Chapter 7 Sandy beaches and dunes — GCR site reports

Introduction

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Sandy beaches and their backing dunes are a common feature of the British coast. Although the European Commission's CORINE project recorded 9.6% of the British coast to be sandy beach (European Commission, 1998), this statistic did not include any diff-foot beaches. Sand beaches and dunes occur throughout the British coast, but are concentrated mainly on the northern and western coasts. For example, 75% of coastal dunes, by area, occur north of the Tees and Solway Firth and sand beaches occur in association with dunes and other sandy structures. Sand beaches also commonly form the lower parts of beaches where shingle ridges occur close to high-water mark. They also occur below many cliffs, for example, the chalk around the Isle of Thanet, Kent, the diffs of eastern England from Flamborough Head to Essex, and along much of the Cornish and Welsh coasts, as well as in association with sand cliffs and other strata that yield sand as a major fraction of weathered debris (Figure 7.1).

Since sand supplies from the upper beach are usually required to build sand dunes, the fact that sandy beaches and dunes commonly coexist is unsurprising. However, some sandy beaches are not backed by dunes, mainly owing to limited throughput of sand, an unfavourable wind regime or lack of availability of a site suitable for deposition.

The relationship between sandy cliffs and beaches has typically been described in the context of beach sediment budgets, beach management and coast protection (e.g. Clayton, 1989b; Psuty and Moreira, 1990; Bird, 1996). Extensive sand cliffs (for example at Bournemouth, Dorset, and Culbin, Moray, and, more widely, along the coast of the Algarve in Portugal and much of the coast of California) often have substantial sand beaches at their foot. Much of the supply of sand from sand cliffs in southern and eastern Britain has been reduced in recent years by coastal protection schemes. For example, before they were progressively protected by sea walls during the 20th century, the Bournemouth cliffs (some 11 km in length) produced about 115 000 m^3 of sediment annually (of which 80% was coarse enough to stay on the beaches). By the mid 1980s, this supply had fallen to 4000 m^3 a^{-1}, coming mostly from the unprotect ed cliffs to the east (Halcrow Maritime, 1999).

A number of writers have argued for a 'systems approach' to sandy beach study, a point also made strongly in respect of cuffed coasts by Brunsden (1973). Such an approach allows each of the influencing factors affecting beach and dune form to be examined in isolation in order to determine its effect. This methodology allows the links between process and form to be better identified. Therefore, much of the investigation of sandy beaches has focused on changes in beach profiles in response to variations in weather conditions, especially wind, and on beach sediment budgets. Long-term trends in beach morphology and the relationship between beach and dune morphology and ecology typify many other studies. However, it is also apparent from the evidence of GCR sites described in this chapter that change in many sand and dune systems is associated with high magnitude/low frequency events superimposed on the more routine processes. Similarly the relationship between many subsystems that make up these features function over different timescales and with different intensities. For example, the sandy beach and dunes at Gibraltar Point, Lincolnshire, comprise many different subsystems, which include nearshore tidal ridges, a ridge-and-runnel foreshore, and a back-shore with arcuate foreshore dune ridges and dune slacks. The spit protects the upper beach ridge sheltering an area of mature (Old Marsh) from New Marsh by a storm beach, which resulted from an occasional extreme event in the evolution of the area. More change occurred in a few hours in 1922 than during years of normal sedimentation; isolation of the storm effects helps in gaining an understanding of the relative importance of both frequent and infrequent events and evolution. This is a theme that is common to many other sand coast GCR sites: Spurn Head on the Holderness cost responded dramatically to a surge in 1849 and both Spurn Head and Gibraltar Point showed different reactions to the 1953 surge. In terms of the development of sub-parallel dune ridges, Gibraltar Point offers considerable contrasts to the GCR site at South Haven Peninsula, Dorset, mostly because of different tidal and wave conditions and differences in sediment supply. In particular, Gibraltar Point lies in a macrotidal and South Haven in a microtidal environment. In both of these sites the processes operating in one subsystem have important repercussions in all of the others.

It is evident from the GCR sites described in this chapter (Figure 7.1) and (Table 7.1) and (Table 7.2)) that both beach and dune features co-exist and depend upon the availability of sand that may come from the seabed, from fluvial sources and from cliff erosion, depending upon their geomorphological setting. Small sand beaches can develop with very limited sediment supplies. For example, small sand beaches form localized pockets within embayments of the Thanet chalk coast and the indented rocky coasts of southwestern Britain and northern and western Scotland. Sand commonly forms a veneer on some shore platforms and displays a range of minor current- and wave-related forms.

In the Chalk, sand derives from attrition of flint and from the release of fossil shell fragments from the chalk itself. Elsewhere, sandstone and soft sediment cliffs provide large quantities of sand to their beaches, which may then be transported alongshore. Erosion of the till coast and shallow seabed off Holderness provides very large volumes of sand and gravel annually that are transported both alongshore to form a large sand spit at Spurn Head and into the North Sea. Along the coast of East Anglia, very large volumes of sand and gravel are derived from erosion of till cliffs, but there are also large volumes in offshore banks that result from the offshore transport of longshore sediment. The sand beaches here largely result from the continued throughput of sand. On the more indented coast of the western and northern British Isles, sand beaches are commonly found in embayments where sand cannot escape, and in estuaries and firths, where sand from landward and seaward sources is locally plentiful. Many beaches that are dominated by gravel at the shoreline are also characterized by extensive, sandy, lower beaches. Similarly many beaches formed in heterogeneous materials are sorted locally into sand and gravel for short periods of time and the sand may be blown into sand dunes to the rear of the beach.

(Table 7.1) Main features and present-day sediment sources of dune types. Exemplar sites described in the present chapter are in bold typeface. See also Table 7.2. (Based on Ranwell, 1972.)

