west England (Burton 2001) and Scotland. In some Machair crofting townships, sheep and cattle are winter-grazed on the Machair grassland. This traditional cattle-based land management, which includes the growing of winter fodder on Machair during the summer, is an important element in maintaining the high biodiversity of Machair. Historically, cliff-tops were valued for summer grazing because grass under coastal bracken often remains green during hot dry spells and coastal slopes have a low incidence of sheep ticks. Today, rare breeds or hardy varieties of ponies, sheep and cattle are now used at many sites primarily for conservation grazing (Radley 1994; Oates *et al.* 1998) and have minimal direct agricultural value; however, preservation of their genetic diversity is an important service.

Crops. Of the Coastal Margin environments, Machair probably provides the most extensive and unique provisioning service in the UK in the form of crop production. In contrast to the acidic, poorly drained and hilly land of the west coast of Scotland and Ireland, the calcium-rich flatlands of Machair offer agricultural opportunities in an otherwise resource-poor periphery. In the past, the inland sectors of the dry Machair, and the seaward sectors of the wet Machair, were extensively cultivated. A traditional rotation involving two or more years fallow following cropping was used to produce black oats, rye and bere barley for animal feed; today, this practice is now largely restricted to the Uists.

Wild foods. A wide range of plant and animal species are gathered in small quantities for use as ‘wild food’ throughout the UK, but these have minor economic importance. They include mushrooms from Sand Dunes, wildfowl from Saltmarshes, miscellaneous edible plants and berries from all habitats, fish/shellfish from Coastal Lagoons, and small-scale, recreational (and commercial in Norfolk) harvesting of common samphire (*Salicornia* species) from Saltmarsh which is sold as a luxury item at around £3.50/kg. Saltmarshes are also important nursery grounds for commercial fish species (Section 11.3.3).

Household goods, building materials and fertilisers. Uses of plant material were historically important, but now have only minor economic importance. For instance, dune grasses such as Marram grass (*Ammophila arenaria*) and Lyme grass (*Leymus* species) were used in the past for animal bedding, thatching, and mat- and basket-weaving (Ranwell 1959; Jones *et al.* 1993; Angus 2001), while wave-torn tangle seaweed (*Laminaria hyperborea*) was, and is still, used as an organic fertiliser and sand-binding agent on Machair. In fact, the character of Machair occurs, in part, because of soil-improvement through the addition of seaweed as fertiliser, and because of shallow tilling for the small-scale cultivation of crops.

Other historical uses. Historically, the well-drained sandy soils of older Sand Dune grasslands were used for rabbit-warrening, grazing or were reclaimed for growing crops such as asparagus (Jones *et al.* 1993). Seabirds and their eggs were harvested from cliffs and islands, but this tradition has largely died out, except on Lewis in the Western Isles, as lifestyles have changed and protective legislation has come into force.

Aquifers. Provision of other resources dependent on Coastal Margin habitats includes coastal aquifers. Sand Dunes, Machair and Shingle with a reasonable depth or extent of substrate form a shallow aquifer of clean water, which is used for small-scale local abstraction such as golf course watering. In Shingle habitats, this often overlies saline water and fluctuates with the tide (Burnham & Cook 2001); Dungeness is the only Shingle site which provides a local source of drinking water.

Biochemical and pharmaceutical products. From a provisioning perspective, the flora of Coastal Margin habitats has some biochemical or pharmaceutical potential, for example, sea holly (*Eryngium maritimum*) is being investigated for its anti-inflammatory properties (Küpeli *et al.* 2006; Meot-Duros *et al.* 2008). The diversity, conservation interest and rarity of much of the UK’s coastal flora and fauna are of interest to many people, and, as such, our wildlife is a resource providing educational and cultural benefits; this is discussed further under Section 11.3.6.

11.3.1.2 Other provisioning services

The following provisioning services are also provided to some extent by the soft coastal habitats (Sand Dunes, Machair, Saltmarsh and Shingle), but are generally considered detrimental to the continued natural function of these habitats.

Afforestation. Uniquely among the Coastal Margin habitats, some Sand Dunes were afforested intermittently from the late 19th Century to the 1960s. Widespread planting occurred between 1922 and 1966, with approximately 8,000 ha (approximately 14% of UK dune area) now afforested (Doody 1989). During the 1940s, there was some clearance of sites, such as Ainsdale in Merseyside (Sturgess & Atkinson 1993), and there has been limited clear felling subsequently at a number of sites to restore functionality of dune processes, but further tree removal is unlikely to be undertaken at a large-scale. The timber produced from this afforestation is used for wood pulp and, after strengthening, furniture and construction. Afforestation also served a sand-stabilising function. However, on the relatively poor sand dune soils, timber is generally of low quality, and harvesting is currently not economically viable. Instead, recreational and amenity uses predominate.

Soil and aggregate removal. Turf-cutting is practised on Saltmarsh in north-west England. Aggregate extraction of sand from beaches and dunes for the glass industry, and from dunes and machair for local agricultural, horticultural and construction use (Jones *et al.* 1993; Radley 1994; Dargie 1995; Hansom & Comber 1996) has substantially declined. Aggregate extraction from Shingle has been considerable in the past (Fuller 1985) and has led to environmental degradation. Some benefits arise through the creation of new habitat, such as flight ponds for wildfowl, once extraction has ceased, but these are generally not considered sustainable practices.

Military use. There are also some industrial uses considered under provisioning services that are potentially reversible. The relative inaccessibility and uncompromising terrain of Sand Dunes, Machair, Saltmarsh and Sea Cliffs make these coastal habitats ideal for military activities including firing ranges and training (Radley 1994). Large-scale military use occurs on more than ten UK Sand Dune systems, most of which are under SAC protection (Doody 1989). Saltmarsh is used as 'over-shoot' protection areas for small arms fire or, when adjacent to tidal flats, on bombing ranges. Undulating Machair and Sand Dunes also lend themselves to military use, as occurs on South Uist (rocket range), Barry Buddon, Angus (military exercises) and at Balnakeil, Sutherland (air bombardment).

Energy production. In terms of energy needs, the development of oil and gas facilities and pipeline construction and their landfall at the coast have occurred in Sand Dunes (Ritchie & Gimingham 1989), such as at St Fergus in Aberdeenshire, Sinclairs Bay in Caithness, and Talacre in North Wales, and have also been built across Saltmarsh, such as at Morrich More in Ross-shire. Ready availability of cooling water and remote locations mean that nuclear power stations are also primarily sited on the coast.

Golf courses. Finally, golf courses are a largely non-reversible use, but sympathetic management can preserve stable dune communities (Simpson *et al.* 2001), albeit in a fragmented state, removed from most natural dune processes.

11.3.2 Regulating Services

11.3.2.1 Hazard regulation

Of the regulating services, hazard regulation is arguably the most important service provided by Coastal Margins; this includes protection from erosion, storm and wave damage and coastal flooding. **Table 11.4** shows the extent of the UK coastline affected by coastal erosion, ranging from 12% in Scotland to 30% in England. Coastal defence is provided by all the Coastal Margin habitats to a greater or lesser extent. In Saltmarsh, vegetation attenuates wave energy: pioneer Saltmarsh has been shown to reduce incident wave energy by 82%, compared with 29% over bare tidal flats (Möller *et al.* 1999). However, under storm conditions, it is likely that water depth thresholds exist that may lower the efficiency with which vegetated surfaces reduce wave energy (Möller *et al.* 1999). Under average tidal inundation depths, up to 50% of wave energy is dissipated in the first 10–20 m of a vegetated Saltmarsh surface (Möller 2006), while an 80 m strip can reduce the height of a seawall needed for landward defences from 12 m to only 3 m (King & Lester 1995). King and Lester (1995) estimated that an 80 m saltmarsh width results in capital cost savings of £2,600–4,600 per metre of seawall (1994 prices). More recent Environment Agency guideline average costs of building seawalls are £1,522 per metre (Environment Agency 2007); scaling this figure by coastline length of Saltmarsh, rather than area, gives a capital cost saving of £2.17 billion on sea defence for England. Beaumont *et al.* (2006), showed that scaling King & Lester values by Saltmarsh area give capital cost savings of £13–32 billion, and annual maintenance cost savings of £0.3 billion for sea defence in England. For areas such as Essex, where 431 km of seawalls provide coastal defence, fronting Saltmarsh helps maintain defence integrity along 70% (300 km) and provides huge cost savings (Lester & King 1995).

In contrast to Saltmarsh, Sand Dunes and Shingle provide direct protection, often replacing the need for artificial sea defence structures providing the dune or shingle system is wide enough, or the primary dune ridge is large enough. Sand and shingle beaches are dissipaters of energy, absorbing, rather than reflecting, wave attack. Shingle provides important natural defence structures, such as those at Chesil Beach, Hurst Spit and Pevensey in England, and at Spey Bay in Scotland. Many of these features are now maintained by artificial nourishment, re-shaping or recycling

Table 11.4 Summary of the length of UK coastline with erosion and protection. Source: Gatliff *et al.* (2010).

	Coast length*	Length of coast eroding		Coast length with defence works and artificial beaches	
Region	km	km	%	km	%
North-east England	297	80	26.9	111	37.4
North-west England	659	122	18.5	329	49.9
Yorkshire and Humber	361	203	56.2	156	43.2
East Midlands	234	21	9.0	234	100.0
East England	555	168	30.3	382	68.8
South-east England	788	244	31.0	429	54.4
South-west England	1,379	437	31.7	306	22.2
England	4,273	1,275	29.8	1,947	45.6
Northern Ireland	456	89	19.5	90	19.7
Wales	1,498	346	23.1	415	27.7
Scotland	11,154	1298	11.6	733	6.6
Northern Ireland	456	89	19.5	90	19.7
UK	17,381	3008	17.3	3,185	18.3

*Coastline length is highly dependent on the scale of the data from which it is measured. Therefore the length of coastline presented in this table differs from that in Chapter 12 due to the different techniques and sources on which these measurements are based.

to retain shingle in front of human assets; **Figure 11.8** gives a striking example of loss of this protective function. Sand Dunes provide a recognised sea defence function around the UK, particularly for residential areas, and for high quality farmland in north-west and eastern England and in north Wales (Everard *et al.* 2010). Vegetation cover and root mass bind the substrate, promote sand deposition and help build wider and higher dunes. Scaled by coastline length and accounting for costs of maintaining natural habitats (Environment Agency 2007), dunes and shingle are estimated to provide £0.52 billion and £0.79 billion sea defence value in England respectively. A more conservative estimate for dunes alone, taking into account only those dunes protecting high value land and those lacking any artificial defence structures (Pye *et al.* 2007), gives a sea defence value of £173.7 million in England and £54.2 million in Wales. With 'room to move' and adequate sediment, dunes and shingle 'roll-over' in response to sea-level rise, retaining a similar shape and therefore similar sea defence properties. This makes them an ideal and sustainable sea defence. Dynamic shingle beaches provide material for new ridges, which have the potential to build up along the shore and create new protective structures elsewhere. Sea Cliffs are, in themselves, a barrier to the sea, but they also support the sea defence role of down-drift Coastal Margin habitats, such as beaches and dunes, via the sediment they supply when they are allowed to erode naturally (Dickson *et al.* 2007; Dawson *et al.* 2009). Vegetation may alter the stability of slopes directly and indirectly through controls on water infiltration. The barriers which form Coastal Lagoons provide a buffer to wave action for the enclosed water body and surrounding environments and are, therefore, a natural sea defence. Additionally, in Machair, some brackish lagoons are connected to the land drainage system and perform a flood control function under normal conditions, but, conversely, may also exacerbate the area of impact of coastal flooding under extreme events. Including the lower and upper estimates for Sand Dunes and Saltmarsh, the sea defence value of soft coast habitats in England ranges from £3.1–£33.2 billion.

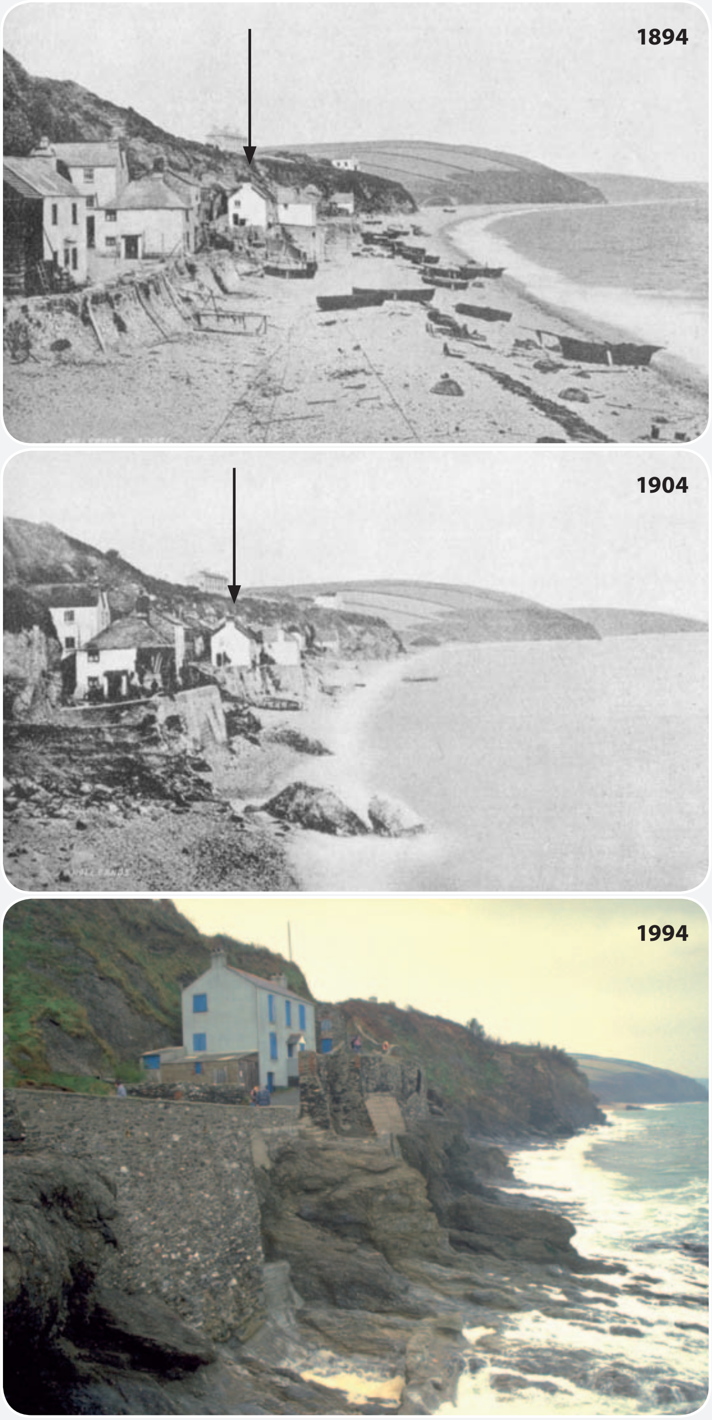


Figure 11.8 Disastrous consequences of losing a protective Shingle beach. Hallsands village, South Devon, in 1894—a postcard by Valentine and Sons. The beach protects the village from erosion. The loss of the beach followed shingle removal offshore. 1904—the village after a series of storms. The house indicated by the arrow was inhabited in 1994 when the third picture was taken. Today there is no public access to what remains of the houses for safety reasons. *Photos courtesy of J.P. Doody; www.hallsands.org.uk/*

11.3.2.2 Climate regulation

A degree of climate regulation is provided by those habitats where rapid soil development or sediment accumulation occurs (primarily Sand Dune, uncultivated Machair and Saltmarsh). Rates of carbon (C) sequestration are high in both dry dune (0.58 ±0.26 tonnes per hectare per year [t C/ha/yr]) and wet slack (0.73 ±0.22 t C/ha/yr) habitats (Jones *et al.* 2008) as they are early successional systems. Rates in uncultivated Machair may be similar to older dune grasslands, at the lower end of the range for dunes. Rates of carbon sequestration within UK Saltmarshes are even higher, storing 0.64–2.19 t C/ha/yr (Cannell *et al.* 1999). In accreting systems, Saltmarshes have the potential for long-term storage of carbon (Shepherd *et al.* 2007). These three habitats may also emit greenhouse gases to an unknown extent. In Saltmarsh, methane emissions are thought to be negligible due to sulphate inhibition of methanogenesis, but nitrous oxide emissions may be important (Andrews *et al.* 2006). In Coastal Lagoons, Mitchell *et al.* (2007) demonstrated the role of salinity stratification on the trapping of sediments at the muddy tidal limits of Pagham Harbour, Sussex. The net effect on climate regulation is likely to be beneficial; however, the contribution to climate regulation is probably small at the UK scale due to the low total area of these habitats. Coastal Margin vegetation and soils (to 15 cm) are estimated to hold at least 7.24 million tonnes of carbon (CEH unpublished), but this figure considerably underestimates the carbon storage component in Saltmarsh soils where soil depth remains largely unquantified.

11.3.2.3 Water quality regulation

This occurs through the purification of groundwater by Sand Dunes, Machair and Shingle, and the purification of surface waters by Saltmarsh and Coastal Lagoons. Sand Dunes are used for water purification in the Netherlands (van Dijk 1989), and similar natural filtration processes almost certainly remove nutrients from groundwater in the UK, thus reducing diffuse pollution to the marine environment; however, this is not well studied. Physical, chemical and biological processing in Saltmarsh (Andrews *et al.* 2006; Andrews *et al.* 2008; Boorman 2009) and saline Coastal Lagoons (Mitchell *et al.* 2007) removes nutrients from seawater, river water, groundwater and land-derived flows from agricultural land. Some lagoon systems (for example, the Fleet), have been overloaded with nutrients for some time (at least 140 years for nitrogen), but the ecosystem has adjusted to this eutrophic condition (Weber *et al.* 2006).

