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Management of coastal vegetated shingle in the United Kingdom

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Abstract. Coastal vegetated shingle is a rare and declining resource worldwide but is found extensively around the UK coastline. Shingle sediments b-axes range between 2 mm and 200 mm and occur as fringing beaches, bars, spits, barrier islands and forelands. Sediment patterns are dependent upon accretion or erosion. With sea-level rise, shingle features tend to move inland. Larger features may support reservoirs of fresh water but risk becoming saline with sea-level rise. Ranker soils may develop but are naturally fragile. Vegetated shingle communities are dependent upon substrate stability, moisture and nutrient availability. Only specialized and some ruderal plants can persist in patterns dependent upon geomorphic history. Coastal defence, agriculture, public access and control of alien species are important factors in habitat management. Because of its dynamic and unusual nature coastal vegetated shingle is an important habitat for environmental education.

Keywords: Coastal squeeze; Geomorphology; Gravel; Sea-level change; Shoreline management; Succession; Vegetation.

Abbreviations: BAP = Biodiversity Action Plan; LNR = Local Nature Reserve.

Introduction

The term ‘shingle’ has been used for at least 400 yr in Britain and some Commonwealth countries, to describe sediments composed of mainly rounded pebbles, larger in diameter than sand (> 2 mm) but smaller than boulders (< 200 mm). Elsewhere terms such as gravel, stone, levées de galets, playas de cantos, Schotterwälle and Steinstrand are used. In many locations shingle is mixed with sand, silt, clay or organic debris, resulting in a ‘mixed’ sediment beach but all shingle and boulder beaches can be regarded as different types of ‘coarse clastic’ beach (Carter & Orford 1993).

In general shingle coasts have received less scientific attention than sandy and muddy shorelines. In part, this reflects the fact that, at a world scale, they are much less common. However, in recent decades there has been an increasing awareness of the geomorphologic, ecological and engineering significance of shingle coasts in the contexts of sea-level change, flood defence and habitat conservation. Such coasts are now recognized as an internationally important, but disappearing resource (Packham et al. 2001).

Land form types and coastal processes

Shingle coasts develop in wave-dominated locations where suitably sized material is available. At a global scale they dominate at high latitudes and in those areas of temperate shores which were affected by Pleistocene glaciation. They are locally important in some other temperate and low latitude areas where high relief landscapes of suitable geology occur near the coast, near the estuaries of high-energy rivers, or occasionally where coral is present. Elsewhere they are of limited importance.

At a regional scale, lithographic composition determines shingle availability and durability. Hard materials such as flint, chert, granite, quartzite, and some metamorphic materials survive much longer at this clast size than sandstones, limestones or shells. Around Great Britain some 19 000 km of shoreline have an important shingle component, with almost 3500 km of these coasts being pure shingle (Sneddon & Randall 1993-1994). Many of the shingle-barrier systems occurring on present-day coastlines were initiated during the Holocene marine transgression and are currently undergoing considerable morphological change as a result of rising relative sea-levels causing landward and long-shore reworking of finite sediment volumes found in beaches and barriers.

Shingle coasts can comprise several different types, which vary according to their history, mobility and oceanicity and therefore offer different habitats to vegetation, wildlife and man (Pye 2001; Sneddon & Randall 1993-1994).

Fringing or *pocket beaches* are narrow strips of shingle coast in contact with the land along the top of the beach. These are usually subject to regular marine inundation. They frequently occur at the foot of sedimentary cliffs such as chalk in southern Britain, but may also occur in front of coastal dunes or salt-marsh cliffs.

Shingle spits are strips of shingle, which grow out from the coast where there is an abrupt change in the direction of the coastline. They commonly occur, therefore, along coasts, which have an irregular plan. Spits often display recurved hooks along their length and at their distal ends. This may occur as a result of refraction of an often dominant single wave direction or where the shingle is, or has been, subject to wave refraction. It is possible to trace the development of a spit's growth via recurved hooks, seen as lateral projections from the lee of the spit, which locate the position of the past distal points, (Randall 1973). Paired spits are found at the entrance of several harbours on the south coast of England, including Pagham and Langstone. These may have originated as submarine 'bars' or more likely 'barriers', which have breached, but in other cases, independent growth of two spits may be due to bi-directional long-shore drift due to wave refraction around inlet sedimentary bodies. Other bi-directional situations may relate to refraction around an estuary flood delta (or palaeo-delta in the case of Pagham-Langstone) which induces local bi-directionality toward the estuary mouth.