Type	Sediment sources	Geomorphological setting	Wind directions	Exemplar GCR sites
Foreshore dunes				
Spit dunes	Intertidal banks and longshore	On promontories at estuary mouths with near-parallel or radiating ridges and slacks	More common with onshore prevailing and dominant, but not restricted to this	Forvie, Strathbeg, South Haven Penin-sula, Moth Harlech, Holy Island (Goswick and the Snook), Culbin, Morrich More
Prograding ness dunes	Accretion at ness, possibly with longshore sediment supply from opposite directions alongshore	On open coast	Prevailing and dominant winds from opposite directions (offshore/ onshore)	Winterton Ness, Barry Links, Tentsmuir
Offshore island dunes	Offshore, longshore and intertidal drying banks	Offshore or barrier islands narrow, subject to washover, often display time- series development in main direction of longshore transport	Can occur with both onshore and offshore prevailing winds	Scolt Head Island, Blakeney Point recurves (North Norfolk Coast), Pembrey (Carmarthen Bay), Culbin, Morrich More
Hindshore dunes				

Bay dunes	Restricted in longshore direction	Usually at bay head on indented coasts	Prevailing onshore	Dunnet Bay, Luce Sands, Upton and — Gwithian Towans, Tywyn Aberffraw, Oxwich Bay Sandwood, Balta Island, Torrisdale Bay and Invernaver
Hindshore dune system	Offshore and intertidal	Extensive sandy coasts	Prevailing and dominant winds from the same direction	Braunton Burrows, Newborough Warren, Ainsdale, Holy Island (Ross Links)
Hindshore sand plains	Offshore, intertidal and beach	Bay-head and low- lying rocky coasts	High wind-speeds that restrict vertical development	Tywyn Aberffraw

Although this chapter covers sandy beaches as well as dunes, there is little further introduction to beaches that has not been covered in Chapter 5. However, is Marsden Bay, County Durham, is exceptional, where a sandy (and locally mixed sandy gravel) beach lies at the foot of Magnesian limestone cliffs. This was the site of pioneering work on beach mobility in response to variations in wind and waves over 50 years ago (King, 1953), and for that reason is the first site covered in this chapter. For the rest, wide, sandy beaches are usually associated with — and indeed allow the formation of — dunes, but given their varied location, their varying exposure to waves and their range of tidal conditions, they show considerable differences from place to place.

Sand dunes are most likely to be associated with stable and accreting beaches, with a wide upper beach that allows drying and sediment movement by strong winds. A typical example is the west-facing beach of Dunnet Bay in Caithness, a sand trap with onshore winds. Other wide beaches, especially where they are not fully open to the ocean (as around the Irish Sea) and so have waves with more limited fetch, are frequently barred, with ridges and runnels, as at Ainsdale, Lancashire (see GCR site report). Other barred beaches are found at Holkham Bay, North Norfolk, which is a prograding beach, and Braunton Burrows, Devon, as the aerial photograph (Figure 7.9) demonstrates.

Most beaches are more likely to be suffering erosion than progradation (Bird, 1985), and this is certainly true of the UK. The exceptions are in northernmost England (e.g. Holy Island) or parts of Scotland, where postglacial isostatic rebound has offset present-day sea-level rise. As a result, these wide, prograding beaches are backed by some of the largest dune fields in Britain, particularly where sediment was moved onshore during the later part of the Holocene sea-level rise, such as in much of Scotland. It is no surprise that 71% of the dune area of Britain is in Scotland. With the virtual stabilization of sea level, many beaches have lost volume and dune cliffing has become more common throughout Britain. In places, climatic and/or sea-level changes have led to an oscillation between dune cliffing and dune growth on varying timescales, such periodic clang maintaining some dynamic stability via contributions of sand to the fronting beach. In general, present sea-level rise and lack of new sediment means that cuffed dunes are more common than active foredune growth in Britain.

The sandy beaches described in this chapter are only a small sample of the important beach sites included in the coastal geomorphology 'Block' of the GCR, since the great majority of the GCR sites have sandy beaches of one type or another. Chapters 9 and 11 also include descriptions of sandy beach and dune sites where such features are an important part of the coastal geomorphological assemblage. The great depositional sites of Morrich More in the Dornoch Firth and Culbin in the Moray Firth, the Northumbrian coast around Holy Island, the North Norfolk coast and Rhossili Bay (Carmarthen Bay GCR site) all provide unmodified, dynamic examples of some of the finest sandy beaches to be found in the UK.

Coastal dunes

There are over 295 separate coastal dune sites around Great Britain (shown on the small-scale map in (Figure 7.1)), the largest of which attain over 8000 ha in area. Their total area is about 70 000 ha of which 71% by area are in Scotland (Dargie, 2000).

(Table 7.2) Main features, sediment sources, tidal ranges of sandy beach and dune GCR sites, including coastal geomorphology GCR sites described in other chapters of the present volume that contain dune features in the assemblage. It should be noted that all of the machair sites in Chapter 9 have dune features (see Table 9.1). Sites described in the present chapter are in bold typeface.

Site	Main features	Other features	Present-day sediment sources	
Marsden Bay	Beach phases	Cliffs and stacks	Local cliff erosion — small	4.2
South Haven Peninsula	Shore-parallel dune ridges, originating from the 16th century, slacks, sand-spit	Relict and active cliffs., caves, rock platform	Longshore — restricted Offshore — significant	1.5
Upton and Gwithian Towans	Climbing dunes, exhumed bedrock base	Stacks	Offshore — restricted	5.8
Braunton Burrows	Large dune field, parabolic dunes, slacks	Ridge and runnel	Intertidal and estuarine	7.3
Oxwich Bay	Bay-head beach and dunes	Cliffs and emerged platform	Offshore — limited	8.2
Tywyn Aberffraw	Sand plain, isolated parabolic dunes shore-parallel linear dunes		Offshore, probably in deficit	4.7
Ainsdlale	Large dune field, slacks, ridge and runnel, long dated history		Offshore — limited — in deficit	8.3
Luce Sands	Bay-head dunes	Holocene emerged gravel ridges	Onshore and longshore — significant	5.6
Sandwood Bay	Dynamic beach-dune complex, climbing dunes	Gravel-cored bar, blowouts	Offshore and recycled — limited	4.2
Dunnet Bay	Bay-head dunes and sand plain	Blowouts	Offshore — limited	4.0
Baba Island	Climbing dunes	Beach-dune-grassland continuum	Local — limited	1.9
Strathbeg	Shore-parallel dune ridges, large blowouts	Holocene emerged gravel ridges	Longshore — restricted, loch outlet source	3.3
Forvie	Shore-parallel dune ridges, originally moved as waves northwards		Longshore — cycled from estuary	3.1
Barry Links	Foreland sand plain, linear parabolic dunes		Estuarine, longshore — limited	4.4
Tentsmuir	Shore-parallel dune ridges-intertidal sands		Estuarine and longshore — significant	4.4
Torrisdale and Invernaver	Beach-dune, hill-top dunes, glaciofluvial terraces	Archaeological context	Offshore and fluvial recycled — now limited	4.0
Morrich More	Shore-parallel beaches and dunes: sandplain	Holocene beaches and cliffs	Offshore — restricted	4.3
Culbin	Shore-parallel dunes, large dune field now stabilized by forest	Holocene emerged gravel ridges and spits	Longshore -restricted, offshore — limited	3.6