11.3.2.4 Soil quality regulation

This is provided by those habitats where soil development, and, therefore, the accumulation of soil organic matter, is rapid. However, since these are often dynamic environments, localised destruction of established soils also occurs. Where more fertile soils occur on Sand Dunes, Saltmarsh and Machair, they can support low intensity agriculture; today, this type of farming is often maintained by agri-environment schemes. Traditional mixed agriculture is possible on Machair by striking a fine balance between the rates of recycled sand deposition, the application of seaweed fertiliser and the cropping regime (Angus 2009). Cliff-top vegetation plays an important role in preventing surface soil erosion (Brenner-Guillermo 2007), and probably acts as a buffer in the prevention of erosion of adjacent agricultural land, especially where this inclines towards the sea.

11.3.2.5 Air quality regulation

Taller vegetation types scavenge more particulates and aerosols from the atmosphere than short vegetation, partly due to their greater leaf area index (Petroff *et al.* 2008); on a local scale, this acts to regulate and improve air quality. The Coastal Margin habitats are oligotrophic (nutrient-poor) and are generally a sink for ammonia (Loubet *et al.* 2009). However, agricultural stock grazing on Saltmarsh, Sand Dunes and Machair may be a low-level local source of ammonia, and some ammonia emissions may also occur from seaweed spreading on Machair.

11.3.2.6 Waste breakdown and detoxification

This service is primarily provided by Saltmarsh, where processes in the water column, sediment-trapping by vegetation and high rates of sediment accumulation all contribute to the immobilisation of heavy metals and other pollutants. This storage is not permanent and they can be remobilised as sediment is reworked, and may enter the food chain. In 54 ha of Saltmarsh in the Humber Estuary, 90 tonnes of zinc, 46 tonnes of lead, 16 tonnes of arsenic and 19 tonnes of copper have been recorded (Andrews *et al.* 2008).

11.3.2.7 Pollination, pest control, nursery grounds

Sand Dunes, Machair, Saltmarsh, Shingle and Sea Cliffs support a wide range of natural pollinators. Dunes and cliffs in particular support a high diversity of aculeate hymenoptera, including parasitoids (Whitehouse 2007; Howe *et al.* 2010). Together with ground predators, these may be of local importance in providing services of pollination and pest control to adjacent arable fields. However, the extent of these services is not well known and depends on the proximity of crop fields to these Coastal Margin habitats. Another biotic function which may be considered a regulating service is that of nursery grounds for fish species, provided by Coastal Lagoons with a good tidal exchange (Johnston & Gilliland 2000) and Saltmarsh, including managed realignment sites (Colclough *et al.* 2004). In a study on Essex Saltmarshes, commercially important species, such as herring (*Clupea harengus*) and sea bass (*Dicentrarchus labrax*), comprised 45.5% of the 14 species caught (Green *et al.* 2009). Lastly, certain characteristics of Coastal Margin habitats are key to their importance as breeding, feeding, migratory stopover sites or overwintering grounds for a wide range of bird species including wildfowl, several species of passerine and breeding shorebirds, seabirds and birds of prey. These characteristics include: relatively unimproved habitats; linear habitats with good connectivity which aids migrating species; frequent wetlands and damp pasture; bare, open ground for ground-nesting species; inaccessible rock ledges for cliff-nesting species; and islands uncolonised by ground predators. Machair, in particular, with its mosaic of crops, different stages of fallow and a lack of herbicides, provides a highly varied habitat for invertebrates and breeding birds.

11.3.2.8 Noise regulation

Direct regulation of noise pollution is provided by a varied topography, particularly in Sand Dunes and along coasts with Sea Cliffs. The exposure and subsequent high wind speeds in many of the habitats produce natural 'white noise' of wind over vegetation and the sound of the sea. These natural sounds are usually considered pleasant and contribute to the wilderness appeal of these habitats.

11.3.3 Cultural Services

11.3.4.1 Reasons for visiting the coast

A large part of the attraction to the coast hinges on its juxtaposition between land and sea. In the UK, human settlement is thought to have been based around the coastline, and the first Mesolithic peoples exploited the coastal environment for fish and shellfish (Gregory *et al.* 2005). Our view of the coast is shaped by history and cultural memories (explored in the television series 'Coast'), which are themselves partially dependent on other ecosystem services: provisioning (fish/shellfish, livestock/crops/wildfood, timber and biodiversity); and regulating (hazard/flood regulation, noise regulation). As an island nation, the coast has an important place in our national psyche—

negative associations include the threats of invasion, flooding and sea-level rise, while positive connotations include an empire based on naval strength, livelihoods such as fishing, and seaside holidays. The coast is highly valued by the public as: living space for coastal communities; a symbol of identity; a place for rest and relaxation; somewhere that provides a sense of freedom; a place where people can enjoy scenery and wildlife; and a site for specific activities including boating, swimming, walking, birdwatching, climbing and wildfowling (Ipsos Mori 2006). In 2005, there were around 250 million visits to the UK coast, of which, around one-third were to natural habitats such as beaches, sand dunes, shingle and cliffs (UKTS 2006; VisitBritain 2007). For 32% of visitors to the seaside in 2005, the key draw was sunbathing and paddling in the sea; eating and drinking came second by attracting 28% of visitors, and seaside towns and cities also drew 16% of visitors (VisitBritain 2007). Visitors to the Welsh seaside in 2006 were most interested in walking (69%), putting cultural and heritage interests second (32%) and shopping and entertainment third (25%), but closely followed by active land- and water-based sports (23%); wildlife-watching also attracted a number of visitors (5%) (VisitWales 2008). Tourists in Scotland rated seashores as representing the most freedom of use of all countryside destinations (TNS 2005); as a comparison, **Box 11.3** provides data on tourist-use of different coastal habitats in north Norfolk. The UK coast has many iconic landmarks, particularly related to Sea Cliffs, and is a focus for art, literature and creativity, for example, Anthony Gormley's sculptures in north-west England (**Figure 11.9**). Remote coastlines and islands have also been a focus for shrines, monastic settlements and holy sites for Christianity and earlier religions (e.g. Bardsey, Iona, Lindisfarne).

11.3.3.1 Economic value (and trends) in coastal tourism

Coastal areas generate substantial economic benefits. Pugh and Skinner (2002) valued coastal activities within the UK marine sector; most important was recreation and tourism: £19.2 billion, of which, seaside tourism revenue was £17 billion. In 2006, British residents took 27.1 million overnight seaside trips, of which, 22.5 million were holidays. The latter generated a tourism spend of £4.2 billion (£3.3 billion in England, £0.6 billion in Wales and £0.29 billion in Scotland). An additional 270 million day trips to the coast generated £3.1 billion in spending (www.britishresorts.

Box 11.3 Tourism case studies.

a) The Sefton Coast

The Sefton coast, north of Liverpool, has 4.5 million visits per year, generating £62.7 million towards the economy (Steward 2001). Of those visits, 26% came specifically to visit the beach. Information from a visitor survey at Ainsdale Sand Dunes National Nature Reserve (NNR) suggested that most people come to walk, relax and enjoy the scenery (one in five visitors mentions 'nature' as a reason for the visit). Annual visitor numbers at the principal Sand Dune nature reserves are 340,000 at Formby (National Trust), and 55,000 at Ainsdale Sand Dunes NNR.

b) Visitor spend on seabird-watching

Visitor spend was estimated at four Royal Society for the Protection of Birds (RSPB) seabird reserves around the UK (RSPB 2010; **Table 1**). Combined visitor numbers in 2009 at the four sites were 145,000, spending an estimated £1.2 million. The opportunity to watch seabirds was the main reason for visiting Bempton Cliffs, while it was just one of the reasons for visiting the other three sites.

Table 1 Visitor spend at seabird Royal Society for the Protection of Birds (RSPB) reserves around the UK. Source: RSPB (2010).

	Visitors in 2009	Estimated spend (£)
Bempton Cliffs, England	67,500	750,000
South Stack, Wales	44,000	223,000
Mull of Galloway, Scotland	19,000	126,000
Rathlin Island, Northern Ireland	14,500	115,000
Totals	**145,000**	**1,214,000**

c) The North Norfolk Coast

Holkham and Cley are coastal nature reserves forming part of the North Norfolk Coast SAC. Holkham is a wide sandy beach, fronting sand dunes and saltmarsh, receiving 500,000 visitors per year (English Nature 2003). Cley is a narrow, shingle beach, fronting saltmarsh and mudflats, receiving 25,000–100,000 visitors per year (Klein & Bateman 1998).

Visitor use and preferences were studied over 18 months by Coombes and Jones (2010). Dog walking was the predominant activity at these sites (**Table 2**), followed by walking. Birdwatching, relaxing/sunbathing and playing/paddling were minor activities. Remoteness was scored highly by all groups except those playing/paddling. Habitat preferences (Likert scores) were strongest for sand or sand dunes in all groups except birdwatchers who valued saltmarsh highest. At these sites, facilities such as tea rooms/large car parks were given low preference scores, although toilets scored slightly higher. All visitor activities were predicted to increase under climate change, despite beach fore-shortening under coastal erosion.

Table 2 Visitor use and preferences. Source: based on Coombes & Jones (2010). Copyright (2010) reproduced with permission from Elsevier.

	Dog walkers	Walkers	Bird watchers	Relaxing or sunbathing	Playing or paddling
Major activity	57%	22%	14%	6%	1%
Habitats most used	Dunes	Dunes	Sand/shingle	Sand/shingle	Sand/shingle
Mean Likert preference scores by habitat (highest in bold):					
Sand	**1.3**	**1.2**	0.8	**1.1**	**1.3**
Rocks/rock-pools	0.0	0.4	0.6	0.6	0.0
Sand dunes	**1.3**	**1.2**	1.1	1.0	1.0
Saltmarsh	0.6	0.4	**1.4**	0.3	0.1
Cliffs	0.1	0.6	0.7	0.2	0.4

co.uk/tourismfacts.aspx) (Cooper 2009). The coastal share of domestic tourism is greatest in Wales (43%), somewhat lower in England (24%), but very low in Scotland (13%) (UKTS 2009). In Wales, the overall economic impact of the coastal environment equated, in 2005, to nearly 100,000 direct and indirect jobs, nearly £5 billion per annum income to businesses, and a contribution of £1.5 billion to Wales' Gross Domestic Product (GDP; Valuing our Environment Partnership 2006).

Coastal tourism is highly significant in the more remote areas of the UK where it can form a major source of employment and economic activity. In the Western Isles, tourist activity is mainly coastal in distribution, and, between 1999 and 2002, saw a 9% growth in tourist numbers and a 20% growth in value to £40 million per annum (Macpherson Research 2003), much of this strongly biased towards ecotourism. This value had increased to around £50 million per annum by 2006 (Taylor *et al.* 2010).

Coastal tourism in the UK increased during the early 1800s, a trend which continued after 1945, and peaked in the 1970s (Walton 2000). Since that peak, the number of tourism bed-nights at the coast has declined consistently (**Figure 11.10**), reflecting national trends for the population increasingly taking their main holiday abroad (Cooper 1997; Williams & Shaw 1997), but also reflecting the decline in the seaside share of domestic tourism in favour of cities and large towns (Williams & Shaw 2009). The downward trend in long stays is consistent in all regions (**Figure 11.11a**), but is not the whole picture, and is partially offset by an increase in short stays and day visits (**Figure 11.11b**), facilitated by rising private car ownership (Williams & Shaw 2009). In Wales, day visits increased from 1 million in 1993 to 2.2 million in 2006 (Welsh Assembly Government 2008). Long-term trends in tourism as a pressure are discussed in Section 11.2.5.

The seaside still remains a more popular destination in the UK than the countryside/villages for overnight stays, both in number of visits and in expenditure: in 2009, 24% (worth £4.8 billion) of UK overnight tourism expenditure occurred at the seaside compared with 18% (worth £3.4 billion) at the countryside (UKTS 2009). The value of overnight stays (**Figure 11.11c**) shows a further offset in the decline as rising disposable income means greater spend per visit. The value of day visits to the GB seaside in 2002 (**Figure 11.11d**), was £3.1 billion (GB Leisure Day Visits 2004). In England, seaside visits were worth £2.2 billion in 2005, and comprised 7% of the market share. This was roughly half the value of overnight stays and less than the value of visits to the countryside (worth £4 billion, 16% of market share) (VisitBritain 2007). However, people were prepared to travel for considerably longer on day trips to coastal areas, with a mean journey time of 3.4 hours to the seaside compared with 2 hours to the countryside (VisitBritain 2007). Although long-term trends in tourism patterns and spend are apparent, they are difficult to quantify. Since 2005, a consistent methodology has been applied through the United Kingdom Tourism Survey to estimate overnight stays, but no such survey exists to quantify day visits. Prior to 2005, sporadic data collection, changing survey methodologies and incomplete sampling across the UK preclude accurate quantification of national trends.

Figure 11.9 'Another Place' coastal art installation by Anthony Gormley. One hundred life-sized cast-iron figures exploring man's relationship with nature. Crosby Beach, north-west England, 2006. *Photo courtesy of L. Jones.*

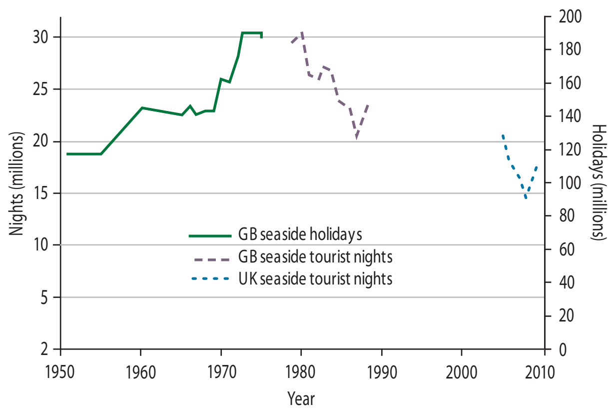


Figure 11.10 Coastal tourism, showing long-term trends in the number of seaside holidays (primary axis) in GB, 1951 to 1974*, seaside holiday nights (secondary axis) in GB, 1979 to 1988†, and UK, 2005 to 2009‡. Number of seaside holidays assumes seaside market share of 75% of GB main holidays in 1968 (British Travel Association 1968). Source: data from British National Travel Survey (1976), reported in Demetriadi (1997)*; Wales Tourist Board (1992), reported in Cooper (1997)†; UKTS (2009)‡.

Projections for coastal tourism are that long, main holidays by UK residents are likely to be static in volume or decline, but growth in short breaks and additional holiday markets will be sustained. Specialised activities for the elderly, the active and environmentally aware are likely to increase (VisitWales 2008; Williams & Shaw 2009). Visitor numbers are likely to be higher in warmer summers under climate change, despite reductions in beach area due to sea-level rise (Coombes & Jones 2010).

In contrast to the trend of a general decline in overnight leisure visits to the coast, over the last decade, the demand for specialist activities that require specific habitats has increased. These include coastal hiking, birdwatching, whale-watching and extreme sports such as cliff-climbing, sand-yachting and coasteering (Mintel 2005, 2008). The biodiversity, landscapes and wildness of coastal habitats make them a focus for statutory protection as nature reserves, or for management by Non-governmental Organisations (NGOs) such as the National Trust, the Royal Society for the Protection of Birds (RSPB) and The Wildlife Trusts. There are five coastal National Parks and 26 coastal Areas of Outstanding Natural Beauty (AONBs) in England, Wales and Northern Ireland. England and Wales have 45 Heritage Coasts covering 1,500 km of coastline. The National Trust owns 900 km of coast in England, Wales and Northern Ireland. Scotland has 415 coastal SSSIs covering 290,000 ha and 33 NNRs covering 41,000 ha (Cooper 2009). These underline the importance that society attaches to coastal habitats and the biodiversity they support. The text below discusses specific habitat characteristics underlying the cultural services described above.

11.3.3.2 Sand Dunes

Everard *et al.* (2010) discuss in detail the ecosystem services provided by dunes. Sand Dunes are a very distinctive landscape, with some form of dunes backing many of the sandy beaches in the UK. Dunes and beaches are a major part of the reason for visiting the coast, including seaside towns (VisitBritain 2007; Coombes & Jones 2010). The Sefton Coast, north of Liverpool, has 4.5 million visits per year, generating £62.7 million towards the economy (Steward 2001; **Box 11.3**). As well as tourism and leisure, the cultural services provided by dunes include archaeological (heritage) interest, aesthetic value and artistic inspiration (e.g. poems by Robert Frost and Carl Sandburg) (Everard *et al.* 2010). Dunes and sandy beaches also provide a wide range of amenity uses and activities including playing, paddling, sunbathing, walking, dog walking, cycling, horse riding, athletics training, orienteering and nudism (VisitBritain 2007; VisitWales 2008; Coombes & Jones 2010; Everard *et al.* 2010). Dunes modified by afforestation or by golf courses can provide amenity and recreation of significant financial value. Golf courses in Scotland have an estimated gross value added (GVA) figure of £120 million, but the proportion attributable to courses on dunes is not known. The unique biodiversity and ecology of dunes provides a focus for education (understanding succession theory, for example: Cowles 1899; Clements 1916; Connell & Slatyer 1977) and for encouraging membership of conservation organisations. Along with beaches, they are probably the semi-natural habitat directly experienced by the greatest number of people in the UK.