On transgressive coasts, shingle spits tend to retreat and frequently overlay back-barrier marsh or lagoon deposits as at Shingle Street, Suffolk. In some instances spits may be dissected to form barrier islands (Scolt Head, Norfolk, also provides a good graphical example of this process). Transgressive ridges, often composed mainly of shell-shingle, are well developed on the marsh-coast of Essex. Similar features are also found in the Gulf of Mexico and in Auckland Bay, New Zealand. In the Gulf of Mexico they are known as 'cheniers'. This term is also applied to shell ridges on the Essex Marshes.

Tombolo barriers, or *bars*, are geomorphologically similar to spits, representing the extreme case where a spit has grown across an estuary or coastal indentation. This results in the formation of a lagoon behind the bar, which clearly affects the hydrology, and ecology of the leeward slope. Chesil Beach in Dorset is a prime British example of a tombolo barrier beach. Rivers, which provide a source of shingle-sized sediment, may have prograded strand plains or deltas of shingle at their mouth. In Scotland the Kingston Shingles are found at the mouth of the Spey (Sneddon & Randall 1993-1994) and South Island, New Zealand has particularly good examples, such as at the mouth of the Waitaki River.

At points of littoral drift convergence the formation of a second set of apposition ridges deposited at a different angle, will lead to the formation of a ness or cuspate foreland, a triangular mass of shingle such as Rhunahaorine Point, Argyll and Cape Canaveral in Florida. The island of Rügen in Baltic Germany is effectively a *cuspate foreland* cut off from the mainland. Cuspate forelands can also be due to consistent littoral drift. Dungeness may well be the result of the old delta of the River Rother acting as a groyne to long-shore drift from west to east. Such features often support a terrestrial geomorphic system inland of the coastal ridges.

The final type of shingle formation is the *offshore barrier island*, formed where a large mass of shingle has been deposited offshore and which may act as the 'skeleton' for a coastal sand-dune system. Culbin Bar, Morayshire, is a prime example. Scolt Head Island may have originated as a spit, which was subsequently segmented as sediment supply was stretched.

Most shingle coasts have a steep upper beach slope, a gentle lower beach slope and a relatively steep overall near-shore profile. Partial wave energy on steep, reflective beaches results in the formation of edge-waves sufficient to induce rhythmic long-shore features such as beach cusps on shingle beaches. Shingle morphologies are frequently of considerable ecological importance in terms of habitat diversity and play a vital protective geomorphologic role in determining the stability of adjoining low energy 'soft' sediments of mud flats and salt marshes. Unless the shingle coastal features are mobile, a partial vegetation cover is the norm for shingle above the water line. The middle and lower beach are usually kept bare by wave action, but upper beaches are vegetated. The rate and extent of plant colonization is dependent upon the degree of disturbance and shingle mobility, the presence or otherwise of a fine sediment matrix within the spaces between larger sediments and the hydrological regime of the shingle.

Sediment patterns

All shingle coasts contain a mixture of different sized sediments. Some are well sorted and consist entirely of pebbles, while others are poorly sorted and may also contain sand and/or boulders. Because there is frequently considerable temporal and spatial variation in shingle and mixed shingle/sand beaches, accurate determination of average textural qualities is difficult. Most coarse sediment coasts become coarser up-beach, because backwash and gravity cannot move larger clasts initially located by swash excursion. Hence many locations have shingle only on the upper beach. Discoid pebbles are sorted preferentially on the upper parts of the beach with spheres and rods occurring nearer the sea (Bluck 1967). Sediment grading along-shore also occurs due to selective transport of finer sediments in the down-drift direction as at Chesil Beach. However, other sites show much more complex patterns as a result of bi-directional wave-induced currents of varying magnitudes. Shingle coast micro-relief dynamics depend upon spring to neap tidal patterns and wind and wave conditions. The upper 50 - 80 cm of sediment is frequently re-mobilized forming berms and cusps that change from one tidal-cycle to another. More major changes occur seasonally as a result of spring to neap tidal fluctuations and especially at those times when storm-wave energy is higher.