East Head	Small spit-based dunes		Intertidal	3.4
Holy Island	Dune field, spits, barrier beach	Cliffs, Holocene saltmarsh, intertidal mudflats	Longshore, offshore — significant	4.1
Dawlish Warren	Parallel spit-based linear dunes	Recurved spit	Intertidal and possibly estuarine In deficit	4.1
North Norfolk Coast	Major mainly linear dunes	Spits, barrier beach	Longshore and offshore	6A-4.7
Morfa Harlech	Linear shore-parallel dunes		Longshore — restricted, estuarine	4.5
Morfa Dyffryn	Linear shore-parallel dunes, blowouts, dunes invading slacks		Longshore — restricted, offshore	4.3
Winterton Ness	Linear dunes on cuspate foreland		Longshore	2.6
Ynyslas	Spit-based dunes		Longshore — restricted, estuarine	4.3
Carmarthen Bay				
Pendine	Shore-parallel linear dunes		Offshore, estuarine to distal end	8.0
Pembrey	Large dune field, spit-based linear dunes		Offshore and estuarine	8.0
Whitford spit	Estuary-mouth spit		Longshore, drying intertidal	8.0
Laugharne Burrows	Cliff-top dunes		Local redistribution, drying intertidal	8.0
Newborough Warren and Morfa Dinlle	Major dune field, parabolic and linear dunes, spit, tied island and slacks	Saltmarsh	Offshore and estuarine	4.7

(Table 7.3) Calcium carbonate content of upper beach/foredune in selected coastal geomorphology GCR sites. Sites described in the present chapter are in bold typeface. (Based in part on Goudie, 1990, and various sources cited by Ritchie and Mather, 1984.)

Dune location	**$CaCO_3$ (%)**	**Median grain size (Phi)**
Culbin	0.0	2.0
South Haven Peninsula	0.015	?
Lossiemouth	0.26	2.0
Tentsmuir	0.4	2.5
Luce Sands	0.5	2.4
Forvie	0.55	1.9
Buddon Ness (Barry Links)	1.0	2.0
Walney Island	1.51	2.21
Morfa Dyffryn	3.34	2.31
Ainsdale	3.57	2.13
Invernaver	3.8	1.9
Morfa Harlech	3.96	2.13
Newborough Warren	4.56	2.50

Ynyslas	4.98	2.29
Strathbeg	7.86	2.0
Rattray (Strathbeg site)	9.10	1.9
Laugharne (Pendine)*	11.15	2.40
Morrich More	12.0	2.4
Pembrey*	12.04	2.33
Oxwich Bay	12.45	1.93
Tywyn Aberffraw	13.20	2.47
Llangennith*	15.65	1.63
Braunton Burrows	19.59	2.13
Dunnet Bay	20.4	1.7
Dunbar	20.4	1.5
Westward Ho!	21.79	2.45
Machir, Islay	33.6	2.2
Mangersta, Lewis	38	1.4
Luskentyre, Harris	44	2.0
Tràigh na Berie, Lewis	47	2.4
St. Ninian's Tombolo, Shetland	47.5	2.0
Balnakiel	52.0	1.8
Hayle (Upton and Gwithian Towans)	56.80	1.56
Loch Gruinart, Islay	59.0	2.1
Eoligarry, Barra	80.0	2.0
Ardivachar, South Uist	84.0	1.7
Balta Island, Shetland	95.5	1.8

*Camarthen Bay

Most British dune systems originated when substantial seabed deposits were moved onshore during the early and middle part of the Holocene Epoch and began to be deposited dose to their present locations from about 6500 years BP In some areas where the sea-level history is more complex, such as in the Western Isles of Scotland, the arrival of dune sands first began about 8700 years BP and may have been non-synchronous between sites (see Chapter 9; Hansom and Angus, 2001). Dune systems such as those at Ainsdale and Braunton Burrows can be shown to have developed over the past six millennia, especially from the evidence of preserved peat associated with dune slacks and larger wetlands that developed shorewards of the coastal beaches. In contrast, other dunes are more recent, for example at South Haven Peninsula the dunes have formed since the 16th century. Some dunes, for example at Culbin, Moray, Newborough Warren on the Isle of Angelsey, and Hayle and Upton and Gwithian Towans, Cornwall, have migrated inland covering buildings and farmland. British dunes tend to be located:

1. in areas of high tidal range,
2. where prevailing winds provide the main means of landward aeolian transport, and
3. in association with estuary mouths dominated by large sandy sediment loads or at the heads of inlets and bays,
4. on north-eastern coasts, where strong winds from the north and east provide the means for landward aeolian transport e.g. the coasts between Aberdeen and Fraserburgh and Northumberland.

Narrow, linear-dune systems occur along eastern coasts that are associated with sandy estuaries or high tidal ranges, but the size of the dunes is generally much less than those of the exposed and windy western coasts, even though the intertidal sandy area may be very extensive.

There are few significant dunes on the eastern coast of England, apart from the dunes around Holy Island, Northumberland, and along the Lincolnshire and north Norfolk coasts. Between the Tees and the Tamar there are 24 dune sites (*c.* 8%) and between the Tamar and the Mull of Galloway 67 dune sites (*c.* 23%). The remaining 204 (*c.* 69%) sites lie along the coast of Scotland and the English coast north of the Tees. The largest area of dunes is in north-west Scotland, particularly in the Outer Hebrides where machair predominates (Ritchie and Mather, 1984; Dargie, 2000; see

Chapter 9). Of 43 nationally important sand dune sites, only six lie on the south or east coast (Doody, 1985).