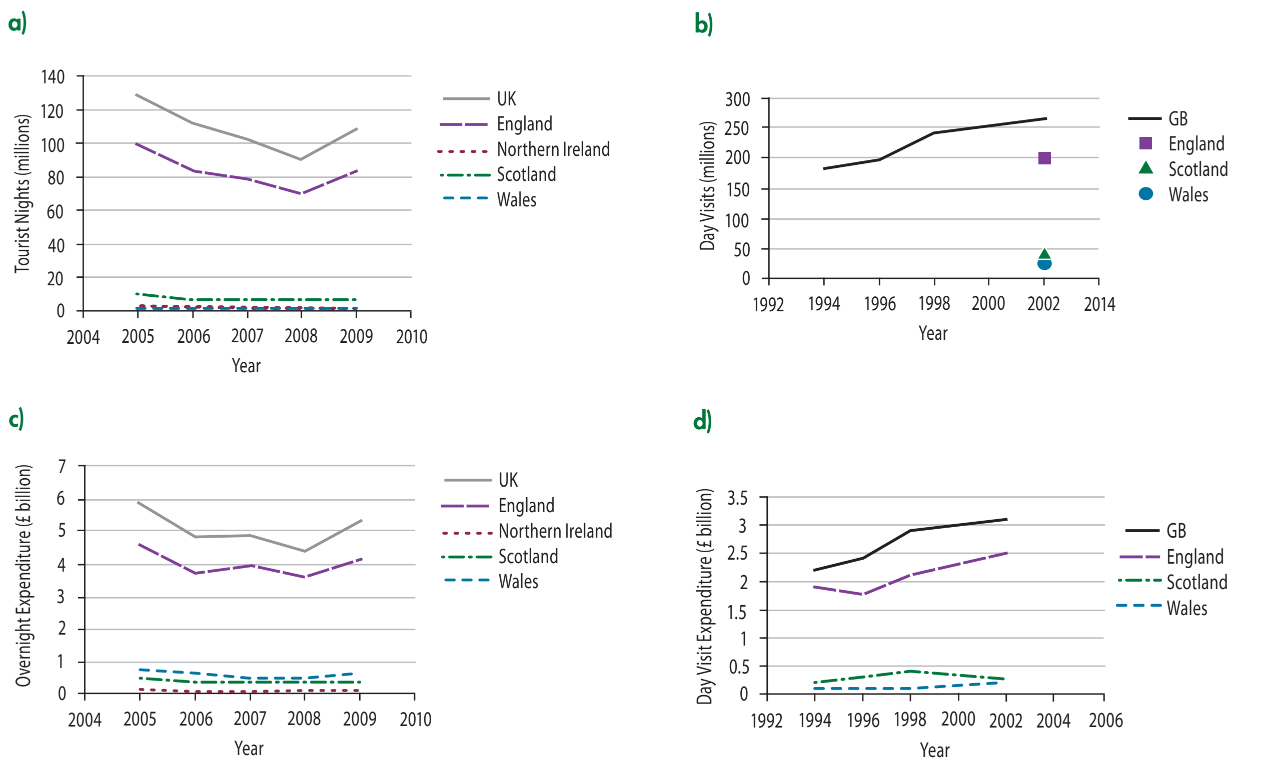


Figure 11.11 Coastal tourism, trends and value to the UK, showing: a) Seaside holiday nights (millions); b) Seaside day visits (millions); c) Overnight expenditure (£ billion); and d) Seaside day visits expenditure (£ billion). Source: data from a) UKTS (2009); b) GB Leisure Day Visits (2004); c) UKTS (2009) and d) GB Leisure Day Visits (2004).

11.3.3.3 Machair

The cultural services provided by Machair are extensive and deeply rooted within Gaelic culture. The flatlands of the sea remain interwoven within a storytelling and song tradition that extends back into legend (Angus 2001). Indeed, most modern and archaeological burial sites in the Western Isles are on Machair. Thus this 'wild' landscape has strong historical and cultural connotations for both communities and visitors because of the overpowering sense that Machair has been 'lived in'—shaped by past generations of Gaels whose traditions remain. There even exists a BBC ALBA television soap called Machair! Partly for these cultural reasons, and partly for the isolation and perceived emptiness of hectares of grass and meadow plants fronted by sweeps of brilliant white shell-sand beaches, coastal tourism is very important to Machair communities. Much of the ecotourism expansion of recent years is Machair-based, providing a wide range of amenity uses and activities including ornithology, walking, surfing, angling, cycling, horse riding, caravanning and wild camping. A few golf courses exist on Machair but these are neither extensive nor numerous.

11.3.3.4 Saltmarsh

Saltmarshes are wild places, creating iconic landscapes depicted in art and literature. There is a long history of landscape art depicting saltmarshes, usually associated with wild geese and ducks and hunting; some of the most famous examples are by Sir Peter Scott. In literature, *The Snow Goose* by Paul Gallico was one of the most popular fiction/natural history crossover books of the last century, inspired by the Saltmarsh landscapes of south-east England.

Access to Saltmarsh is restricted in many places by coastal defences and/or adjacent agricultural land, with designated nature reserves receiving the majority of visitors. Visitors are generally dominated by those with natural history interest and remain near the landward edges of the habitat. The UK's estuaries (including mudflats; Chapter 12) are internationally important for their vast numbers of overwintering waterbirds (Cayford & Waters 1996; Rehfisch *et al.* 2003), attracted by a combination of productive wetlands and relatively mild winters. Many are designated SSSI/ASSI, SPA or Ramsar sites specifically for wildfowl. A new nature reserve created in 2002 provided public access to The Wash; it attracted more than 50,000 visits in its second year of opening, with visitors spending an estimated £500,000 locally on food and services (Manly 2004). Hunting wildfowl is a traditional sport, still practised on all the major Saltmarsh complexes in the UK. There may be adverse health implications of stored pollutants transferred via Saltmarsh food products, but this is not well studied.

11.3.3.5 Shingle

Shingle structures provide landscapes that reflect the power of the sea. Their dynamic nature can inspire wonder. They provide excellent examples of coastal processes and are often used for outdoor education. Shingle beaches also provide locations for sunbathing and recreational activities (Spurgeon 1999). Estimates of recreational value for Cley Marshes (a site with shingle, saltmarsh and mudflats) ranged from £40,000–£480,000 per annum (Klein & Bateman 1998). Other recreational and cultural values include stark and remote coastal landscapes used in advertising, provision of access to the sea, areas for boat-mooring, and a local amenity for walking (Coates *et al.* 2001). Some areas are not only remote, but also have a significant historical value, e.g. Orford Ness due to its association with wartime activities, weapons testing and use of radar. Coastal gravel pits, once restored, can be important birdwatching areas; some also provide opportunities for sailing and windsurfing.

11.3.3.6 Sea Cliffs

In addition to having important value for nature conservation in their near natural state (Howe 2002; Whitehouse 2007; Howe *et al.* 2008), Sea Cliffs often have tremendous aesthetic (heritage) value, such as the iconic coastal 'cliffscapes' of The White Cliffs of Dover in England, Stockpole Head in Wales, the Old Man of Hoy in Scotland and the Giants Causeway in Northern Ireland. They are widely recognised for their geological or geomorphological interest and the majority are notified as geological SSSIs, with some having higher status as Geological Conservation Review (GCR) sites (May & Hansom 2003). However, their ecological importance, and in particular their invertebrate interest, is less well known. They support much of the length of the UK's numerous coastal paths and provide a human interest focus due to dramatic scenery and clear views. High seabird densities on cliffs and islands provide opportunities for birdwatching, with UK coasts supporting around 8 million breeding seabirds every year (RSPB 2010). Visitor spend to watch seabirds on cliffs at four RSPB reserves was estimated at more than £1.2 million in 2009 (RSPB 2010; **Box 11.3**). Cliffs also facilitate specific activities such as whale-watching, walking, coasteering, climbing, and fossil collecting, particularly along the Jurassic Coast in Dorset and in north-east England; the East Devon and Dorset coast is, in fact, a World Heritage Site. In addition, the inaccessibility of most islands is a key part of their allure, and also their nature conservation potential since disturbance by humans is minimal.

11.3.3.7 Coastal Lagoons

Cultural services are provided through the aesthetic value of lagoons. There is a diverse range of contemporary recreational activities. In resort towns they are used as boating lakes and natural swimming pools, and can become intensively developed around their shorelines with waterfront properties, marinas, jetties and quays. Other lagoons are important for scientific research, education and activities such as birdwatching, wildfowling and fishing. Between 1997 and 2002, visitor numbers to the Porlock Visitor Centre averaged 40,000–50,000 per year (Jennings 2004); Abbotsbury Swannery (www.dorsetforyou.com/index.jsp?articleid=332842) attracted around 100,000 visitors per year between 1999 and 2002.

11.3.4 Supporting Services

Primary production, nutrient cycling and soil formation are inextricably linked. Together, they support the soil- and vegetation-mediated regulating and provisioning services. Water cycling, combined with the first three services, helps to maintain those regulating services involving water and the provisioning services which are dependent on water flows/quality/biota, as well as soils and vegetation. These supporting services are common to all UK NEA Broad Habitats and are discussed in Chapter 13. However, sediment supply and transport, discussed elsewhere in this chapter (Section 11.2.1), could also be considered a physical supporting service as it is fundamental to the existence of the Coastal Margin habitats and to the delivery of a wide range of ecosystem services.

Coastal Margins often provide supporting functions to other margin, marine or terrestrial habitats, or are supported by them. The fringing cordon of Sand Dunes provides coastal defence for Machair. Shingle is a significant part of the wider coastal ecosystem, providing the basis for services associated with Sand Dunes, Saltmarsh and Mudflats. Shingle can form the backbone of sand dune spits and bars, and provide shelter for lagoons and for the sedimentation of tidal mudflats and the growth of saltmarshes (**Figure 11.5**). Erosion of soft cliffs provides a source of sediment, maintaining other Coastal Margin habitats which are linked by sediment transport (Dawson *et al.* 2009). Sediment storage and transport occurs in both the marine and terrestrial zones, with the greatest exchange between beaches and adjacent dunes and shingle structures during storms. Saltmarsh provides nutrient and silica exchanges with the sea between the marsh itself and the water column, providing resources for primary production in nearshore communities (Boorman *et al.* 1996; Andrews *et al.* 2006; Struyf *et al.* 2006; Shepherd *et al.* 2007).

11.3.5 The Role of Wild Species Diversity

The Coastal Margin contains a very wide diversity of ecological niches (Howe 2002; Whitehouse 2007; Howe *et al.* 2008; Everard *et al.* 2010). The dynamic nature of these habitats means that they provide among the best examples of early successional environments in the UK. They support a wide range of highly specialised and distinctive species due to the harsh environmental gradients associated with their proximity to the sea (**Box 11.4**). Their general unsuitability for agricultural development means that they

Box 11.4 Wild species diversity in Coastal Margin habitats.

Sand Dunes
Sand Dune habitats in the UK support a wide range of species, including more than 680 Red Data Book or Nationally Rare/Scarce invertebrate species alone (Howe *et al.* 2010). These include the vernal sand-mining bee (*Colletes cunicularius*), dune tiger beetle (*Cicindela maritima*) and various spiders (e.g. wolf spider *Arctosa cinerea*) (Archer 1994; Houston 2008). Red Data Book vertebrate species include the natterjack toad (*Epidalea calamita*), and sand lizard (*Lacerta agilis*) (Brooks & Agate 2001; Denton *et al.* 2003). Plant species of conservation importance include fen orchid (*Liparis loeselii*) (Jones 1998) and the Annex II-listed liverwort *Petalophyllum ralfsii* (petalwort).

Machair
The following UK BAP priority species have significant populations on Machair: skylark (*Alauda arvensis*), corncrake (*Crex crex*), corn bunting (*Miliaria calandra*), the beetle *Protapion ryei*, great yellow bumble bee (*Bombus distinguendu*), northern colletes (*Colletes floralis*), slender naiad (*Najas flexilis*), and Shetland pondweed (*Potamogeton rutilus*).

Saltmarsh
The following UK BAP priority species have significant populations on Saltmarsh: the eyebright (*Euphrasia heslop-harrisonii*), ground beetles *Amara strenua* and *Anisodactylus poeciloides*, natterjack toad, narrow-mouth whorl snail (*Vertigo angustior*) and endemic sea-lavenders (*Limonium species*).

Shingle
Mobile and stable Shingle provides habitats for a unique and fascinating flora and invertebrate fauna. At least 11 shingle-specialist taxa occur in the UK, of which four are endemic (Shardlow 2001). Neon pictus, a rare spider, has only one site in the UK, which is on Shingle. Breeding terns, plovers and oystercatchers rely on bare shingle.

Sea Cliffs
Maritime cliffs and slopes support 26 priority species, with a further 59 priority species using the habitat (Simonson & Thomas 1999). Nine UK BAP priority invertebrates are restricted to, or strongly associated with, soft cliffs including Luccombe click beetle (*Anostirus castaneus*), large mason bee (*Osmia xanthomelana*), chalk carpet moth (*Scotopteryx bipunctaria*), and Glanville fritillary butterfly (*Melitaea cinxia*) (Whitehouse 2007). Around 8 million seabirds from 26 species, including gannets, terns, and puffins, breed in the UK. The UK and Ireland support 90% of the world's Manx shearwaters (*Puffinus puffinus*) and 68% of the world's northern gannets (*Morus bassanus*).

Coastal Lagoons
Lagoon specialists include lagoon cockle (*Cerastoderma glaucum*) (Ivell 1979) and the snail *Hydrobia/Ventrosia ventrosa*. Some 36 species (of algae, vascular plants, Cnidaria, Bryozoa, Polychaeta, Mollusca, Crustacea, Coleoptera, Diptera and birds) are particularly associated with saline lagoons. Of these, 25 rely entirely on lagoonal habitats, and 20 are Red Data Book listed (Barnes 1989b; Symes & Robertson 2004).

North Wales coast. *Photo courtesy of L Jones.*

form important refugium habitats for species lost from other lowland habitats. This biological diversity supports a number of services. Directly, these habitats supply wild food and commercially harvestable resources, and provide living space to charismatic species like puffins or orchids which are a strong focus for many cultural services and can provide significant economic value through visitor spend (RSPB 2010). Indirectly, they modify the ecosystem level processes underlying the regulating services including sea defence, pest control and pollination. Their biological diversity forms part of the reason why so much of the UK coastline is under statutory protection.

11.4 Trade-offs and Synergies Among Coastal Margins Goods and Ecosystem Services

A large proportion of the area of Coastal Margin habitats has SAC protection under the Habitats Directive, is protected within SSSIs, or comes under other designations such as AONBs. Therefore, protection and maintenance of the biodiversity, geomorphological interest and unspoilt character remain primary objectives. Evaluation of the likely synergies and trade-offs for Sand Dunes (**Table 11.5**) are typical for most of the Coastal Margin habitats and show the potential for clear synergies between different services, allowing the identification of 'win-win' combinations. Synergistic services are clearly linked to similar geomorphological and ecological processes, with disturbance and natural dynamics promoting one set of services, while natural and artificial stability promote another set. This dichotomy also defines the principal conflicts: in general, the disturbance resulting from natural processes provides the essential dynamics in a healthy system which is usually beneficial for biodiversity, but may place constraints on other services. Therefore, a balance is required, particularly if there is insufficient room to allow natural processes to operate, or where there is conflict with fixed assets or infrastructure such as ports. By contrast, some natural processes like succession also promote stability. The optimum balance between disturbance and stability differs according to the habitat characteristics and the requirements of society. Other conflicts occur between those services causing deterioration of other services, for example excessive water abstraction, or altered water quality; those services promoting single use of land versus multi-functional uses; and those services which enhance or maintain the coastal margin 'character' versus those which replace it with characteristics available elsewhere.

Timescales of use and extent of use are both relevant issues. For example, small-scale turf-cutting or aggregate extraction are damaging but may create new habitat in the long-term. Synergies are, therefore, complex, and depend on the intensity of use and the timescales over which benefits are assessed.

11.4.1 Sand Dunes

Table 11.5 lists the main trade-offs and synergies for dunes, with key points discussed here. Land uses which involve major change to the functioning of dunes, such as forestry, golf courses and sand extraction, are incompatible with maintaining a characteristic dune landscape, although some are more multi-functional than others.

Forestry on dunes increases carbon stocks in soils (Hill & Wallace 1989) and above-ground, but it reduces recharge to dune aquifers (Clarke & Sanitwong 2010), potentially threatening the conservation status of adjoining dune slack habitat. Forestry adds to amenity value by providing a diversity of possible activities, but these are generally forest-related and not specific to the Coastal Margin habitat. Forest replaces natural dune habitat, although a few dune rarities persist and can thrive in forest, for example, dune helleborine (*Epipactis leptochila* var. *dunensis*) in the plantation at Newborough Warren. However, the net effect of dune forestry on wild species diversity is negative. Invertebrate diversity at Newborough Warren is far higher in the dunes than in the forest. The dunes support around 80% of over 900 beetle species found within the SAC (Loxton 2010), despite covering a similar area to the plantation forest. Red squirrels (*Sciurus vulgaris*) have been re-introduced into the dune conifer plantation at Newborough Warren (Ogden *et al.* 2005), and there is a population in the dune plantations at Ainsdale and Formby on the Sefton coast. Interactions between dune (coniferous) forestry and dune habitats, and the relative proportions of each, remain contentious in the UK, particularly within the context of UK BAP targets to restore 1,000 ha of degraded dunes by 2010 and to create Atlantic Dune Woodland at two sites by 2015.