The internal sedimentary architecture of shingle land forms reflects the process regime and net evolutionary trends of the structure (Randall 1973). The external structure of ridges varies depending on whether they are vertically accreting but laterally stable, laterally migrating or developing on a seaward prograding plain. The depressions between ridge crests may be partly filled by washover and storm-tossed deposits, so that there is often a marked difference in average particle size and shape between ridge fulls (crests) and lows (Randall & Fuller 2001). Sediment grading may also occur as a result of long-shore drift with selective transport of finer sediments downdrift. However, on many coasts sediment grading has been found to be complex in relation to seasonal variation in the long-shore current and wave regime (Pye 2001).

Sea-level change

Sea-level rise has the tendency to move shingle land forms inland (Carter & Orford 1993) but if sea-level rise is particularly rapid, shingle structures may be drowned in situ by overstepping (Forbes et al. 1991). Normally, however, under moderate storm-wave activity, shingle is pushed to the top of the front-beach ridge; while in major storms the ridge is overtopped or breached, creating shingle aprons in the back-barrier area. As this pattern is repeated, so the ridge migrates landward by roll-over. Many of the major shingle formations present today formed in this way during the Holocene marine transgression, initiating at a time of lower sea stand and reaching their present location by around 4000 BP. Most current shingle features are relict or dependent upon erosional sediments often derived from glacial debris. Given the low relative sea level conditions of the last millennium, there is currently a shortage of sediment at the updrift end of many transport cells and hence, increasing risk of overwashing and breaching in those areas (Orford et al. 2001).

Hydrology

Burnham & Cook (2001) reported that substantial areas of coastal shingle support a fresh water table that overlies saline water near the coast. Dungeness, Pevensey Beach, Blakeney Point and Shingle Street are good examples but there is little doubt that the hydrology is similar elsewhere. The importance of shingle as an aquifer, is the great rate at which water passes through the coarse sediment. At Denge Beach, Dungeness, this ranges from 300 - 1000 m^3/day. Such easy transmission means that any ‘doming’ of the water table is of low amplitude and water levels oscillate with the tidal phase. Penetration by seawater during storm tides can be equally rapid. Water abstraction from the Denge aquifer has taken place since the early years of the twentieth century. Following a report in 1984 that highlighted saline incursion this aquifer was seen as a finite and fragile resource. The abstraction licence was reduced to 3300Ml/yr and a management regime incorporated. Penetration by seawater during storm tides can be equally rapid.

Soils

Most shingle substrates do not develop a stratified soil. However, on shingle that has been stable for a very long period of time a ‘ranker’ or ‘ranker-like’ alluvial soil may develop within which the fine component is primarily plant-derived and earthworms are normally absent. The development of vegetation seems to be associated more with the presence of fine sediment rather than elevation or exposure. Using the studies at Orfordness and Dungeness Fuller (1987) suggests that the distribution of vegetated shingle is determined by a number of factors:

- Coarse shingle – seeds fall too deeply for germination and growth to the surface to occur;
- Poor water retention of the shingle substratum inhibits germination and seedling establishment;
- Plants, even if they survive the initial stages of growth,

may succumb to drought conditions and die, with the exception of a few highly specialized plants with long tap roots such as *Crambe maritima*;

Where plants do become established they help promote the build up of organic residues through the decay of roots and above-ground organic material. Mites and collembolans can help break down these plant remains to dark molder-like humus. At the same time the plant's ability to trap wind-blown debris increases litter accumulation. The soils so developed tend to be naturally highly acid, but can be nearer neutral if the shingle contains a large amount of shelly material. This accumulation of humus enhances moisture retention and with it the nutrient status of the soils and hence helps the establishment of more permanent plant cover. Hence, the more mature vegetation of the Culbin Shingle Bar, Scotland which is located in an area of high rainfall supports low-growing scrub in a matrix including *Salix repens*, *Empetrum nigrum* and *Calluna vulgaris*.