(Table 7.4) Variations in calcium carbonate content and pH in foredunes and main dunes. (Based on Salisbury, 1952; and Willis, 1985)

Location	**Calcium carbonate**	**content of dunes**	**pH**	
	Foredunes	Main dunes	Foredunes	Main dunes
South Haven Peninsula	0.015	0.01	7.0	3.6
Southport (near Ainsdale)	6.0	0.2	8.2	5.5
Braunton Burrows	20.0	8.5	9.05	8.2
Blakeney Point, North Norfolk Coast	0.6	0.02	7.3	4.2

The foredunes around the coast of England and Wales are notable for their generally low calcium carbonate content (Table 7.3). Goudie (1990) shows that of 42 foredune areas in England and Wales, 29 had less than 20% $CaCO_3$. The highest values occur between Land's End, Cornwall, and Woolacombe, Devon, and along the south coast of Pembroke, with many greater than 50%. The highest $CaCO_3$ content in England and Wales occurs in Constantine Bay, Cornwall (87.5%). Studland Bay, Dorset, in contrast, has almost no $CaCO_3$ (only 0.015%). There is also a tendency for the main dunes to have lower $CaCO_3$ and pH than the foredunes (Table 7.4). The very high $CaCO_3$ content of the foredunes of the south-west coast is probably a result of the high concentrations of shell debris. The more carbonate-rich sands also tend to be coarser with mean D_{50} (median grain size value) of 1.75 phi (Goudie, 1990). This, with their comparatively low density and often platy form, may make them more readily transported by wind (Goudie, 1990). Where the main source is estuarine, the grain size is usually smaller. Scottish dunes and beaches, and especially machair, tend to follow a pattern of very high $CaCO_3$ content where biogeneic sources predominate often reaching extremely high values (Mather and Ritchie, 1984; e.g. Balta Island has 95.5% shell sand, see GCR site report in the present chapter).

On much of the southern coast of Britain, sand was in plentiful supply for dune building at the end of the main Holocene rise when sea level attained present levels about 6500 years BP In recent centuries, however, the supply of sand has diminished significantly and erosional conditions generally prevail.

In England, few southern or eastern dunes are accreting, the most important exceptions being at Holy Island and South Haven Peninsula, and even the latter is affected by erosion of its older southern beach and dunes. In contrast, on western and northern coasts, dunes are common features, reflecting the combination of plentiful sand supplies mainly from the seabed in the past, but also from upland river catchments, and the effects of prevailing onshore winds. However, many are now affected by wave erosion of their fronts either by occasional storms or by long-term changes in sea-level and storminess, together with reduced sediment supply. Prior to 6500 years BP sand supply for dune building was plentiful, but it is now much reduced, and, as a result, frontal dune erosion is commonplace (Hansom, 1988; Hansom and Angus, 2001).

The conservation value of sandy beaches and dunes

Dunes are geomorphologically important because of:

1. their natural dynamism and the relationship with their ecology
2. their role in preserving and then exhuming Holocene sedimentary sequences and
3. their role in coast protection.

The selected GCR sites (Table 7.2) include the beach and dune sites that best exemplify the different ways in which the physical coast responds to the effects of climate, waves and currents when there is a substantial and continuing provision of sand-sized sediments. They are areas of both progradation and erosion which provide a highly dynamic foundation for some of Britain's most important sites for fauna and flora. Internationally, they have been recognized by geomorphologists as exemplifying especially well the ways in which coastal dunes form, change and are modified.

Most dune systems around the British coast are complex, and very few have individual isolated stable dunes within them. English east coast dunes are generally narrow, have only limited periods of onshore winds, and lack large and constant sand supplies. Many of those on the west coast lie upon bedrock surfaces of varying height and so lack the level foundations of sand plains. They also have usually had ample supplies of sand in the past that have produced a complex dune topography in which 'dunes are at many stages of development and sand is transferred from erosional phases to depositional ones (for example at Newborough Warren and Morfa Dyffryn). Tywyn Aberffraw is an important member of the network of dune systems because of its relatively limited sediment supply and restricted development of dunes. In this respect it contrasts especially strongly with its neighbour at Newborough Warren.

In this chapter the site reports are ordered in a clockwise fashion starting with the Marsden Bay GCR site.

Dunes and sandy beaches as biological SSSIs and Special Areas of Conservation (SACs)

In Chapter 1, it was emphasized that the SSSI site series is constructed both from areas nationally important for wildlife, and GCR sites. An SSSI may be established solely for its geology/ geomorphology, or its wildlife/habitat, or it may comprisc a 'mosaic' of biological and GCR sites that may be adjacent, partly overlap, or be coincident. There are a number of sand dune and beach sites that are crucially important to the natural heritage of Britain that are notified as SSSIs primarily for their wildlife value, but implicitly will contain interesting coastal geomorphology features that are not included independently in the GCR because of the 'minimum number' criterion of the GCR rationale (see Chapter 1). These sites are not described in the present geomorphologically focused volume.

(Table 7.5) Candidate and possible Special Areas of Conservation in Great Britain supporting Habitats Directive Annex I coastal dune habitat(s) (other than machair) as qualifying European features. Non-significant occurrences of these habitats on SACs selected for other features are not included. (Source: JNCC International Designations Database, July 2002.)