High groundwater levels are undesirable for golf and some golf courses abstract water for irrigation; however, if water tables are lowered, potential conflicts with dune slack biodiversity may arise. Replacement of natural dune habitat, fertilisation, minimising natural erosion processes and the control of rabbit populations on golf courses are all activities which occur to the detriment of most dune species, although sensitive management of the roughs can protect older dune habitats such as acid dune grassland and dune heath (Simpson *et al.* 2001) and can retain some open dunescapes (i.e. landscape as well as habitats).

Disturbance caused by military use interrupts soil carbon accumulation, but at low levels, disturbance benefits wild species diversity by promoting the area of early successional habitats (Baker 2001). The restricted public access on golf courses, industrial and military sites limits amenity-related cultural services.

Large-scale but largely non-destructive uses, such as grazing, water abstraction and amenity use, also impact on other services. Grazing prevents invasion of scrub and benefits plant diversity (van Dijk 1992; Plassmann *et al.* 2010), and, through small-scale disturbance, benefits some vertebrate, invertebrate and fungal diversity (Howe *et al.* 2010). Surprisingly, it has negative effects on a number of other services: stock are incompatible with forestry, golf and sand-extraction; the public are often fearful of large livestock, dogs can worry animals, and fencing hinders public access; and disturbance to soils disrupts carbon accumulation.

Over-abstraction of groundwater impacts on wild species diversity in dune slacks, and may reduce carbon accumulation rates which are faster in wet slacks than dry grassland (Jones *et al.* 2008). This may become more of an issue where water scarcity is increased due to climate change and rising demand.

Maintaining dunes as a coastal defence on all but the largest sites involves maintaining a continuous vegetated foredune ridge, which reduces wind speeds and sand supply to the rest of the dune system and promotes stabilisation. This benefits commercial grazing and carbon accumulation,

Table 11.5 Trade-offs and synergies for final ecosystem services in Sand Dunes. = No effect, - Minor negative or net negative if mixed, -- Strong negative, + Minor positive or net positive if mixed, ++ Strong positive, +/- Balanced positive/negative. Note: scores should not be summed due to potential double-counting across services. P=Provisioning service, R=Regulating service, C=Cultural service. Waste breakdown not relevant to dunes.

			P		P			R	P R	R	R	P R	R	C	C	
			Crops, plants, livestock, fish, etc. (wild and domesticated)		Trees, standing vegetation & peat			Climate regulation	Water quantity	Hazard regulation –vegetation & other habitats	Waste breakdown & detoxification	Wild species diversity including microbes	Purification	Environmental Settings: *Meaningful places inc. green & blue space*	Environmental Settings: *Socially valued landscapes and waterscapes*	
			Livestock related	Wild food	Forestry	Sand extraction	Military; pipelines								Golf courses	Other amenity activities
P	Crops, plants, livestock, fish, etc. (wild and domesticated)	Livestock related		=	-*	--	=	-	=	=		++	- †	- ‡	--	- ‡
		Wild food			±	--	=	=	=	=		++	=	+	=	+
P	Trees, standing vegetation & peat	Forestry				--	±¶	+	-	+		-	=	+	--	+
		Sand extraction					--	--	-	--		±§	=	-	--	--
		Military; pipelines						-	=	=		++	- †	-	--	-
R	Climate regulation								=	++		--	=	-	+	-
P R	Water quantity									=		=	+	=	±	=
R	Hazard regulation –vegetation & other habitats											-	=	±	++	±
R	Waste breakdown & detoxification															
P R	Wild species diversity including microbes												=	+	±	+
R	Purification													=	- †	=
C	Environmental Settings: *places (inc. green & blue space)*														- **	++
C	Environmental Settings: *landscapes and waterscapes*	Golf courses														- **
		Other amenity activities														

* Stock damage young trees; trees limit grazing; † Potential faecal/chemical contamination of water; ‡ People are afraid of stock, fences hinder access; ¶Woodland neutral for military use, but restricts pipeline laying; § Sand extraction removes habitat, but creates early successional habitat afterwards; ** Golf courses restrict access, management options and modify the natural dune landscape.

but is detrimental to wild species diversity. Where a continuous, high, frontal dune is not maintained, dunes still provide coastal defence, but this function may vary spatially and the level of protection is less predictable (Lee, 2001).

The interaction of amenity uses with other services depends on their intensity. At low intensity, most uses are compatible with other services, while at high intensity amenity uses can conflict with each other (e.g. horse riding and walking) and with other services. Limited disturbance may benefit wild species diversity in over-stabilised systems, but excessive disturbance disrupts carbon accumulation and wild species diversity, and may reduce the effectiveness of coastal defence since pressure is concentrated on particular areas such as beach access through the foredune (Doody 1989; Coombes & Jones 2010).

11.4.2 Machair

Many of the trade-offs and synergies that affect Sand Dunes also affect Machair. Services involving major land use change, such as golf courses and sand extraction, are incompatible with maintaining a characteristic Machair landscape and usage, although golf courses are more multi-functional than other uses. The few golf courses that exist on Machair (e.g. at Askernish, South Uist and Sanday, Orkney) tend to be managed in a traditional and conservation-friendly fashion, and promote the grazing of fairways by sheep (but not cattle). However, this has not prevented crofters viewing such developments as impinging on their rights of common grazing to deploy cattle onto the Machair, and has resulted in their mounting challenges to development. Limited military disturbance benefits wild species diversity (Baker 2001) in much the same way that cattle-grazing promotes disruption of the turf cover and favours biodiversity.

Removal of sand from Machair for local constructional activity also creates trade-offs. Importing sand from the mainland to the islands, or even to remoter parts of the mainland, is cost-prohibitive. But since the only source of economically viable construction sand is contained within the extensive Machair systems, this sand is viewed as an exploitable resource (Merritt & Cavill 1993). Machair habitat and species conservationists recognise the critically important role played by crofting in maintaining Machair biodiversity, and also that the skilled, active crofting that delivers biodiversity must be an integral part of a healthy socioeconomic system. Any blanket prohibition of sand removal threatens the viability of local building and so the viability of the crofting communities themselves.

Machair is part of a highly complex system of mutually supportive ecosystem services: readily available seaweed supplies both reverse nutrient deficiencies in the Machair soils and provide a contribution to coast protection, while still retaining the natural mobility of the system.

11.4.3 Saltmarsh

The intensity of grazing by livestock and other herbivores (such as migratory geese and brown hares) produces trade-offs between meat production, biodiversity, conservation, climate regulation and coastal defence. Grazing impacts on vegetation structure and species-composition, both directly through feeding, and indirectly through habitat modification as a result of trampling and soil compaction (Bos *et al.* 2005). Soil compaction impacts on processes relating to carbon cycling, some of which have conflicting implications for climate regulation. High intensity livestock-grazing reduces litter deposition, and organic matter returned as faeces rapidly decomposes; collectively, these factors depress carbon storage. On the other hand, the absence of grazing or low intensity grazing can lead to the domination of the plant community by productive grass species with decreased biodiversity value, faster decomposition rates and, therefore, lower carbon accumulation. Hence grazing intensity can be an effective regulator of biodiversity, with intermediate levels usually producing the most diverse assemblages and structure.

Vegetation structure also impacts on the ability of saltmarshes to trap sediment and, therefore, store nutrients and pollutants, and adjust to changing sea levels. Although saltmarsh width remains the most important variable, the potential for grazing to influence coastal protection is important. High intensity grazing reduces shore zonation, transforming plant communities with a variable structure into homogenous lawns dominated by short grass, which reduces the ability of the marsh to dissipate wave energy. Low grazing intensity increases vegetation patchiness and overall plant height, creating increasing wave friction. Saltmarsh biodiversity, coastal protection and climate regulatory services exist in trade-off against meat production. High diversity assemblages are often more productive, which would be expected to lead to greater below-ground biomass and carbon sequestration. Very low grazing pressure may, however, lead to higher biomass and the greatest wave attenuation.

There are trade-offs to be made between the protection of material assets and infrastructure on the coast and the services Saltmarshes provide. Assets worth about £120 billion are currently at risk from flooding and coastal erosion in England and Wales. The UK governmental budget for managing flood risk and coastal erosion for 2009–2010 is £800 million (Defra 2009).

11.4.4 Shingle

So long as the Shingle beach or structure has room to move, then the goods and services will remain largely unimpaired. However, sea defence requirements and shingle reprofiling may prevent this movement, resulting in a loss of natural values such as the "Annual vegetation of drift lines": a key element for designating Shingle SACs (JNCC 2007). Rising sea levels, increasing costs and a more enlightened approach to the value of the 'natural' environment for coastal defence are shifting this paradigm, and artificial coastal defences are no longer sacrosanct. This is important since there is currently a shortage of sediment in many coastal cells and an increasing risk of over-washing and breaching (Orford *et al.* 2001). As a result, other, more environmentally friendly, 'soft' approaches, such as beach nourishment, have less impact and may help create conditions for shingle beach vegetation to develop. However, this will require more sediment material, putting pressure on the diminishing supplies offshore and on land-based resources.

Solutions that are more radical can involve a trade-off between different habitats. At Cley, on the North Norfolk coast, reprofiling of a shingle ridge complex for sea defence purposes adversely affected shingle beach vegetation forming part of an SSSI and SAC. Following detailed appraisal of alternatives, a £7 million management scheme to create a new defence inland was dropped in favour of a modified scheme involving 'limited intervention'. This will result in the gradual reduction of grazing marsh and reedbed as the ridge moves landward. More frequent overtopping by the sea will help recreate saline lagoons, saltmarsh and shingle wash-over fans (www.eclife.naturalengland.org.uk/). This occurred despite reservations about the trade-off between maintenance costs (£20,000–£30,000 per annum) and an estimated loss in recreational value (£40,000–£120,000, assuming 25,000 visits per year) to a popular freshwater nature reserve (Klein & Bateman 1998).

There is also a significant trade-off with gravel extraction. This replaces stable and often undisturbed vegetated shingle ridges with areas of open water. Man-made gravel pits can develop a significant interest, especially for waterbirds, and some may become nature reserves in their own right. However, the new habitat and coastal bird populations that colonise these areas, and the opportunity for water-based sports activities, do not represent an acceptable trade-off for the loss of rare coastal vegetated Shingle from a nature conservation perspective.

At Dungeness, water abstraction has lowered the water table and saline intrusion threatens the water supply. This has resulted in changes in species composition of some of the low-lying fresh water 'open pits' of high nature conservation value. Reducing water abstraction in the face of rising sea levels may be required.

Walking with or without dogs is a significant activity affecting Shingle beaches (Coombes & Jones 2010). Often the crest of the beach is the most attractive. Unfortunately, it is here that some of the more important plants such as sea pea (*Lathyrus japonicus*), or lichens on Scottish gravel complexes, occur. Trampling causes significant disturbance, with the loss of sea pea in some areas. Trampling also affects ground-nesting terns and ringed plover (*Charadrius hiaticula*) on Shingle. In many places, especially on the east coast, nesting areas are roped-off to avoid such damage.

11.4.5 Sea Cliffs

The fundamental trade-offs occur between services requiring a stable coastline (agriculture, built infrastructure and, to a certain extent, amenity and recreation use of footpaths) and services requiring natural dynamics (erosion, sediment supply for natural coastal defence structures, biological diversity). Since Sea Cliffs are such a narrow, linear habitat, the greatest conflicts occur between services provided by cliffs and those provided by the adjacent non-cliff habitats—primarily agriculture, but some built infrastructure. Likewise, attempts to control cliff erosion affect sediment supply to other Coastal Margin habitats (Dawson *et al.* 2009), as well as negatively impacting the biodiversity and amenity services provided by cliffs themselves.

11.4.6 Coastal Lagoons

Because of their accessibility, Coastal Lagoons have historically experienced a range of demands on their ecosystem services. The fact that they still exist as functioning ecosystems indicates that some uses are compatible with a healthy ecosystem. Yet there are clearly other activities that are incompatible. The regulating service provided by lagoons for terrestrial pollutants compromises the lagoon ecosystem. The construction of dwellings and infrastructure adjacent to lagoons to take up their aesthetic services, damages those services themselves. In addition, there are potential conflicts between permanent developments and infrastructure sited adjacent to lagoons, and the ability of the lagoon to adapt to sea-level rise. Protection of these developments is often likely to be in conflict with the natural operation of the lagoon. Similarly, artificial regulation of water levels to prevent flooding of adjacent lands alters lagoon hydrography.

11.5 Options for Sustainable Management

11.5.1 Overview

In general, sustainable management should enhance or maintain the specific characteristics of the Coastal Margin habitat, rather than replicate services provided better elsewhere. It should also take into account the uniqueness and irreplaceability of services. The synergies and trade-offs show that win-win combinations of services can be achieved by identifying complementary services within the context of sustainable management of these largely natural systems. In this context, maximising economic value, or maximising diversity of service provision may not be appropriate. Two particular issues are pertinent to the sustainable management of coastal erosion and sea-level rise at all Coastal Margin habitats: sediment supply and managed realignment.

11.5.1.1 Sediment supply

Historically, sediment supply and sediment budgets have not been considered (Hansom 2001; Hansom & McGlashan 2004), or worse have been seen as a problem. However, the importance of the links between Coastal Margin habitats through sediment supply and transport are increasingly recognised. The principle of 'working with natural processes' in the EU recommendation on ICZM is fraught with problems due to different interpretations of the concept (Cooper & McKenna 2008). In the future, active sediment management is required within shoreline management planning. Sites with significant beach nourishment are already following this path using techniques like bypassing (Section 5.11.5.5) or re-nourishment, as are some estuaries, such as the Humber. In others, shoreline management planning will need to avoid interfering with natural sediment budgets. Due regard for sediment budgets needs to become universal to maximise the multiple benefits for all coastal habitats.

11.5.1.2 Managed realignment or roll-back

Managed realignment has primarily been applied to Saltmarshes; however, the principles are relevant to all the

Coastal Margin habitats, including Sea Cliffs and Coastal Lagoons (Lee, 2001). It has the potential to give them room to migrate inland with rising sea levels, and use their sea defence characteristics to reduce the cost of hard defences which can be set back behind the natural habitat if required. Although individual beneficiaries change, managed realignment is often a win-win situation if the wider set of ecosystem services are considered (**Box 11.2**). Managed realignment schemes in the Humber and Blackwater Estuaries pass the economic efficiency test, i.e. aggregate benefits outweigh the costs. However, sites or zones in which significant numbers of people, property and other cultural assets are potentially at risk present complex social decision-making contexts. In such circumstances, cost benefit analysis (CBA) will provide useful, but not necessarily decisive, information on trade-offs (Turner *et al.* 2007). The latest examples of managed realignment are multi-objective schemes developed in partnership with local organisations (www.abpmer.net/wallasea/). It is recognised that the land required for realignment must come from some other land use but, unless this occurs, the main loser will be the coastal habitats with their high biological diversity and high social and economic value.

11.5.2 Sand Dunes

While most large dune systems are designated SACs under the Habitats Directive, or are SSSIs, appropriate management may enhance both biodiversity and ecosystem services. Sympathetic management is particularly important for those sites lacking legal protection, where biodiversity may not be seen as a primary objective. Management for sea-level rise may include beach nourishment or roll-back options (Lee, 2001), and these requirements for sustainability need to be included in planning consents. Beach nourishment provides extra sediment to the system, bolstering the foredune and, therefore, coastal defence, and creating an element of sand mobility, providing new bare-sand habitat for early successional species. Allowing roll-back onto land purchased immediately inland of dune systems maintains dune area and the sea defence role of the dunes, and can create successionally young habitat. Passive roll-back measures would allow space for natural processes to create dune habitat over time, yet, given current climatic constraints (Jones *et al.* 2010a), natural processes are unlikely to achieve large-scale mobility. Therefore, active roll-back measures to restore or create dune habitat (for example, by topsoil inversion (Rhind *et al.* 2008; Jones *et al.* 2010b) or remobilisation schemes (Arens *et al.* 2004; Arens & Geelen 2006)) would be necessary. These measures will also benefit biodiversity in over-stabilised systems. Turf-cutting and dune slack reprofiling (Rhind *et al.* 2008) may protect biodiversity, and its related cultural services, against the drying out of dune slacks under climate change. This would not be necessary in a dynamic system where new slacks would form naturally, but intervention is required in over-stabilised systems.

With reference to **Table 11.5** showing trade-offs and synergies, maximising ecosystem services generally means avoiding large, single-use services, such as forestry and golf courses, and maximising the diversity of habitats. On the other hand, some services are scale-dependent and service provision is better within a larger area. Sea defence can be provided by a single foredune ridge, but the resilience of the system is improved if it is backed by a larger dune hinterland, providing a range of habitats for biodiversity, space for other ecosystem services and reducing the exposure of inland areas to coastal flooding (Everard *et al.* 2010).

The local meaningful value of dunes is largely independent of their character; generally, it is sudden change (such as forest felling or dune remobilisation) which affects this cultural service. Sustainable management needs to achieve buy-in for these activities through stakeholder involvement as part of the decision-making process.

11.5.3 Machair

Most Machair systems are designated SAC under the Habitats Directive, or are SSSI, and so, protection and maintenance of biodiversity and geomorphological interest remain primary conservation objectives. A conundrum facing managers of Machair is that any engineered protection measures to reduce frontal erosion of the coastal edge and conserve habitat, risks cutting-off the erosional recycling of sand that is the lifeblood of that habitat. The accepted position on coastal protection and resilience is that, if backed by a dune system larger than a single cordon, exposure of inland areas to coastal flooding is reduced. However, in many cases this grassland has a negative landward gradient and erosion of the frontal dune cordon can result in wave overtopping, accelerated frontal erosion and salinisation of the backslope habitat, with potential for lateral flooding of low-lying areas from a breach (Angus *et al.* 2011). Present management focuses on the hard protection of a few sites (e.g. Balivanich airport, short stretches of roadway), as well as allowing roll-back in undeveloped areas. Future options could include beach nourishment to allow sediment delivery while slowing erosion, although sourcing sufficient sand is an issue. Any roll-back on to land immediately inland of the Machair dune cordon systems would replace or stabilise the dune area lost to coastal erosion. Intervention to allow remobilisation of dune sand is not needed on the already highly dynamic Machair.

There is an intensity of integration between human activity, biodiversity and the natural heritage in Machair management, which is now rare in the UK; this positive interaction is not only pivotal to the international value of the habitat, but is critical to its future. Sustainable management of Machair landform and habitat depends on policies that acknowledge the wider sediment-machair system and fully embrace the socioeconomic and cultural dimension of Machair. As agriculture, economy and culture are inextricably interlinked with the landform and habitat of Machair itself, management strategies aimed at sustainable stewardship of the resource need to fully engage the people who live there.

Conservationists encourage the use of tangle seaweed as fertiliser on Machair crops in preference to artificial fertiliser, as it is believed that it promotes wider wild flower diversity in the crop. It is important to leave at least some seaweed on eroding coastlines to provide a binding agent and nutrients for strandline plant growth, and crofters recognise the importance of maintaining the dune cordon. Moreover, the role of tangle beds in wave energy reduction is now fully recognised to the extent that no application for commercial tangle-cutting to the west of the Uists is likely to obtain consent.

Most conservationists also recognise that even traditional agricultural management must be able to evolve, and some aspects of change might be damaging, but essential, if crofting is to continue in any meaningful way. This compromise results in the erection of buildings and the compartmentalisation of formerly open common land into fenced 'apportionments'. Without such compromises, it is possible that cattle-rearing could be reduced or even locally abandoned. Likewise, new, more economic technology has resulted in the increased use of local agricultural contractors for ploughing and harvesting, and the practical amalgamation of crop areas and entire crofts to ease management. Despite the legal constraint on the amalgamation of crofts (the croft will always be a discrete legal and land tenure unit), its physical boundaries will become difficult to identify on the ground due to such merged management (Angus 2009).

11.5.4 Saltmarsh

Saltmarsh area is declining: to maintain its 1992 extent, 2,240 ha of Saltmarsh need to be created between 1999 and 2015 in the UK, primarily through managed realignment. Broadly speaking, managed realignment schemes in the UK have shown that, with relatively minimal pre-treatment and/or management of the area, allowing tidal ingress through a simple, relatively small breach of the existing seawall onto low-lying agricultural land will quickly produce intertidal mudflats which are subsequently colonised by Saltmarsh plants (French *et al.* 2000; Wolters *et al.* 2005). Research into flood risk management benefits established the flood defence benefits of seawalls with an area of Saltmarsh in front to attenuate wave energy—if there was a wide Saltmarsh, seawalls could be lower (and therefore less expensive) than if there were no Saltmarsh (King & Lester 1995; Möller *et al.* 2001). Experience to date has shown that managed realignment sites are sinks of sediment and, given time and the appropriate elevation, recognisable plant, invertebrate and bird communities can develop (Garbutt *et al.* 2006), although these do not always match exactly the surrounding saltmarsh (Atkinson *et al.* 2004). Nonetheless, there is growing evidence that restored Saltmarsh can perform many of the ecosystem services provided by natural systems including coastal defence and the storage of pollutants. High intertidal parts of managed realignment sites have also been found to be important nursery areas for fish, and Colclough *et al.* (2004) give recommendations for the design of habitat creation and survey methods. Where Saltmarsh regenerates on former agricultural land, and where grazing is not introduced, there may be a transfer in services from provisioning services (e.g. farmed food and fibre), towards regulatory services (e.g. flood risk), supporting services (e.g. biodiversity) and cultural services (e.g. amenity). Cultural services, in particular, can benefit from this regeneration (**Box 11.2**).

11.5.5 Shingle

Maintaining natural dynamics where possible is key to the sustainable management of Shingle. Under 'natural' conditions, Shingle moves in response to sea-level change and storms. For example, between 1978 and 1991, the Shingle beach at Kessingland in Suffolk had migrated several kilometres to the north, covering a groyne field with sand and shingle (Rees 2005; **Figure 11.12**).

Adopting a flexible approach to managing Shingle beaches and structures is likely to be more sustainable and should enhance or maintain the specific characteristics of that habitat. Allowing the habitat to move inland in response to storms and, in the longer-term, sea-level rise, will be the best option. The replacement of some valuable habitats may occur, but others may develop in their place, helping to maintain the ecosystem services—as seen at Porlock on the north Somerset coast (Jennings *et al.* 1998; Doody & Randall 2003a,b; **Figure 11.5**).

Engineering approaches to coastal protection have been, and in many places still represent, the preferred solution to problems of flooding and erosion, especially where high quality agricultural land, life or property are threatened. In the south and south-east, the trend is for nourishment schemes involving Shingle bypassing (e.g. Shoreham harbour) and recycling (e.g. Dungeness). The Dungeness nuclear power stations initially required the annual transport of 30,000 m^3 of shingle (subsequently increased to 67,000 m^3) from east (down-drift) of the station to be inserted west (up-drift) of the station in order to maintain the coastal protection function of the fronting beaches (Hansom 1988; Doody 2001).

In recent years, there has been greater recognition of the value of Shingle habitats for landscape, nature conservation and recreation. This is reflected in a number of local authority and research initiatives. On the south coast, several projects seek to create a better understanding of the value of Shingle as a habitat for rare plants and animals, improving conservation measures. In Sussex, Shingle is one of the key habitats included in the Sussex Biodiversity Action Plan (www.biodiversitysussex.org/habitats/vegetated-shingle). In East Sussex, there is a Vegetated Shingle Management Plan (www.eastsussex.gov.uk/environment/conservation/shingleplants/download.htm), and the Channel Beaches at Risk programme (2003–2008) included Shingle beach management (www.geog.susx.ac.uk/BAR/home.html). Shingle vegetation can be successfully restored by appropriate conservation measures, as at Sizewell in Suffolk (Walmsley & Davy 1997, 2001). Opportunities exist even in built-up Shingle areas to highlight the importance of the Shingle habitat and to promote demonstration Shingle habitats in show-home gardens.

11.5.6 Sea Cliffs

Coastal soft cliffs are amongst the most natural habitats in the UK: on many sites, active human intervention or management is not required to maintain the habitat and species diversity. However, due to a lack of recognition for their nature conservation interest, much of the UK resource has been altered or lost behind coastal protection schemes, or degraded through inappropriate management of cliffs and slopes and their immediate surroundings.

The ecological and geomorphological benefits of soft cliffs are intrinsically linked to the rate of erosion. Armouring and stabilisation measures should, therefore, not be considered routine, and the nature conservation interest and sediment supply role of coastal soft cliffs must be

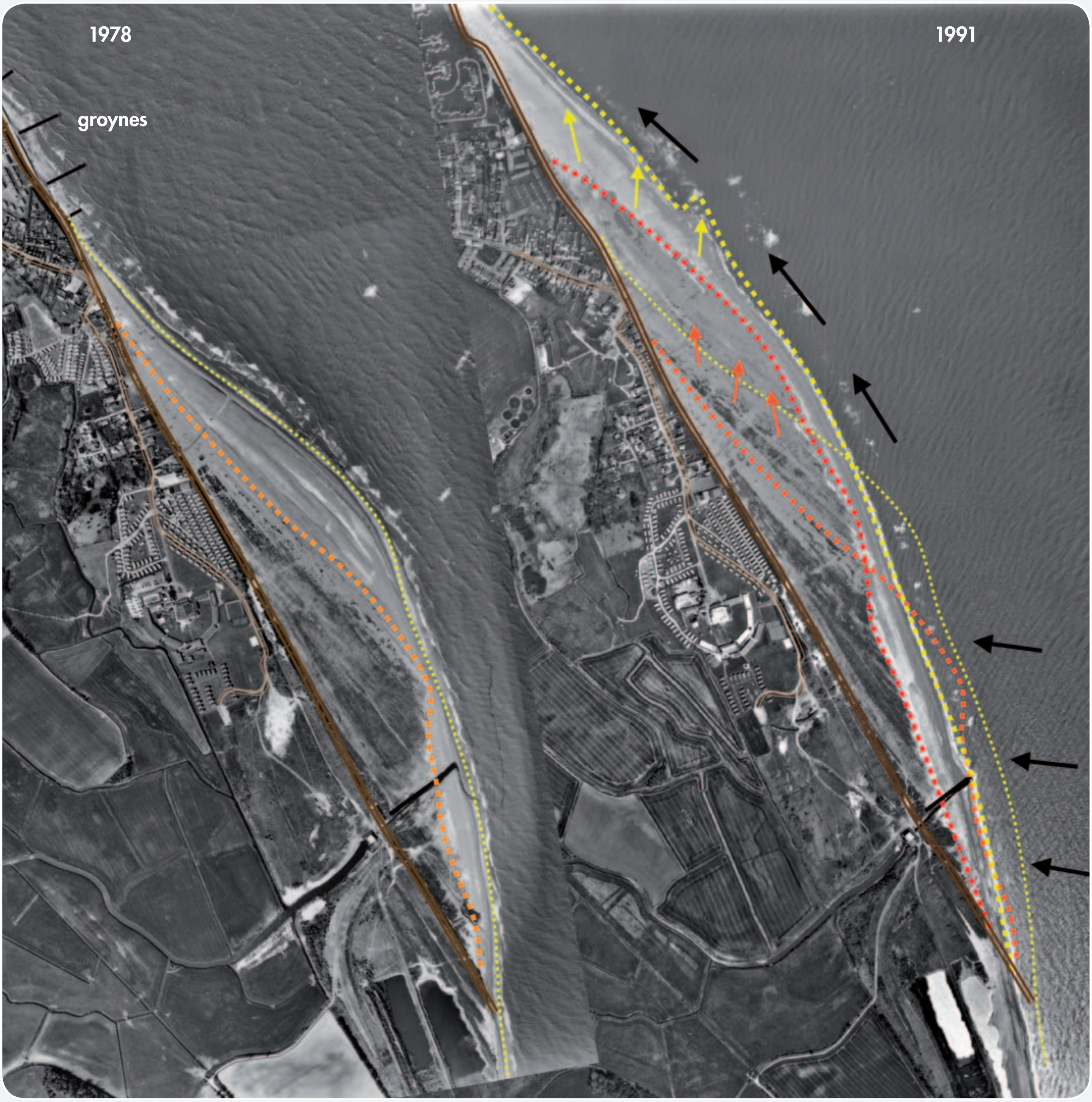


Figure 11.12 Lateral migration of Shingle. Aerial photographs of Kessingland Beach, Suffolk, south-east England, showing approximate position of the sandy shoreline (yellow, thin line) and shingleness (orange thin line) in 1978, and changes to 1991 (thicker dotted yellow and red lines). Black arrows show where the beach has eroded in the south and accreted in the north to cover the groynes (hard sea defences). Source: courtesy of J.P. Doody (January 2011).

given full consideration in the SMP process where relevant. Any proposed changes to coastal management must be assessed in terms of their impact on soft cliff faunal and floral assemblages, and on sediment supply. Where this data is not available, surveys must be included as part of a full environmental assessment.

Water abstractions within the catchment of soft cliff sites, and altered drainage near cliffs, may affect seepages and other hydrological features of high value to invertebrates, and may affect rates of erosion. Appropriate cliff-top management can provide a range of resources for invertebrates of the cliff slope, seed sources for plant colonisation of slumped or eroded areas, and ecological linkages between isolated or fragmented soft cliff sites.

There remain many opportunities for enhancing and protecting sites through effective targeting of agri-environment schemes to revert arable and intensive grazing management of cliff-tops to herb-rich semi-natural cliff-top grassland. One approach is through the use of cliff-top buffer strips designed to accommodate the natural retreat ('roll-back') of the cliff-top and promote the development of semi-natural vegetation. Buffer strips provide opportunities for combining new and improved coastal access for people, alongside the enhancement of biodiversity on soft cliff sites.

11.5.7 Coastal Lagoons

Management of lagoons poses some dilemmas. Many are natural systems that experience long-term processes of evolution such that they may change their state quite dramatically in terms of salinity and connection with the sea. Attempting to maintain the current conditions in such lagoons would, in effect, be resisting their natural patterns of evolution, and would be inconsistent with policies of non-intervention such as those contained in the Department for Environment, Food and Rural Affairs (Defra) 'Making Space For Water' (Defra 2005). Maintaining the conditions in artificial lagoons is likely to be the only option for such systems, but these will be affected by changing external environmental conditions such as sea-level rise. In Natura 2000 sites likely to experience change, creation of compensatory habitat is one option for management.

In Scotland, management currently concentrates on maintaining existing levels of marine water exchange and on minimising catchment enrichment, but there is a need to become more actively involved in advising on new or upgraded infrastructure that often uses lagoon impoundment ridges and sills.

Sea-level rise may present opportunities for creation of new lagoonal habitat where sea water inundates low-lying land and freshwater areas. Managed realignment schemes often include provision for the creation of lagoons. Managed realignment has also been applied directly to Anne's Point—a small lagoon in Strangford Lough, Northern Ireland—where the National Trust and Northern Ireland's River's Agency agreed to breach the sea defences. A benefit of the enhanced salinities that resulted was the reappearance of a rare snail, *Hydrobia acuta*.

Artificial lagoon creation can also be achieved through direct engineering works. In Belfast Lough, for example, a decision to discontinue landfill on the foreshore led to the transformation of artificial impoundments into saline lagoons, as did the construction of a motorway across the foreshore. The likely total cost, in England and Wales, of replacing freshwater and brackish habitat predicted to be lost due to sea-level rise "on a hectare-for-hectare basis, is estimated to be in the order of £50–£60 million, including site purchase, set-up and on-going management costs" (Lee 2001).

11.6 Future Research and Monitoring Gaps

Key knowledge gaps in the Coastal Margins are:

1. *Basic information on extent and trends*: Estimates of the area of Sand Dunes, Saltmarsh and Shingle vary by up to 50% depending on methodology. There is still no definitive classification of saline lagoons, different interpretations of Machair exist and the habitats of UK cliffs are only partially surveyed. A consistent and thorough survey methodology for each habitat would allow accurate estimates of change in extent and habitat condition over time (Article 17 reporting only covers Natura 2000 i.e. SAC sites, and assessment methodologies of conservation status differ by region).
2. *A national picture of the likely effects of climate change*: Coastal Margin habitats are among the most sensitive to climate change, being affected by sea-level rise, increased storminess, changing rainfall and temperature. However, there is no national picture of the likely impacts on them with respect to: loss of area; geomorphological responses to sea-level rise; direct and indirect impacts on species; and consequent impacts on ecosystem services, particularly the role of sea defence. Data from Scotland and Northern Ireland are especially lacking. There is a clear need to identify priorities for a national strategic monitoring programme.
3. *Information on the management options required to respond to sea-level rise*: In particular, how to apply roll-back or managed realignment to the other Coastal Margin habitats as well as Saltmarsh. More research is needed on any habitat restoration measures needed to make this feasible.
4. *Basic quantification of many of the ecosystem services of Coastal Margins*: This is difficult, in part because some are shared with the Marine environment, but also because the Coastal Margins constitute a narrow zone of land, are not a distinct habitat and data gathering does not differentiate between certain aspects, for example, coastal farms and inland farms. Particular services that merit more attention are: a) the value of Coastal Margin habitats in providing or contributing to 'soft' sea defences, including system thresholds which govern this role; b) the realised pollination and pest control services provided by Coastal Margin insects to agriculture; and c) greenhouse gas emissions from coastal wetland habitats and carbon storage.
5. *Understanding how to achieve trade-offs between competing Coastal Margin uses*: Cultural and societal benefits from the Coastal Margins are large. This can create tensions between different societal services, such as solitude and wildness versus increasing recreational use of the coast, but also between societal and environmental services, particularly the role of biodiversity. Understanding how to accommodate multiple uses of this environment is important.

References

Allen, J.R.L. & Pye K. (1992) Coastal saltmarshes: their nature and significance. Saltmarshes: Morphodynamics. Conservation and Engineering Significance (eds J.R.L. Allen & K. Pye) pp.1–19. Cambridge University Press, Cambridge.

Andrews, J.E., Burgess, D., Cave, R.R., Coombes, E.G., Jickells, T.D., Parkes, D.J. & Turner, R.K. (2006) Biogeochemical value of managed realignment, Humber estuary, UK. *Science of the Total Environment*, **371**, 19–30.

Andrews, J.E., Samways, G. & Shimmield, G.B. (2008) Historical storage budgets of organic carbon, nutrient and contaminant elements in saltmarsh sediments: Biogeochemical context for managed realignment, Humber estuary, UK. *Science of the Total Environment*, **405**, 1–13.

Angus, S. & Elliott, M.M. (1992) Problems of erosion in Scottish machair with particular reference to the Outer Hebrides. Coastal dunes: geomorphology, ecology and management for conservation (eds R.W.G. Carter, T.G.F. Curtis & M.J. Sheehy–Skeffington) pp. 93–112. A.A. Balkema, Rotterdam.