SAC name	Local authority	Dune habitat extent (ha)
Barry Links	Angus	447.6
Braunton Burrows	Devon	767.5
Carmarthen Bay Dunes/Twyni Bae Caerfyrddin	Abertawe/ Swansea; Caerfyrddin/ Carmarthenshire	780.2
Coll Machair	Argyll and Bute	409.0
Culbin Bar	Highland; Moray	612.9
Dawlish Warren	Devon	28.2
Dee Estuary/ Aber Dyfrdwy*	Cheshire; Fflint/ Flintshire; Wirral	4.0
Dornoch Firth and Morrich More	Highland	974.4
Dorset Heaths (Purbeck and Wareham) and Studland Dunes	Dorset	95.9
Drigg Coast	Cumbria	519.8
Durness	Highland	386.7
Humber Estuary*	City of Kingston upon Hull; East Riding of Yorkshire; Lincolnshire; North East Lincolnshire; North Lincolnshire	529.0
Invernaver	Highland	54.2
Kenfig/ Cynffig	Pen-y-bont ar Ogwr/ Bridgend	673.8
Limestone Coast of South West Wales/ Arfordir Calchfaen de Orllewin Cymru	Abertawe/ Swansea; Penfro/ Pembrokeshire	397.1
Monach Islands	Western Isles / Na h-Eileanan an Iar	215.1
Morecambe Bay	Cumbria; Lancashire	220.5
Morfa Harlech a Morfa Dyffryn	Gwynedd	228.6
North Norfolk Coast	Norfolk	387.3
North Northumberland Dunes	Northumberland	1078.6

North Uist Machair	Western Isles / Na h-Eileanan an Iar	963.3
Oldshoremore and Sandwood	Highland	165.3
Penhale Dunes	Cornwall	422.4
Saltfleetby-Theddlethorpe Dunes and Gibraltar Point	Lincolnshire	265.6
Sands of Forvie	Aberdeenshire	469.7
Sandwich Bay	Kent	258.3
Sefton Coast	Sefton	1072.7
Solent Maritime	City of Portsmouth; City of Southampton; Hampshire; Isle of Wight; West Sussex	113.2
Solway Firth	Cumbria; Dumfries and Galloway	32.6
South Uist Machair	Western Isles / Na h-Eileanan an Iar	545.7
Tiree Machair	Argyll and Bute	237.4
Torrs Warren-Luce Sands	Dumfries and Galloway	819.5
Winterton-Horsey Dunes	Norfolk	44.7
Y Twyni o Abermenai i Aberffraw/ Abermenai to Aberffraw Dunes	Gwynedd; Ynys Mon/ Isle of Anglesey	672.3
* Possible SAC not yet submitted to EC.	Bold type indicates a coastal GCR interest within the site.	

The importance of dunes as areas of national ecological significance was recognized and described by Tansley (1939, 1945) and Steers (1946a, 1953a). Soon after the Nature Conservancy was established in 1949, it designated a number of major dunes as National Nature Reserves, including Braunton Burrows, Newborough Warren, Ainsdale and Holy Island. The *Nature Conservation Review* (Ratcliffe, 1977) confirmed the great importance of dunes as part of the network of nationally significant sites.

In addition to being protected through the SSSI system for their national importance, certain types of dune are Habitats Directive Annex I habitats, eligible for selection as Special Areas of Conservation (see Chapter 1). The Directive identifies a suite of dune vegetation types (see below), representing the succession from dune initiation to mature, stable dune habitat. Collectively, these types encompass almost the full range of coastal dune habitats present in the UK.

Dune SAC site selection rationale

The sites are, for the most part, the most extensive examples in the UK and have the best conserved structure and function, demonstrating transitions between Annex I types, while also representing the range of geographic and ecological variation of each habitat type.

- **Embryonic shifting dune vegetation** exists in a highly dynamic state and is dependent on the continued operation of physical processes at the dune/beach interface. It is the first type of vegetation to colonize areas of incipient dune formation at the top of a beach.
- **Shifting dunes along the shoreline with *Ammophila arenaria* ('white dunes')** encompass most of the vegetation of unstable dunes where there is active sand movement. Under these conditions sand-binding marram *A. arenaria* is always a prominent feature of the vegetation and is usually dominant.
- **Fixed dune vegetation** occurs mainly on the largest dune systems, being those that have the width to allow it to develop. It typically occurs inland of the zone dominated by mar-ram *Ammophila arenaria* on coastal dunes, and represents the vegetation that replaces marram as the dune stabilizes and the organic content of the sand increases.
- **Decalcified fixed dunes with crowberry *Empetrum nigrum***represent the later, more mature, stages of the successional sequence characteristic of sand dunes. Exposure to rainfall over long periods means that there is leaching of the surface layers, causing a loss of calcium carbonate and increased soil acidity.
- **Atlantic decalcified fixed dunes (*Calluno-Ulicetea*)**occur on mature, stable dunes where the initial calcium carbonate content of the dune sand is low. The surface soil layers rapidly lose their remaining calcium carbonate

through leaching, and become acidified.

- **Dunes with *Hippophae rbamnoides***comprise scrub vegetation on more-or-less stable sand dunes in which sea-buckthorn is abundant.
- **Dunes with *Salix repens* ssp. *argentea*,** where creeping willow is dominant, forming prominent, low scrubby growth.
- **Humid dune slacks** are low-lying areas within dune systems that are seasonally flooded and where nutrient levels are low. Dune slacks are often rich in plant species.
- **Coastal dunes with juniperJuniperus spp.** comprises common juniper scrub in a variety of dune situations.
- **Machair** — see Chapter 9 of the present volume.

(Table 7.5) lists coastal sand dune SACs, and indicates which of these sites are also (at least in part) important as part of the GCR and are described in the present chapter.

(Figure 7.1) Great Britain sandy beaches and coastal dunes, also indicating the location of GCR machair–dune sites (see chapter 9) and other coastal geomorphology GCR sites that contain dunes in the assemblage.

all of the others.

It is evident from the GCR sites described in this chapter (Figure 7.1 and Tables 7.1 and 7.2) that both beach and dune features co-exist and depend upon the availability of sand that may come from the seabed, from fluvial sources and from cliff erosion, depending upon their geomorphological setting. Small sand beaches can develop with very limited sediment supplies. For example, small sand beaches form localized pockets within embayments of the Thanet chalk coast and the indented rocky coasts of south-western Britain and northern and western Scotland. Sand commonly forms a veneer on some shore platforms and displays a range of minor current- and wave-related forms.

In the Chalk, sand derives from attrition of flint and from the release of fossil shell fragments from the chalk itself. Elsewhere, sandstone and soft sediment cliffs provide large quantities of sand to their beaches, which may then be transported alongshore. Erosion of the till coast and shallow seabed off Holderness provides very large volumes of sand and gravel annually that are transported both alongshore to form a large sand spit at Spurn Head and into the North Sea. Along the coast of East Anglia, very large volumes of sand and gravel are derived from erosion of till cliffs, but there are also large volumes in offshore banks that result

Table 7.1 Main features and present-day sediment sources of dune types. Exemplar sites described in the present chapter are **in bold** typeface. See also Table 7.2. (Based on Ranwell, 1972.)

Type	Sediment sources	Geomorphological setting	Wind directions	Exemplar GCR sites
Foreshore dunes				
Spit dunes	Intertidal banks and longshore	On promontories at estuary mouths with near-parallel or radiating ridges and slacks	More common with onshore prevailing and dominant, but not restricted to this	**Forvie**, **Strathbeg**, **South Haven Peninsula**, Morfa Harlech, Holy Island (Gosnick and the Snook), Culbin, Morrich More
Prograding ness dunes	Accretion at ness, possibly with longshore sediment supply from opposite directions alongshore	On open coast	Prevailing and dominant winds from opposite directions (offshore/ onshore)	Winterton Ness, **Barry Links**, **Tentsmuir**
Offshore island dunes	Offshore, longshore and intertidal drying banks	Offshore or barrier islands narrow, subject to washover, often display time-series development in main direction of longshore transport	Can occur with both onshore and offshore prevailing winds	Scolt Head Island, Blakeney Point recurves (North Norfolk Coast), Pembrey (Carmarthen Bay), Culbin, Morrich More
Hindshore dunes				
Bay dunes	Restricted in longshore direction	Usually at bay head on indented coasts	Prevailing onshore	**Dunnet Bay**, **Luce Sands**, **Upton and Gwithian Towans**, **Tywyn Aberffraw**, **Oxwich Bay Sandwood**, **Balta Island**, **Torrisdale Bay and Invernaver**
Hindshore dune system	Offshore and intertidal	Extensive sandy coasts	Prevailing and dominant winds from the same direction	**Braunton Burrows**, **Newborough Warren**, **Ainsdale**, Holy Island (**Ross Links**)
Hindshore sand plains	Offshore, intertidal and beach	Bay-head and low-lying rocky coasts	High wind-speeds that restrict vertical development	**Tywyn Aberffraw**

(Table 7.1) Main features and present-day sediment sources of dune types. Exemplar sites described in the present chapter are in bold typeface. See also Table 7.2. (Based on Ranwell, 1972.)

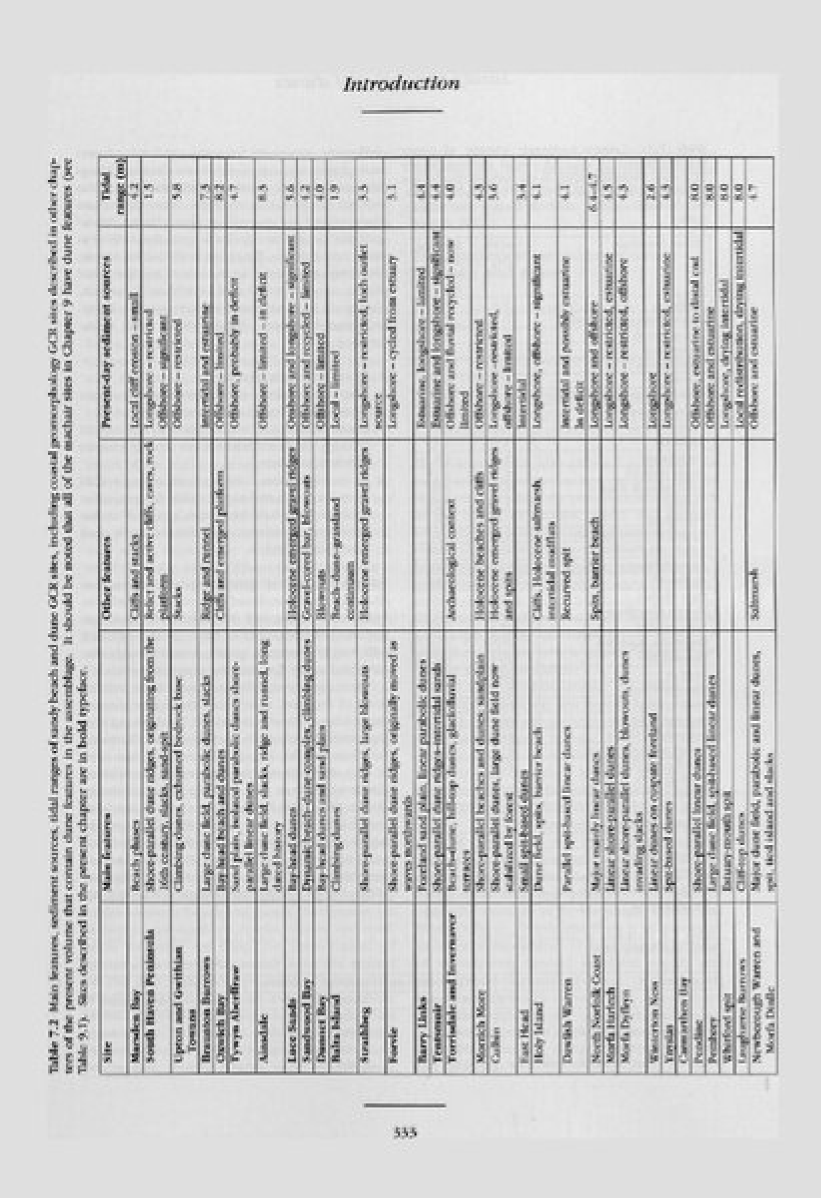

Table 7.2 Main features, sediment sources, tidal ranges of sandy beach and dune GCR sites, including coastal geomorphology GCR sites described in other chapters of the present volume that contain dune features in the assemblage. It should be noted that all of the machair sites in Chapter 9 have dune features (see Table 9.1). Sites described in the present chapter are in **bold** typeface.