Angus, S. (2001) The Outer Hebrides: moor and machair. White Horse Press, Cambridge.

Angus, S. & Hansom, J.D. (2004) Tir a' Mhachair, Tir nan Loch? Climate change scenarios for Scottish Machair systems: a wetter future? Delivering Sustainable Coasts: connecting science and policy (eds D.R. Green, S. Angus, D. Bailey, M. Eleveld, K. Furmanczyk, J. Hansom, R.A. Longhorn, R. Paskoff, N.P. Psuty, R. Randall, W. Ritchie, A. Salman, J. Taussik, F.T. Pinto, & H. Wensink), pp. 565–569. 7th International Symposium, Littoral 2004, (EUROCOAST-EUCC), Aberdeen, Scotland.

Angus, S. (2009) De tha cearr air a'mhachaire? Biodiversity issues for Scottish machair: an initial appraisal. *The Glasgow Naturalist*, **25**, 53–62.

Angus, S., Hansom, J. & Rennie, A. (2011) Oir-thìrean na h-Alba ag atharrachadh: habitat change on Scotland's coasts. The Changing Nature of Scotland (eds S.J. Marrs S. Foster, C. Hendrie, E.C. Mackey, & D.B.A. Thompson). TSO, Edinburgh.

Archer, M.E. (1994) Survey of Aculeate Wasps and Bees (Hymenoptera) on the Sand Dune Systems of South Wales. Countryside Council for Wales, Bangor.

Arens, S.M., Slings, Q. & de Vries, C.N. (2004) Mobility of a remobilised parabolic dune in Kennemerland, The Netherlands. *Geomorphology*, **59**(1–4), 175–188.

Arens, S.M. & Geelen, L. (2006) Dune landscape rejuvenation by intended destabilisation in the Amsterdam water supply dunes. *Journal of Coastal Research*, **22**(5), 1094–1107.

Atkinson, P.W., Crooks, S., Dixon, M. Drewitt, M. Grant, A., Rehfisch, M.M., Sharpe, J. & Tyas, C. (2004) Managed Realignment in the UK – the first five years of colonisation by birds. *Ibis*, **146**(S1), 101–110.

Baily, B. & Pearson, A.W. (2001) Change detection mapping of saltmarsh areas of south England from Hurst Castle to Pagham Harbour. Department of Geography, university of Portsmouth report to Posford Haskoning consultants, English Nature and Environment Agency.

Baker, J. (2001) Military land use, sand dunes and nature conservation in the UK. Coastal Dune Management: Shared experience of European Conservation Practice. (eds J.A. Houston, S.E. Edmondson & P.J. Rooney), pp. 99–205. Liverpool University Press, Liverpool.

Bamber, R., Gilliland, P. & Shardlow, M. (2001) Saline lagoon guide: A guide to their management and creation (ISBN 1 85716 573 X).

Barnes, R.S.K. (1988) The faunas of landlocked lagoons: chance differences and problems of dispersal. *Estuarine and Coastal Shelf Science*, **26**, 309–18.

Barnes, R.S.K. (1989a) The coastal lagoons of Britain. An overview and conservation appraisal. *Biological Conservation*, **49**, 295–313.

Barnes, R.S.K. (1989b) What, if anything, is a brackish-water fauna? *Transactions of the Royal Society of Edinburgh, Earth Sciences*, **80**, 235–240.

Barne, J.H. *et al.* 1995–1998. *Coasts and Seas of the United Kingdom, the Coastal Directories Project: Regions 5–11 & 13.* UK Joint Nature Conservation Committee, Peterborough [online] Available at: <http://www.jncc.gov.uk/page-2157> [Accessed 09.02.11].

Beatty, C. & Fothergill, S. (2003) The Seaside Economy. Centre for Regional Economic and Social Research, Sheffield Hallam University, Sheffield.

Beaumont N., Townsend M., Mangi S., Austen M.C. (2006) Marine Biodiversity. An economic valuation. Building the evidence base for the Marine Bill. Defra, London, July 2006.

Berry, P.M., Harrison, P.A., Dawson, T.P. & Walmsley, C.A. (eds) (2005) Modelling Natural Resource Responses to Climate Change (MONARCH): A Local Approach. UKCIP Technical Report, Oxford.

Binggeli, P., Eakin, M., Macfadyen, A., Power, J. & McConnel, J. (1992) Impact of the alien sea buckthorn (*Hippophae rhamnoides* L.) on sand dune ecosystems in Ireland. Coastal dunes (eds R.W.G. Carter, T.G.F. Curtis & M.J. Sheehy-Skeffington) Geomorphology, Ecology and Management for Conservation. Proceedings of the third European dune congress. Galway/Ireland. Balkema, Rotterdam, Galway.

Boorman, L.A. (1989) The grazing of British sand dune vegetation. *Proceedings of the Royal Society Edinburgh*, **96B**, 75–88.

Boorman, L.A., Pakeman, R. J., Garbutt, R.A. & Barratt, D. (1996) The effects of environmental exchange on European salt marshes: structure, functioning and exchange potentialities with marine coastal water, Report to the European Union, Volume 5. University of Rennes, France.

Boorman L.A. & Boorman M.S. (2001) The spatial and temporal effects of grazing on the species diversity of sand dunes. Coastal Dune Management: shared experience of European conservation practice (eds J.A. Houston S.E. Edmondson & P.J. Rooney) pp. 161–167. Liverpool University Press, Liverpool.

Boorman, L. (2003) Saltmarsh review: and overview of coastal saltmarshes, their dynamic and sensitivity characteristics for conservation and management. JNCC Report 334. Peterborough.

Boorman, L.A. (2009) The role of freshwater flows on salt marsh growth and development. Coastal Wetlands: An Integrated Ecosystem Approach (eds G.M.E. Perillo, E. Wolanski, D.R. Cahoon, M.M. Brinson) pp. 493–514. Elsevier Science, Amsterdam.

Born, K. (2005) Predicting habitat change in poole harbour using aerial photography. The Ecology of Poole Harbour (eds J. Humphreys & V.J. May), pp. 239–253. Elsevier B.V., Amsterdam.

Bos, D., Loonen, M., Stock, M., Hofeditz, F., van Der Graff, A. & Bakker, J. (2005) Utilisation of Wadden Sea salt marshes by geese in relation to livestock grazing. *Journal for Nature Conservation*, **13**, 1–15.

Brenner-Guillermo, J. (2007) Valuation of ecosystem services in the Catalan coastal zone. Doctorate Dissertation. Laboratori d'Enginyeria Maritima, Universtat Politecnica de Catalunya.

BTA (British Travel Association) (1968) British National Travel Survey. British Travel Association, London.

Brooks A. & Agate E. (2001) Sand dunes. Pp. 109. BTCV. ISBN 0 946752 32 X.

Burd, F. (1989) The Saltmarsh Survey of Great Britain. An Inventory of British Saltmarshes. Research & survey in nature conservation, 17, Nature Conservancy Council, Peterborough.

Burnham, C.P. & Cook, H.F. (2001) Hydrology and soils of coastal shingle with specific reference to Dungeness. Ecology & Geomorphology of Coastal Shingle (eds. J.R. Packham, R.E. Randall, R.S.K. Barnes & A. Neal), pp. 107–131. Westbury Academic & Scientific Publishing, Otley, West Yorkshire.

Burton, P. (2001) Grazing as a management tool and the constraints of the agricultural system: a case study of grazing on Sandscale Haws Nature Reserve, Cumbria, northwest England. Coastal dune management: Shared experience of European Conservation Practice (eds J.A. Houston, S.E. Edmondson, P.J. Rooney), pp. 80–84. Proceedings of the European Symposium Coastal Dunes of the Atlantic Biogeographical Region Southport, northwest England, September 1998. Liverpool University Press, Liverpool.

Cannell, M.G., Milne, R., Hargreaves, K.J., Brown, T.A., Cruickshank, M.M., Bradley, R.I., Spencer, T., Hope, D., Billett, M.F., Adger, W.N. & Subak S. (1999) National Inventories of Terrestrial Carbon Sources and Sinks: The UK Experience. *Climate Change,* **42**(3) 505–530.

Carter, R.W.G., Orford, J.D., Forbes, D.L. & Taylor, R.P. (1987) Gravel barriers, headlands and lagoons: an evolutionary model. Proceedings Coastal Sediment 1987, New Orleans, LA, USA, May 12–14, 1987. American Society of Civil Engineers: 1776–1792.

Cayford, J. & Waters, R. (1996) Population estimates for waders (Charadrii) wintering in Great Britain, 1987/88–1991/92. *Biological Conservation*, **77**, 1–17.

Clarke, D. & Sanitwong na Ayutthaya, S. (2010) Predicted effects of climate change, vegetation and tree cover on dune slack habitats at Ainsdale on the Sefton Coast, UK. *Journal of Coastal Conservation*, **14**, 115–125.

Clayton, K.M. (1989) Sediment input from the Norfolk cliffs, Eastern England – a century of coast protection and its effects. *Journal of Coastal Research*, **5**, 433–442.

Clements, F.E. (1916) Plant succession: an analysis of the development of vegetation. Carnegie Institution of Washington, Washington.

Coates, T.T., Brampton, A.H., Powell, K.A. (2001) Shingle Beach Recharge in the Context of Coastal Defence: Principles and Problems. Ecology & Geomorphology of Coastal Shingle (eds J.R. Packham, R.E. Randall, R.S.K. Barnes & A. Neal) pp. 394–401. Westbury Academic & Scientific Publishing, Otley.

Colclough, S., Fonseca, L., Astley, T., Thomas, K. & Watts, W. (2005) Fish utilisation of managed realignments. *Fisheries Management and Ecology* **12**(6), 351–360.

Conlan, K., White, K.N. & Hawkins, S.J. (1992) The hydrography and ecology of a redeveloped brackish water dock. *Estuarine Coastal and Shelf Science*, **35**, 435–452.

Connell, J.H. & Slatyer, R.O. (1977) Mechanisms of succession in natural communities and their role in community stability and organization. *American Naturalist*, **111**, 1119–1144.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo. J., Raskin, R.G., Sutton, P. & van den Belt, M. (1997) The value of the world's ecosystem services and natural capital. *Nature*, **387**, 253–260.

Coombes, E.G. & Jones, A.P. (2010) Assessing the impact of climate change on visitor behaviour and habitat use at the coast: A UK case study. *Global Environmental Change,* **20**, 303–313.

Cooper, C. (1997) Parameters and indicators of the decline of the British seaside resort. The Rise and Fall of British Coastal Resorts: cultural and economic perspectives (eds G. Shaw & A. Williams), pp. 79–101. Pinter, London.

Cooper, N.J., Cooper, T. & Burd, F. (2001) 25 years of salt marsh erosion in Essex: Implications for coastal defence and nature conservation. *Journal of Coastal Conservation,* **9**, 31–40.

Cooper, J.A.G. & McKenna, J. (2008) Working with natural processes: the challenge for Coastal Protection Strategies. *Geographical Journal*, **174**, 315–331.

Cooper, J.A.G. (2009) Coastal economies and people review in Marine Climate Change Ecosystem Linkages Report Card 2009 (eds J.M. Baxter, P.J. Buckley & M.T. Frost) pp. 18. Online science reviews. [online] Available at: <www.mccip.org.uk/elr/coasts> [Accessed 20.01.11].

COREPOINT (Coastal REsearch POlicy INTegration) (2007) Quantification of the economic benefits of natural coastal systems. Coastal research and policy integration. EU-Interreg IIIb project report.

Cowles H.C. (1899) The Ecological Relations of the Vegetation on the Sand Dunes of Lake Michigan. *Botanical Gazette,* **27**(3), 167–202.

Dargie, T.C.D. (1995) Sand dune vegetation survey of Great Britain. A national inventory. Part 3: Wales, Joint Nature Conservation Committee.

Dargie, T.C.D. (2000) Sand dune vegetation survey of Scotland: national report. Scottish Natural Heritage Report.

Dawson, R.J., Dickson, M.E., Nicholls, R.J., Hall, J.W., Walkden, M.J.A., Stansby, P., Mokrech, M., Richards, J., Zhou, J., Milligan, J., Jordan, A., Pearson, S., Rees, J., Bates, P., Koukoulas, S. & Watkinson, A. (2009) Integrated analysis of risks of coastal flooding and cliff erosion under scenarios of long term change. *Climatic Change,* **95**(1–2), 249–288.

Defra (Department for Environment, Food and Rural Affairs) (2005) Making space for water. Taking forward a new Government strategy for flood and coastal erosion risk management in England. March 2005. [online] Available at <http://archive.defra.gov.uk/environment/flooding/documents/policy/strategy/strategy-response1.pdf> [Accessed 10.02.11).

Defra (Department for Environment, Food and Rural Affairs) (2006) Shoreline management plan guidance. Volume 2: Procedures. March 2006. [online] Available at: <http://archive.defra.gov.uk/environment/flooding/documents/policy/guidance/smpguide/volume2.pdf> [Accessed 09.02.11].

Defra (Department for Environment, Food and Rural Affairs) (2009) Flood and Water Management Bill Impact Assessment – Flood and Coastal Erosion Risk Management Funding Provisions. September 2009. [online] Available at <http://archive.defra.gov.uk/environment/flooding/documents/policy/fwmb/fwmiafunding.pdf> [Accessed 10.02.11].

Delbaere, B.C.W. (1998) Facts and figures on European biodiversity; state and trends 1998–1999. European Centre for Nature Conservation. Tilburg, the Netherlands.

Demetriadi, J. (1997) The golden years: English seaside resorts 1950–1974. The Rise and Fall of British Coastal Resorts: cultural and economic perspectives. (eds G. Shaw & A. Williams) pp. 49–78. Pinter, London.

Denton, J.S., Hitchings, S.P., Beebee, T.J.C. & Gent, A. (2003) A Recovery Program for the Natterjack Toad (*Bufo calamita*) in Britain. *Conservation Biology*, **11**(6), 1329–1338.

Dickson, M.E., Walkden, M.J.A. & Hall, J.W. (2007) Systemic impacts of climate change on an eroding coastal region over the twenty-first century. *Climatic Change,* **84**(2), 141–166.

Doody, J.P. (1984) Spartina in Great Britain (Focus on nature conservation no. 5). Nature Conservancy Council Report, Attingham, UK.

Doody, J.P. (1989) Management for nature conservation. *Proceedings of the Royal Society of Edinburgh*, **96B**, 247–265.

Doody, J.P. (2001) Coastal Conservation and Management: an Ecological Perspective. Conservation Biology Series, 13, Kluwer, pp.306. Academic Publishers, Boston, USA.

Doody, J.P. & Randall, R.E. (2003a) A Guidance Document for the Management of Vegetated Shingle, Contract No. MAR 05-03-002 English Nature.

Doody, J.P. & Randall, R.E. (2003b) A Guidance Document for the Management of Vegetated Shingle, Contract No. MAR 05-03-002 English Nature. Annex 01 Porlock.

Doody, J.P. (2008) Saltmarsh conservation, management and restoration. Coastal Systems and Continental Margins Series. Springer, USA.

Downie, A.J. (1996) Saline lagoons and lagoon-like saline ponds in England. English Nature, Peterborough.

Edmondson, S.E. (2009) Non-native plants on the Sefton Coast sand dunes. Proceedings of the Sefton Natural Coast Conference, Southport.

English Nature (2003) National Nature Reserves in Norfolk. Pp. 28. Report produced by English Nature, Norwich, UK.

Environment Agency (2007) Flood risk management Estimating Guide. Unit cost database.

Everard, M. (2009) Ecosystem services case studies. Science Report SCHO0409BPVM-E-E. Environment Agency, Bristol.

Everard, M., Jones, M.L.M. & Watts, B. (2010) Have we neglected the societal importance of sand dunes? An ecosystem services perspective. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **20**, 476–487.

Farrell, L. & Randall, R.E. (1992) The distribution of *Mertensia maritima* (L.) Gray, Oyster Plant, in Ireland. *Irish Naturalist's Journal*, **24**, 135–140.

Firn Crichton Roberts Ltd (2000) An assessment of the socio-economic cost & benefits of Integrated Coastal Zone Management, Contract NO: B4-3040/99/134414/MAR/D2. Final report to the European Commission. Firn Crichton Roberts Ldt and Graduate Schools of Environmental Studies, Scotland.

Fowler, D.O., Donoghue, M., Muller, J.B.A., Smith, R.I., Dragosits, U. & Skiba, U. (2004) A chronology of nitrogen deposition in the UK between 1900 and 2000. *Water Air Soil Pollution Focus*, **4**, 9–23.

French, P.W. (1997) Coastal and Estuarine Management (Routledge Environmental Management Series). Pp. 251. Routledge, London.

French, C.E., French, J.R., Clifford, N.J. & Watson, C.J. (2000) Sedimentation-erosion dynamics of abandoned reclamations: the role of waves and tides. *Continental Shelf Research*, **20**, 1711–1733.

Frost, M. (2010) Overall Assessment. Charting Progress 2: Healthy and Biologically Diverse Seas Evidence Group Feeder Report (ed M. Frost), UK Marine Monitoring and Assessment Strategy, Defra. [online] Available at: <http://chartingprogress.defra.gov.uk/chapter-3-healthy-and-biologicaly-diverse-seas> [Accessed 19.01.11].

Fuller, R.M. (1985) An assessment of the damage to the shingle beaches and their vegetation. Dungeness: ecology and conservation (eds B. Ferry & S. Waters), pp. 25–42. Focus on nature conservation, No. 12. Nature Conservancy Council, Peterborough.

Garbutt, R.A., Reading, C.J., Wolters, M., Gray, A.J. & Rothery, P. (2006) Monitoring the development of intertidal habitats on former agricultural land after the managed realignment of coastal defences at Tollesbury, Essex, UK. *Marine Pollution Bulletin*, **53**, 155–164.

Gatliff, R., Prior, A., Mason, T., Wolf, J., Pepper, J., Osborne, M., Spillard, R., Stoker, M., Long, D., Stevenson, A., Cotterill, C., Cooper, R. & Hobbs, P., (2010). Sedimentary Processes and Morphology. Charting Progress 2 Feeder Report: Ocean Processes (ed. J. Hunthnance), pp. 211-252. UK Marine Monitoring and Assessment Strategy (UKMMAS), Defra. [online] Available at: <http://chartingprogress.defra.gov.uk/ocean-processes-feeder-report> [Accessed 15.01.11].

GBLDV (GB Leisure Day Visits) (2004) Report of the 2002–03 Great Britain Day Visits Survey.

Gregory, R.A., Murphy, E.M., Church, M.J., Edwards, K.J., Guttmann, E.B. & Simpson, D.D.A. (2005) Archaeological evidence for the first Mesolithic occupation of the Western Isles of Scotland. *The Holocene*, 15, 944–950.

Green, B.C., Smith, D.J., Earley, S.E., Hepburn L.J. & Underwood G.J.C. (2009) Seasonal changes in community composition and trophic structure of fish populations of five salt marshes along the Essex coastline, United Kingdom. *Estuarine, Coastal and Shelf Science*, **85**(2), 247–256.

Halcrow (2002) Futurecoast: Future coastal evolution around England and Wales. Report to DEFRA, London (available on CD).

Hansom, J.D. (1988) *Coasts*. Pp. 96. Cambridge University Press, Cambridge.

Hansom, J.D. & Comber, D. (1996) Eoligarry (Barra) SSSI, site documentation and management. pp. 73. Scottish Natural Heritage Commissioned Report Series, Edinburgh. ISSN 1350–3103.

Hansom, J.D. (2001) Coastal Sensitivity to Environmental Change: a view from the beach. *Catena*, **42**, 291–305.

Hansom, J.D. & Angus, S. (2001) Tir a' Mhachair (Land of the Machair): sediment supply and climate change scenarios for the future of the Outer Hebrides machair. Earth Science and the Natural Heritage (eds J.E. Gordon & K.F. Lees), pp. 68–81. The Stationery Office, Edinburgh.

Hansom, J.D., Lees R. G., Maslen J., Tilbrook, C. & McManus, J. (2001) Coastal dynamics and sustainable management: the potential for managed realignment in the Forth estuary. Earth Science and the Natural Heritage (eds J.E. Gordon & K.F. Lees) pp. 148–160. The Stationery Office, Edinburgh.

Hansom, J.D. & McGlashan, D.J. (2004) Scotland's coast: understanding past and present processes for sustainable management. *Scottish Geographical Journal*, **120**(1), 99–116.

Hansom, J.D., Lees, G., McGlashan, D.J. & John, S. (2004) Shoreline Management Plans and coastal sediment cells in Scotland: *Coastal Management*, **32**, 227–242. DOI:10.1080/08920750490448505.

Hansom, J.D. (2010) Coastal steepening around the coast of Scotland: the implication of sea level changes. Scottish Natural Heritage Commissioned Report Series, Edinburgh.

Hanson, H., Brampton, A., Capobianco, M., Dette, H.H., Hamm, L., Laustrup, C., Lechuga A. & Spanhoff R. (2002) Beach nourishment projects, practices and objectives – a European overview. *Coastal Engineering*, **47**, 81–112.

Harrison, P.A., Berry, P.M. and Dawson, T.P. (eds) (2001) Climate Change and Nature Conservation in Britain and Ireland: Modelling natural resource responses to climate change (the MONARCH project). UKCIP Technical Report, Oxford.

Hill, M.O. & Wallace, H.L. (1989) Vegetation and Environment in Afforested Sand Dunes at Newborough, Anglesey. *Forestry,* **62**(3), 249–267.

Hill, C., Ball, J.H., Dargie, T., Tantram, D. & Boobyer, G. (2002) Maritime cliff and slope inventory. English Nature Research Report, No. 426.

Houston J.A. (2008) Management of Natura 2000 habitats. 2130 Fixed coastal dunes with herbaceous vegetation ('grey dunes'). European Commission.

Howe, M.A. (2002) A review of the coastal cliff resource in Wales, with particular reference to its importance for invertebrates. CCW Natural Science Report. 02/5/1. Countryside Council for Wales, Bangor.

Howe, M.A., Whitehouse, A.T., Knight, G.T. (2008) Life on the edge – key coastal soft cliffs for invertebrates in England and Wales. *British Wildlife*, **19**(3), 172–181.

Howe, M.A., Knight, G.T. & Clee, C. (2010) The importance of coastal sand dunes for terrestrial invertebrates in Wales and the UK, with particular reference to aculeate Hymenoptera (bees, wasps & ants). *Journal of Coast Conservation*, **14**(2), 91–102.

Ipsos Mori (2006) Coastal Access in England (Ipsos Mori – Report prepared for Natural England).

Ivell, R. (1979) Biology and ecology of a brackish lagoon bivalve, *Cerastoderma glaucum* Bruigiere in an English lagoon, the Widewater, sussex. *Journal of Molluscan Studies*, **45**, 383–400.

Jennings, S. (2004) Coastal tourism and shoreline management. *Annals of Tourism Research*, **31**, 899–922.

Jennings, S.C., Orford, J.D., Canti, M., Devoy, R.J.N. & Straker, V. (1998) The role of relative sea-level rise and changing sediment supply on Holocene gravel barrier development; the example of Porlock, Somerset, UK. *The Holocene*, **8**, 165–181.

JNCC (Joint Nature Conservation Committee) (2007) Second Report by the UK under Article 17 on the implementation of the Habitats Directive from January 2001 to December 2006. Joint Nature Conservation Committee, Peterborough. [online] Available at: <www.jncc.gov.uk/article17> [Accessed 20.01.11].

Johnston, C.M. & Gilliland, P.M. (2000) Investigating and managing water quality in saline lagoons based on a case study of nutrients in the Chesil and the Fleet European marine site. English Nature. (UK Marine SACs Project).

Jones, C.R., Houston, J.A., Bateman, D. (1993) A history of human influence on the coastal landscape. The Sand Dunes of the Sefton Coast (eds D. Atkinson & J.A. Houston), pp.3–20. Liverpool Museum, Liverpool.

Jones, M.L.M., Wallace, H.L., Norris, D., Brittain, S.A., Haria, S., Jones, R.E., Rhind, P.M., Reynolds, B.R. & Emmett, B.A. (2004) Changes in vegetation and soil characteristics in coastal sand dunes along a gradient of atmospheric nitrogen deposition. *Plant Biology*, **6**(5), 598–605.

Jones, M.L.M., Sowerby, A., Williams, D.L. & Jones, R.E. (2008) Factors controlling soil development in sand dunes: evidence from a coastal dune soil chronosequence. *Plant and Soil*, **307**(1–2), 219–234.

Jones, M.L.M., Sowerby, A. & Rhind, P.M. (2010a) Factors affecting vegetation establishment and development in a sand dune chronosequence at Newborough Warren, North Wales. *Journal of Coastal Conservation*, **14**(2), 127–137.

Jones, M.L.M., Norman, K., Rhind, P.M. (2010b) Topsoil inversion as a restoration measure in sand dunes, early results from a UK field-trial. *Journal of Coastal Conservation*, **14**(2), 139–151.

Jones, P.S. (1998) Aspects of the population biology of *Liparis loeselii* (L.) Rich. var. ovata Ridd. ex Godfery (Orchidaceae) in the dune slacks of South Wales, UK. *Botanical Journal of the Linnean Society*, **126**, 123–139.

King, S.E. & Lester, J.N. (1995) Pollution Economics. The value of salt marshes as a sea defence. *Marine pollution bulletin*, **30**, 180–189.

Klein, R.J.T. & Bateman, I.J. (1998) The recreational value of Cley Marshes Nature Reserve: an argument against managed retreat? *Journal of the Chartered Institution of Water and Environmental Management*, **12**, 280–285.

Klein, R.J.T., Nicholls, R. J., Ragoonaden, S., Capobianco, M., Aston, J., Buckley, E.N. (2001) Technological options for adaptation to climate change in coastal zones. *Journal of Coastal Research*, **17**(3), 531–543.

Küpeli, E., Kartal, M., Aslan, S. & Yesilada, E. (2006) Comparative evaluation of the anti-inflammatory and antinociceptive activity of Turkish Eryngium species. *Journal of Ethnopharmacology*, **107**(1), 32–7.

Lacambra, C., Cutts, N., Allen, J., Burd, F. & Elliott, M. (2004). *Spartina anglica*: a review of its status, dynamics and management. *English Nature Research Reports* No. 527. English Nature, Peterborough.

Lambeck, K. (1995) Late Devensian and Holocene shorelines of the British Isles and the North Sea from models of glacio-hydro-isostatic rebound. *Journal of the Geological Society, London,* **152**, 437–448.

Leafe, R., Pethick, J. & Townend, I.H. (1998) Realizing the benefits of shoreline management, *The Geographical Journal*, **164**(3), 282–290.

Lee, M. (2001) Coastal Defence and the Habitats Directive: Predictions of Habitat Change in England and Wales. *The Geographical Journal*, **167**(1), 39–56.

Loubet, B., Asman, W.A.H., Theobald, M.R., Hertel, O., Tang, S., Robin, P., Hassouna, M., Dammgen, U., Genermont, S., Cellier, P., Sutton, M.A. (2009) Ammonia deposition near hot spots: processes, models and monitoring methods. (eds M.A. Sutton, S. Reis & S.M.H. Baker) pp. 71–86. Atmospheric Ammonia: Detecting emission changes and environmental impacts. Results of an Expert Workshop under the Convention on Long-range Transboundary Air Pollution. Springer, UK.

Lowe, J.A., Howard, T.P., Pardaens, A., Tinker, J., Holt, J., Wakelin, S., Milne, G., Leake, J., Wolf, J., Horsbaugh, K., Reeder, T., Jenkins, G., Ridley, J, Dye, S. & Bradley, S. (2009) UK Climate Projections Science report: Marine and Coastal Projections. Met Office Hadley Centre, Exeter, UK.

Loxton, R.G. (2010) Records of invertebrates at Newborough Forest, Newborough Warren NNR and Llandwyn Island during 2009 with a discussion of the number of insect species exploiting the conifers. Pp.24. Report to CCW and Forestry Commision.

Lozano, I., Devoy, R.J.N., May, W., Andersen, U. (2004) Storminess and vulnerability along the Atlantic coastlines of Europe: analysis of storm records and of a greenhouse gases induced climate scenario. *Marine Geology,* **210**, 205–225.

Luisetti T., Turner, R.K., Bateman, I.J., Morse-Jones, S., Adams, C. & Fonseca, L. (2010) Coastal and marine ecosystem services valuation for policy and management: managed realignment case studies in England, Ocean and Coastal Management. DIO:10.10.16/j.ocecoaman.2010.11.003

MA (Millennium Ecosystem Assessment) (2005) Ecosystems and human wellbeing: synthesis. Island Press, Washington, D.C.

Macpherson Research (MR) (2003) Western Isles Tourism Facts & Figures Update Review of 2002 Season Final Report for Western Isles Enterprise & Western Isles Tourist Board

MAFF (Ministry of Agriculture, Fisheries and Food) (1995) Shoreline management plans – a guide for coastal defence authorities. May 1995.

Manly, A. (2004) Freiston Shore Visitors' Survey. RSPB Market Research Team Internal Report, November 2004.

May, V.J. & Hansom, J.D. (2003) Coastal Geomorphology of Great Britain. Geological conservation Review Series, No. 28, Joint Nature Conservation Committee, Peterborough.

McKenna, J., Cooper, J.A.G. & O'Hagan, A.M. (2008) Managing by principle: a critical assessment of the EU principles of ICZM. *Marine Policy*, **32**, 941–955.

Meot-Duros, L., Le Floch, G. & Magné, C. (2008) Radical scavenging, antioxidant and antimicrobial activities of halophytic species. Journal of *Ethnopharmacology*, **116**(2) 258–62.

Merritt, J. W. & Cavill, J .E. (1993) Supply and demand of sand and gravel in the Western Isles, Scotland. British Geological Survey Onshore Geology Series TECHNICAL REPORT WA/93/59R. Natural Environment Research Council.

Mintel (2005) Extreme Sports – UK, [online] Available at <http://oxygen.mintel.com/index.html> [Accessed 10.02.11]

Mintel (2008) Wildlife Tourism – International. [online] Available at <http://oxygen.mintel.com/index.html> [Accessed 10.02.11]

Mitchell, S.B., Theodoridou, A. & Pope, D.J. (2007) Influence of freshwater discharge on nutrient distribution in a macrotidal lagoon, West Sussex, UK. *Hydrobiologia,* **588**, 261–270.

Möller, I., Spencer, T., French, J.R., Leggett, D.J. & Dixon, M. (1999) Wave transformation over salt marshes: A field and numerical modelling study from North Norfolk, England. *Estuarine, Coastal and Shelf Science*, **49**, 411–426.

Möller, I., Spencer, T., French, J.R., Leggett, D.J., Dixon, M. (2001) The sea-defence value of salt marshes – a review in the light of field evidence from North Norfolk. *Journal of the Chartered Institution of Water and Environmental Management*, **15**, 109–116.

Möller, I. (2006) Quantifying saltmarsh vegetation and its effect on wave height dissipation: Results from a UK east coast saltmarsh. *Estuarine and Coastal Shelf Science*, **69**, 337–351.

Morris, R.K.A., Reach, I.S., Duffy, M.J., Collins, T.S. & Leafe, R.N. (2004) On the loss of salt marshes in south-east England and the relationship with *Nereis diversicolor. Journal of Applied Ecology*, **41**, 787–791.

NEGTAP (National Expert Group on Transboundary Air Pollution) (2001) Transboundary Air Pollution: Acidification, Eutrophication and Ground-Level Ozone in the UK. ISBN 1 870393 61 9.

Nicholls, R.J., Dredge, A. & Wilson, T. (2000) Shoreline change and fine-grained sediment input: Isle of Sheppey Coast, Thames Estuary, UK. Coastal And Estuarine Environments: Sedimentology, Geomorphology And Geoarchaeology Book Series: Geological Society Special Publication Volume: 175 Pages: 305–315

NIHAP (Northern Ireland Habitat Action Plan) (2003) Saline lagoons. Final Draft April 2003. [online] Available at: <http://www.ni-environment.gov.uk/saline_lagoon_web_version_april_03.pdf> [Accessed 20.01.11].

Nottage, A.S. & Robertson, P.A., (2005) The saltmarsh creation handbook: a project managers guide to the creation of saltmarsh and intertidal mudflat. The RSPB, Sandy & CIWEM, London, UK.

Oates, M., Harvey, H. J., Glendell, M. (1998) Grazing sea cliffs and dunes for nature conservation. The National Trust, Estates Department, Cirencester.

Oates, M. (1999) Sea cliff slopes and combes – their management for nature conservation. *British Wildlife,* **10**(6), 394–403.

Ogden, R., Shuttleworth, C., McEwing, R. & Cesarini, S. (2005) Genetic management of the red squirrel, Sciurus vulgaris: a practical approach to regional conservation. *Conservation Genetics*, **6**, 511–525.

Orford, J.D., Jennings, S.C. & Forbes, D.L. (2001) Origin, development, reworking, and breakdown of gravel dominated coastal barriers in Atlantic Canada: future scenarios for the northwest European coast. *Ecology & Geomorphology of Coastal Shingle*, (eds J.R. Packham, R.E. Randall, R.S.K. Barnes & A. Neal) pp. 23–55.Westbury Academic and Scientific Publishing, Otley, West Yorkshire.

Orford, J.D., Pethick, J.S. & McFadden, L. (2007) Reducing the vulnerability of natural coastal systems – A UK perspective. *Managing coastal vulnerability*. (eds McFadden, L., Nicholls, R.J. & Penning-Rowsell, E) pp. 177–194. Elsevier Publishing, Amsterdam.

Packham, J.R. & Willis, A.J. (1997) Ecology of dunes, salt marsh and shingle. Chapman and Hall, London.

Pethick J.S. (200)1 Coastal management and sea-level rise. *Catena*, **42**, 07–22.

Petroff, A., Mailliat, A., Amielh, M. & Anselmet, F. (2008) Aerosol dry deposition on vegetative canopies. Part I: Review of present knowledge. *Atmospheric Environment*, **42**, 3625–3653.

Plassmann, K., Jones, M.L.M. & Edwards-Jones, G. (2010) Effects of long-term grazing management on sand dune vegetation of high conservation interest. *Applied Vegetation Science*, **13**, 100–112.

Provoost, S., Jones, M.L.M. & Edmondson, S.E. (2010) Changes in landscape and vegetation of coastal dunes in northwest Europe: a review. *Journal of Coastal Conservation*. [online] DOI: 10.1007/s11852-009-0068-5.

Pugh, D. & Skinner, L. (2002) A new analysis of marine related activities in the UK economy with supporting science and technology. IACMST Information Document, No. 10. Pp. 48.

Pugh, D.T. (2004) Changing Sea Levels. Pp. 265. Cambridge University Press, Cambridge.