Site	Main features	Other features	Present-day sediment sources	Tidal range (m)
Marsden Bay	Beach phases	Cliffs and stacks	Local cliff erosion – small	4.2
South Haven Peninsula	Shore-parallel dune ridges, originating from the 16th century, slacks, sand-spit	Relict and active cliffs, caves, rock platform	Longshore – restricted Offshore – significant	1.5
Upton and Gwithian Towans	Climbing dunes, exhumed bedrock base	Stacks	Offshore – restricted	5.8
Braunton Burrows	Large dune field, parabolic dunes, slacks	Ridge and runnel	Intertidal and estuarine	7.3
Oxwich Bay	Bay-head beach and dunes	Cliffs and emerged platform	Offshore – limited	8.2
Tywyn Aberffraw	Sand plain, isolated parabolic dunes shore-parallel linear dunes		Offshore, probably in deficit	4.7
Ainsdale	Large dune field, slacks, ridge and runnel, long dated history		Offshore – limited – in deficit	8.3
Luce Sands	Bay-head dunes	Holocene emerged gravel ridges	Onshore and longshore – significant	5.6
Sandwood Bay	Dynamic beach-dune complex, climbing dunes	Gravel-cored bar, blowouts	Offshore and recycled – limited	4.2
Dunnet Bay	Bay-head dunes and sand plain	Blowouts	Offshore – limited	4.0
Balta Island	Climbing dunes	Beach-dune-grassland continuum	Local – limited	1.9
Strathbeg	Shore-parallel dune ridges, large blowouts	Holocene emerged gravel ridges	Longshore – restricted, loch outlet source	3.3
Forvie	Shore-parallel dune ridges, originally moved as waves northwards		Longshore – cycled from estuary	3.1
Barry Links	Foreland sand plain, linear parabolic dunes		Estuarine, longshore – limited	4.4
Tentsmuir	Shore-parallel dune ridges-intertidal sands		Estuarine and longshore – significant	4.4
Torrisdale and Invernaver	Beach-dune, hill-top dunes, glaciofluvial terraces	Archaeological context	Offshore and fluvial recycled – now limited	4.0
Morrich More	Shore-parallel beaches and dunes: sandplain	Holocene beaches and cliffs	Offshore – restricted	4.3
Culbin	Shore-parallel dunes, large dune field now stabilized by forest	Holocene emerged gravel ridges and spits	Longshore – restricted, offshore – limited	3.6
East Head	Small spit-based dunes		Intertidal	3.4
Holy Island	Dune field, spits, barrier beach	Cliffs, Holocene saltmarsh, intertidal mudflats	Longshore, offshore – significant	4.1
Dawlish Warren	Parallel spit-based linear dunes	Recurved spit	Intertidal and possibly estuarine In deficit	4.1
North Norfolk Coast	Major mainly linear dunes	Spits, barrier beach	Longshore and offshore	6.4–4.7
Morfa Harlech	Linear shore-parallel dunes		Longshore – restricted, estuarine	4.5
Morfa Dyffryn	Linear shore-parallel dunes, blowouts, dunes invading slacks		Longshore – restricted, offshore	4.3
Winterton Ness	Linear dunes on cuspate foreland		Longshore	2.6
Ynyslas	Spit-based dunes		Longshore – restricted, estuarine	4.5
Carmarthen Bay				
Pendine	Shore-parallel linear dunes		Offshore, estuarine to distal end	8.0
Pembrey	Large dune field, spit-based linear dunes		Offshore and estuarine	8.0
Whiteford spit	Estuary-mouth spit		Longshore, drying intertidal	8.0
Laugharne Burrows	Cliff-top dunes		Local redistribution, drying intertidal	8.0
Newborough Warren and Morfa Dinlle	Major dune field, parabolic and linear dunes, spit, tied island and slacks	Saltmarsh	Offshore and estuarine	4.7

(Table 7.2) Main features, sediment sources, tidal ranges of sandy beach and dune GCR sites, including coastal geomorphology GCR sites described in other chapters of the present volume that contain dune features in the assemblage. It should be noted that all of the machair sites in Chapter 9 have dune features (see Table 9.1). Sites described in the present chapter are in bold typeface.

(Figure 7.9) Aerial photograph of dunes and Crow Point. 1, Westward Ho! cobble beach; 2, Taw–Torridge estuary; 3, Crow Point; 4, Airy Point; 5, Braunton Burrows showing main dune ridges and blowthroughs; 6, ridge-and-runnel beach. (Photo: courtesy Cambridge University Collection of Aerial Photographs, Crown Copyright, Great Scotland Yard.)

Table 7.3 Calcium carbonate content of upper beach/foredune in selected coastal geomorphology GCR sites. Sites described in the present chapter are in **bold** typeface. (Based in part on Goudie, 1990, and various sources cited by Ritchie and Mather, 1984.)

Dune location	$CaCO_3$ (%)	Median grain size (phi)
Culbin	0.0	2.0
South Haven Peninsula	0.015	?
Lossiemouth	0.26	2.0
Tentsmuir	0.4	2.5
Luce Sands	0.5	2.4
Foevie	0.55	1.9
Buckton Ness (**Barry Links**)	1.0	2.0
Walney Island	1.51	2.21
Morfa Dyffryn	3.34	2.31
Ainsdale	3.57	2.13
Invernaver	3.8	1.9
Morfa Harlech	3.96	2.13
Newborough Warren	4.56	2.50
Youlas	4.98	2.29
Strathbeg	7.86	2.0
Rattray (Strathbeg site)	9.10	1.9
Laugharne (Pendine)*	11.15	2.00
Morrich More	12.0	2.4
Pembrey*	12.04	2.53
Oxwich Bay	12.45	1.93
Tywyn Aberffraw	13.20	2.47
Llangennith*	15.65	1.63
Braunton Burrows	19.59	2.13
Dunnet Bay	20.4	1.7
Dunbar	20.4	1.5
Westward Ho!	21.79	2.65
Machir, Islay	33.6	2.2
Mangersta, Lewis	38	1.4
Luskentyre, Harris	44	2.0
Traigh na Beric, Lewis	47	2.4
St. Ninian's Tombolo, Shetland	47.5	2.0
Balnakiel	52.0	1.8
Hayle (Upton and Gwithian Towans)	56.80	1.56
Loch Gruinart, Islay	59.0	2.1
Rodgarry, Barra	80.0	2.0
Ardivachar, South Uist	84.0	1.7
Balta Island, Shetland	95.5	1.8

* Carmarthen Bay

millennia, especially from the evidence of preserved peat associated with dune slacks and larger wetlands that developed shorewards of the coastal beaches. In contrast, other dunes are more recent, for example at South Haven Peninsula the dunes have formed since the 16th century. Some dunes, for example at Culbin, Moray, Newborough Warren on the Isle of Angelsey, and Hayle and Upton and Gwithian Towans, Cornwall, have migrated inland covering buildings and farmland. British dunes tend to be located:

1. in areas of high tidal range,
2. where prevailing winds provide the main means of landward aeolian transport, and
3. in association with estuary mouths dominated by large sandy sediment loads or at the heads of inlets and bays,
4. on north-eastern coasts, where strong winds from the north and east provide the means for landward aeolian transport e.g. the coasts between Aberdeen and Fraserburgh and Northumberland.