Pye, K. & French, P.W. (1992) Targets for Coastal Habitat

Recreation. English Nature Science Series No. 17, English Nature, Peterborough.

Pye, K. (2001) The nature and geomorphology of coastal shingle. Ecology & Geomorphology of Coastal Shingle (eds J.R. Packham, R.E. Randall, R.S.K. Barnes & A. Neal), pp. 2–22. Westbury Academic and Scientific Publishing, Otley, West Yorkshire.

Pye, K. & Saye, S.E. (2005) The Geomorphological Response of Welsh Sand Dunes to Sea Level Rise Over the Next 100 Years and the Management Implications for SAC and SSSI Sites. CCW Contract Science Report 670, Countryside Council for Wales, Bangor.

Pye, K., Saye, S.E. & Blott, S.J. (2007) Sand Dune Processes and Management for Flood and Coastal Defence. Parts 1 to 5. Joint DEFRA/EA Flood and Coastal Erosion Risk Management R & D Programme, R & D Technical Report FD1 1302/TR.

Pye, K. & Blott, S.J. (2008) Decadal-scale variation in dune erosion and accretion rates: an investigation of the significance of changing storm tide frequency and magnitude on the Sefton coast, UK. *Geomorphology*, **102**, 652–666.

Pye, K. & Blott, S.J. (2009) Progressive breakdown of a gravel-dominated barrier system, Dunwich–Walberswick, Suffolk, UK. *Journal of Coastal Research*, **25**, 589–602.

Radley, G.P. (1994) Sand dune vegetation survey of Great Britain. A national inventory. Part 1: England, Joint Nature Conservation Committee.

Randall, R.E. & Sneddon, P. (2001) Initiation, development and classification of vegetation on British shingle beaches: a model for conservation management. Ecology & Geomorphology of Coastal Shingle (eds. J.R. Packham, R.E. Randall, R.S.K. Barnes & A. Neal), pp. 202–223. Westbury Academic & Scientific Publishing, Otley, West Yorkshire.

Randall, R.E. (1977) Shingle foreshores. *The Coastline* (ed R.S.K., Barnes), pp. 49–61. Wiley, London.

Randall, R.E. (2004) Management of coastal vegetated shingle in the United Kingdom. *Journal of Coastal Conservation*, **10/1**, 159–168.

Ranwell, D.S. (1959) Newborough Warren, Anglesey 1: the dune system and dune slack habitat. *Journal of Ecology*, **47**, 571–601.

Ranwell, D.S. & Boar, R. (1986) Coast dune management guide. Institute of Terrestrial Ecology, Norwich.

Rees, S.M. (ed) (2005) Coastal Evolution in Suffolk: an evaluation of geomorphological and habitat change. English Nature Research Reports No. 647. English Nature, Peterborough.

Rehfisch, M.M., Austin, G.E., Armitage, M.J.S., Atkinson, P.W., Holloway, S.J., Musgrove, A.J. & Pollitt, M.S. (2003) Numbers of wintering Waterbirds in Great Britain and the Isle of Man (1994/1995–1998/1999): II. Coastal waders (Charadrii). Biological Conservation, **112**, 329–341.

Remke, E., Brouwer, E., Kooijman, A., Blindow, I., Esselink, H. & Roelofs, J.G.M. (2009) Even low to medium nitrogen deposition impacts vegetation of dry, coastal dunes around the Baltic Sea. Environmental Pollution, **157**, 792–800.

Rennie, A.F. & Hansom, J.D. 2011. Sea level trend reversal: Land uplift outpaced by sea level rise on Scotland's coast. *Geomorphology*. 125, 193–202.

Rhind, P.M., Blackstock, T.H., Hardy, H.S., Jones, R.E., Sandison, W. (2001) The evolution of Newborough warren dune system with particular reference to the past four decades. Coastal dune management, shared experience of European conservation practice (eds J. Houston, S.E. Edmondson, P.J. Rooney), pp. 345–379. Liverpool University press, Liverpool.

Rhind, P.M., Jones, R., Jones, M.L.M. (2008) Confronting the impact of dune stabilisation and soil development on the conservation status of sand dune systems in Wales. Proc. International conference on management and restoration of coastal dunes, Santander, Spain (ICCD 2007). Universidad de Cantabria, pp. 143–152.

Ritchie, W. & Gimingham C.H. (1989) Restoration of coastal dunes breached by pipeline landfalls in north-east Scotland. Coastal sand dunes (eds W. Ritchie, C.H. Gimmingham, B.B. Willets, A.J. Willis), pp. 231–245. Proceedings of the Royal Society of Edinburgh, Edinburgh.

RoTAP (Review Of Transboundary Air Pollution) (2011) Review of Transboundary Air Pollution: Acidification, Eutrophication, Ground Level Ozone and Heavy Metals in the UK. Contract Report to the Department for Environment, Food and Rural Affairs. Centre for Ecology & Hydrology.

RSPB (Royal Society for the Protection of Birds) (2010) The Local Value of Seabirds: Estimating spending by visitors to RSPB coastal reserves and associated local economic impact attributable to seabirds. The RSPB, Sandy, UK.

Rupp-Armstrong, S. & Nicholls, R.J. (2007) Coastal and Estuarine Retreat: A Comparison Of The Application Of Managed Realignment In England And Germany. *Journal of Coastal Research*, **23**(6), 1418–1430.

Saye, S.E. & Pye, K. (2007) Implications of sea level rise for coastal dune habitat conservation in Wales, UK. *Journal of Coastal Conservation*, **11**, 31–63.

Sevink, J. (1991) Soil development in the coastal dunes and its relation to climate. *Landscape Ecology*, **6**, 49–56.

Shardlow, E.A. (2001) A review of the conservation importance of shingle habitat for invertebrates in the United Kingdom (UK). Ecology & Geomorphology of Coastal Shingle, (eds J.R. Packham, R.E. Randall, R.S.K. Barnes, & A. Neal), pp. 355–377. Westbury Academic and Scientific Publishing.

Shennan, I., Milne, G. & Bradley, S.L. (2009) Late Holocene relative land – and sea-level changes: providing information for stakeholders. *GSA Today*. **19**:52–53.

Shepherd, D., Burgess, D., Jickells, T., Andrews, J., Cave, R., Turner, R.K., Aldridge, J., Parker E.R. & Young, E. (2007) Modeling the effects and economics of managed realignment on cycling and storage of nutrients, carbon and sediments in the Blackwater estuary, UK. *Estuarine Coastal and Shelf Science,* **73**, 355–367.

Simonson, W. & Thomas, R. (1999) Biodiversity: Making the links. English Nature, Peterborough.

Simpson, D.E., Rooney, P.J., Houston, J.A. (2001) Towards best practice in the sustainable management of sand dune habitats: Management for golf and nature on the Sefton Coast. Coastal dune management: shared experience of European conservation practice (eds J.A. Houston, S.E. Edmondson, P.J. Rooney) pp. 271–280. Liverpool University Press, Liverpool.

Sival, F.P. & Strijkstra-Kalk, M. (1999) Atmospheric deposition of acidifying and eutrophicating substances in dune slacks. *Water Air and Soil Pollution*, **116**, 461–477.

Smith, B.P. & Laffoley, D. (1992) Saline lagoons and lagoon-like habitats. English Nature Science No. 6. English Nature, Peterborough.

Smith, T. (2009) East Sussex Vegetated Shingle Management Plan Source. [online] Available at: <http://www.

eastsussex.gov.uk/NR/rdonlyres/04C8BD90-8E98-4DB7-87CA-47AA0BA94E4A/0/shingle_mgmt_plan.pdf> [Accessed 03.02.11].

Spurgeon, J. (1999) The Socio-Economic Costs and Benefits of Coastal Habitat Rehabilitation and Creation. *Marine Pollution Bulletin*, **37/8**, 373–382.

Steward, H. (2001) Quality of Coastal Towns. Merseyside Coast Visitor Research 2000. Formby Council Offices, Formby.

Struyf, E., Dausse, A., Van Damme, S. Bal, K., Gribsholt, B, Boschker, H.T.S. Middelburg, J.J. & Meire, P. 2006. Tidal marshes and biogenic silica recycling at the land–sea interface, *Limnology and Oceanography*, **51**(2), 838–846.

Sturgess, P. & Atkinson, D. (1993) The clearfelling of sanddune plantations: soil and vegetational processes in habitat restoration. *Biological Conservation*, **66**, 171–183.

Symes, N.C. & Robertson, P.A. (eds) (2004) A Practical Guide to the Management of Saline Lagoons. The RSPB, Sandy.

Tantram, D. & Dargie, T. (2005) Maritime Cliff and Slope Inventory for Wales. Contract Science Report. Countryside Council for Wales, Bangor.

Taylor, J.A., Murdock, A.P., & Pontee, N.I. (2004) A macroscale analysis of coastal steepening around the coast of England and Wales, *The Geographical Journal,* **170**(3), 170–188.

Taylor, W.A., Bryden, D.B., Westbrook, S.R., & Anderson, S. (2010) Nature Based Tourism in the Outer Hebrides. Scottish Natural Heritage Commissioned Report No. 353 (Tender 29007).

Turner, R.K., Burgess, D., Hadley, D., Coombes, E.G. & Jackson, N. (2007) A cost–benefit appraisal of coastal managed realignment policy. *Global Environmental Change*, **17**, 397–407.

TNS (2005) Scottish Recreation Survey: annual summary report 2003/04. Scottish Natural Heritage Commissioned Report No. 105 (ROAME No. F02AA614/2).

UKTS (United Kingdom Tourism Statistics) (2006) United Kingdom Tourism Statistics 2006. Tourism volumes and values in 2006. [online] Available at: <http://tourisminsights.info/STATISTICS/UKTS.htm> [Accessed 09.02.11].

UKTS (United Kingdom Tourism Statistics) (2009) United Kingdom Tourism Statistics 2009. Tourism volumes and values in 2009. [online] Available at: < http://www.visitengland.org/insight-statistics/major-tourism-surveys/overnightvisitors/index.aspx> [Accessed 09.02.11].

VEP (Valuing our Environment Partnership) (2006) The economic impact of the coastal and marine environment of Wales. [online] Available at: < http://www.nationaltrust.org.uk/main/w-wales-valuing_our_environment-marine-english.pdf> [Accessed 09.02.11].

van Dijk, H.W.J. (1989) Ecological impact of drinking-water production in Dutch coastal dunes. Perspectives in coastal dune management. Proceedings of the European Symposium Leiden, September 7–11, 1987 (eds F. van der Meulen, P.D. Jungerius, J. Visser), pp. 163–182. SPB Academic Publishing, The Hague.

van Dijk, H.J.W. (1992) Grazing domestic livestock in Dutch coastal dunes: Experiments, experiences and perspectives. Coastal dunes: Geomorphology, ecology and management for conservation. Proceedings of the third European Dune Congress, Galway, Ireland, 17–21 June 1992. (eds R.W.G. Carter, T.G.F. Curtis, M.J. Sheehy-Skeffington), pp. 235–250. Balkema, Rotterdam.

van Wijnen, H.J. & Bakker, J.P. (1999) Nitrogen and phosphorus limitation in a coastal barrier salt marsh: the implications for vegetation succession. *Journal of Ecology*, **87**, 265–272.

VisitBritain (2007) England Tourism Day Visits 2005. VisitBritain, London.

VisitWales (2008) Coastal Tourism Strategy (2008). Published by Visit Wales, the Tourism and Marketing Division of the Welsh Assembly Government.

WTB (Wales Tourist Board) (1992) Prospects for coastal resorts – a Paper for Discussion. Wales Tourist Board, Cardiff.

Walmsley, C.A. & Davy, A.J. (1997) The restoration of coastal shingle vegetation; effects of substrate composition on the establishment of seedlings. *Journal of Applied Ecology*, **34**, 143–153.

Walmsley, C.A. & Davy, A.J. (2001) Habitat creation and restoration of damaged shingle communities. Ecology & Geomorphology of Coastal Shingle (eds J.R. Packham, R.E. Randall, R.S.K. Barnes & A. Neal), pp. 409–420. Westbury Academic and Scientific Publishing.

Walton, J.K. (1983) The English Seaside Resort: a Social History 1750–1914. Leicester.

Walton, J.K. (1997) The seaside resorts of England and Wales, 1900 – 1950: growth, diffusion and the emergence of new forms of coastal tourism. The Rise and Fall of British Coastal Resorts: cultural and economic perspectives (eds G. Shaw & A. Williams), pp. 21–48. Pinter, London.

Walton J.K. (2000) The British Seaside: Holidays and Resorts in the Twentieth Century. Manchester University Press, Manchester.

Weber, G.J., O'Sullivan, P.E. & Brassley, P. (2006) Hindcasting of nutrient loadings from its catchment on a highly valuable coastal lagoon: the example of the Fleet, Dorset, UK, 1866–2004. *Saline Systems*, **2**, 15.

WAG (Welsh Assembly Government) (2008) Coastal Tourism Strategy. Visit Wales, the Tourism and Marketing Division of the Welsh Assembly Government, Cardiff.

Whitehouse, A.T. (2007) Managing coastal soft cliffs for invertebrates. Buglife – The Invertebrate Conservation Trust, Peterborough.

Williams, J.M. (ed) (2006) Common Standards Monitoring for Designated Sites: First Six Year Report. JNCC, Peterborough.

Williams, A. & Shaw, G. (1997) Riding the big dipper: the rise and decline of the British seaside resort in the twentieth century. The Rise and Fall of British Coastal Resorts: cultural and economic perspectives (eds G. Shaw & A. Williams). Pinter, London.

Williams A.M. & Shaw, G. (2009) Future play: tourism, recreation and land use. *Land Use Policy*, **26S**, S326–S335.

Wolters, M., Garbutt, A. & Bakker, J.P. (2005) Salt-marsh restoration: evaluating the success of de-embankments in north-west Europe. *Biological Conservation*, **123**, 249–268.

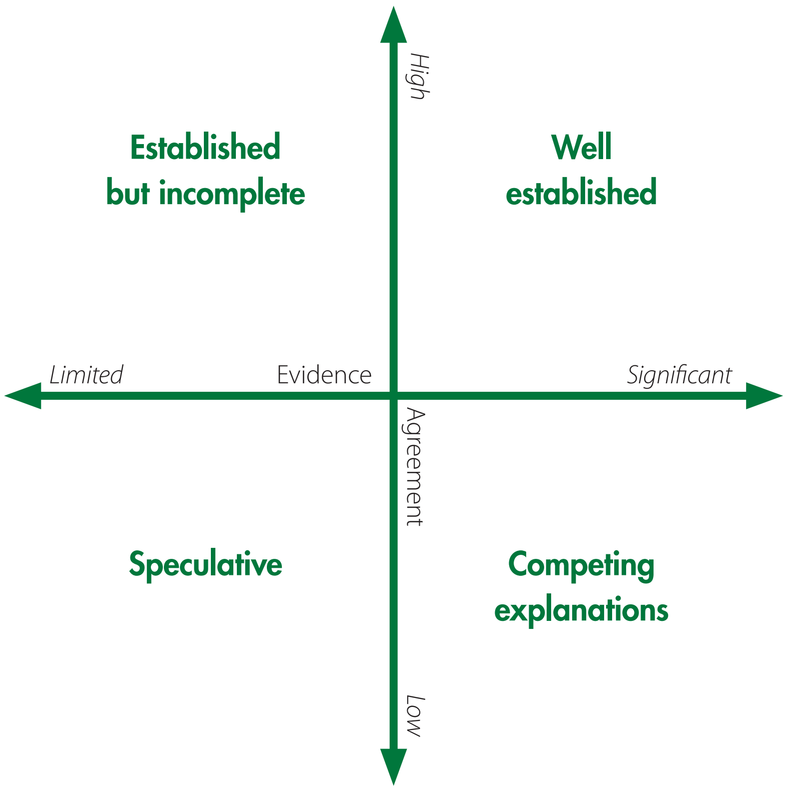
Woodworth, P.L., Shaw, S.M. & Blackman, D.L. (1991) Secular trends in mean tidal range around the British Isles and along the adjacent European coastline. *Geophysical Journal International*, **104**, 593–609.

Appendix 11.1 Approach Used to Assign Certainty Terms to Chapter Key Findings

This chapter began with a set of Key Findings. Adopting the approach and terminology used by the Intergovernmental Panel on Climate Change (IPCC) and the Millennium Assessment (MA), these Key Findings also include an indication of the level of scientific certainty. The 'uncertainty approach' of the UK NEA consists of a set of qualitative uncertainty terms derived from a 4-box model and complemented, where possible, with a likelihood scale (see below). Estimates of certainty are derived from the collective judgement of authors, observational evidence, modelling results and/or theory examined for this assessment.

Throughout the Key Findings presented at the start of this chapter, superscript numbers and letters indicate the estimated level of certainty for a particular key finding:

1.	*Well established:*	high agreement based on significant evidence
2.	*Established but incomplete evidence:*	high agreement based on limited evidence
3.	*Competing explanations:*	low agreement, albeit with significant evidence
4.	*Speculative:*	low agreement based on limited evidence



a.	*Virtually certain:*	>99% probability of occurrence
b.	*Very likely:*	>90% probability
c.	*Likely:*	>66% probability
d.	*About as likely as not:*	>33–66% probability
e.	*Unlikely:*	<33% probability
f.	*Very unlikely:*	<10% probability
g.	*Exceptionally unlikely:*	<1% probability

Certainty terms 1 to 4 constitute the 4-box model, while *a* to *g* constitute the likelihood scale.