Narrow, linear-dune systems occur along eastern coasts that are associated with sandy estuaries or high tidal ranges, but the size of the dunes is generally much less than those of the exposed and windy western coasts, even though the intertidal sandy area may be very extensive.

There are few significant dunes on the eastern coast of England, apart from the dunes around Holy Island, Northumberland, and along the Lincolnshire and north Norfolk coasts. Between the Tees and the Tamar there are 24 dune sites (c. 8%) and between the Tamar and the Mull of Galloway 67 dune sites (c. 23%). The remaining 204 (c. 69%) sites lie along the coast of Scotland and the English coast north of the Tees. The largest area of dunes is in north-west Scotland, particularly in the Outer Hebrides where machair predominates (Ritchie and Mather, 1984; Dargie, 2000; see Chapter 9). Of 43

Table 7.4 Variations in calcium carbonate content and pH in foredunes and main dunes. (Based on Salisbury, 1952; and Willis, 1985)

Location	Calcium carbonate content of dunes		pH	
	Foredunes	Main dunes	Foredunes	Main dunes
South Haven Peninsula	0.015	0.01	7.0	5.6
Southport (near Ainsdale)	6.0	0.2	8.2	5.5
Braunton Burrows	20.0	8.5	9.05	8.2
Blakeney Point, North Norfolk Coast	0.6	0.02	7.3	4.2

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Mangersta, Lewis	38	1.4
Luskentyre, Harris	44	2.0
Traigh na Beric, Lewis	47	2.4
St. Ninian's Tombolo, Shetland	47.5	2.0
Balnakiel	52.0	1.8
Hayle (Upton and Gwithian Towans)	56.80	1.56
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1. in areas of high tidal range,
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Dunes and sandy beaches as biological SSSIs and Special Areas of Conservation (SACs)

In Chapter 1, it was emphasized that the SSSI site series is constructed both from areas nationally important for wildlife, and GCR sites. An SSSI may be established solely for its geology/geomorphology or its wildlife/habitat, or it may comprise a 'mosaic' of biological and GCR sites that may be adjacent, partly overlap, or be coincident. There are a number of sand dune and beach sites that are crucially important to the natural heritage of Britain that are notified as SSSIs primarily for their wildlife value, but implicitly will contain interesting coastal

Table 7.5 Candidate and possible Special Areas of Conservation in Great Britain supporting Habitats Directive Annex I coastal dune habitat(s) (other than machair) as qualifying European features. Non-significant occurrences of these habitats on SACs selected for other features are not included. (Source: JNCC International Designations Database, July 2002.)

SAC name	Local authority	Dune habitat extent (ha)
Barry Links	Angus	447.6
Braunton Burrows	Devon	767.5
Carmarthen Bay Dunes/Twyni Bae Caerfyrddin	Abertawe/ Swansea; Caerfyrddin/ Carmarthenshire	780.2
Goll Machair	Argyll and Bute	409.0
Culbin Bar	Highland; Moray	612.9
Dawlish Warren	Devon	28.2
Dee Estuary/ Aber Dyfrdwy*	Cheshire; Flint/ Flintshire; Wirral	4.0
Dornoch Firth and Morrich More	Highland	974.4
Dorset Heaths (Purbeck and Wareham) and Studland Dunes	Dorset	95.9
Drigg Coast	Cumbria	519.8
Durness	Highland	386.7
Humber Estuary*	City of Kingston upon Hull; East Riding of Yorkshire; Lincolnshire; North East Lincolnshire; North Lincolnshire	529.0
Invernaver	Highland	54.2
Kenfig/ Cynffig	Pen-y-bont ar Ogwr/ Bridgend	673.8
Limestone Coast of South West Wales/ Arfordir Calchfaen de Orllewin Cymru	Abertawe/ Swansea; Penfro/ Pembrokeshire	397.1
Monach Islands	Western Isles / Na h-Eileanan an Iar	215.1
Morecambe Bay	Cumbria; Lancashire	220.5
Morfa Harlech a Morfa Dyffryn	Gwynedd	228.6
North Norfolk Coast	Norfolk	387.3
North Northumberland Dunes	Northumberland	1078.6
North Uist Machair	Western Isles / Na h-Eileanan an Iar	963.3
Oldshoremore and Sandwood	Highland	165.3
Penhale Dunes	Cornwall	422.4
Saltfleetby-Theddlethorpe Dunes and Gibraltar Point	Lincolnshire	265.6
Sands of Forvie	Aberdeenshire	469.7
Sandwich Bay	Kent	258.3
Sefton Coast	Sefton	1072.7
Solent Maritime	City of Portsmouth; City of Southampton; Hampshire; Isle of Wight; West Sussex	113.2
Solway Firth	Cumbria; Dumfries and Galloway	52.6
South Uist Machair	Western Isles / Na h-Eileanan an Iar	545.7
Tiree Machair	Argyll and Bute	237.4
Torrs Warren–Luce Sands	Dumfries and Galloway	819.5
Winterton–Horsey Dunes	Norfolk	44.7
Y Twyni o Abermenai i Aberffraw/ Abermenai to Aberffraw Dunes	Gwynedd; Ynys Môn/ Isle of Anglesey	672.3

* Possible SAC not yet submitted to EC.

Bold type indicates a coastal GCR interest within the site.

(Table 7.5) Candidate and possible Special Areas of Conservation in Great Britain supporting Habitats Directive Annex I coastal dune habitat(s) (other than machair) as qualifying European features. Non-significant occurrences of these habitats on SACs selected for other features are not included. (Source: JNCC International Designations Database, July 2002.)