Vegetated shingle

Vegetated shingle is recognized as an internationally important 'Natura 2000' habitat. It is scarce in Europe with the UK supporting a high proportion of the European resource. Elsewhere, coastal shingle has few occurrences outside Japan and New Zealand. Coastal vegetated shingle is listed as a priority habitat in the UK Biodiversity Action Plan (BAP) and supports nine BAP priority species. It is characterized by specialized plants that have adapted to survive in harsh coastal conditions where lack of fresh water and nutrients are compounded by fierce winds and impact by waves. Shingle habitats are also particularly important for invertebrates and for some breeding and roosting birds. Much shingle in the UK has already been lost to housing developments, agriculture, Ministry of Defence activity and sea defence while the remaining area faces a number of threats including trampling and unnatural enrichment of the shingle substrate. One of the main long-term threats to vegetated shingle is as a result of man's intervention in natural coastal processes, with coast protection work changing the accretion rate of shingle to coastal areas. Trapped between urban development on the landward side and rising sea levels on the seaward side, vegetated shingle is also threatened by 'coastal squeeze'.

Shingle ridges form a natural coastal defence, which may require replenishment in order to maintain the ridge crest height and width. With coastal protection techniques moving towards a more integrated approach allowing natural processes to work where possible and relying more on 'soft' defences rather than 'hard' structures such as sea walls, there is an opportunity to create new, semi-stable areas of shingle. If planned with care, these could be used to create new areas of shingle vegetation with limited life but valuable for ephemeral species The Pett Levels at Winchelsea fit this category.

Communities of the vegetated shingle

The frequency with which shingle beaches are disturbed by the action of the sea varies according to wave climate and the frequency of extreme events; and the resultant vegetation is similarly altered (Randall 1977). In practise the majority of shingle foreshores are unvegetated or have extremely sparse vegetation cover. Scott (1963) recognized three foreshore stability classes which can be observed on a vegetation basis, dependent on the length of time over which the shingle is undisturbed by environmental factors. These are:

- No vegetation – disturbance too frequent to support plant growth: as at the foot of sea-cliffs, distal points of spits, high-energy beaches etc.;
- Summer annuals – beach stable over growing season only: mainly *Galium aparine* and *Atriplex* spp. on drift line;
- Short-lived perennials – beach stable for ≥ 3 yr: considerable strand and foreshore vegetation e.g. *Glaucium flavum*, *Rumex crispus*, *Beta maritima*.

These three stability habitat classes may occur at different levels on the same beach. For instance at Shingle Street, Suffolk, the exposed foreshore is unvegetated, the lagoon foreshores have drift lines supporting *Atriplex* spp., whereas the main ridge crest with more stable shingle supports growth of *Lathyrus japonicus*, *Beta maritima* and *Rumex crispus*. On some shingle foreshores as at Cley, Norfolk, mobility of the substrate results in accretion around plants of *Suaeda vera*. Various authors (e.g. Kidson 1959) have discussed the role of this species in local/short-term shingle stabilization. However, protection from wave activity is needed for longer-term stability. Because of the instability of many shingle foreshores they usually have low levels of animal life.

Although the geomorphic classification of shingle is determined by predominant particle size, the vegetation is primarily controlled by the proportion and size of the fine fraction material of the matrix between shingle clasts under 2 mm diameter at rooting depth. In fact, because this is the main source of nutrients, it is commonly recorded that, even on stable beaches, the absence of a fine matrix results in a marked reduction in vegetation. Early workers such as Oliver (1912) suggested the importance of the fine fraction and this has also been emphasized frequently since (Chapman 1947; Salisbury 1952). The fine fraction is critical at germination and seedling stages since, without it, enough moisture may not be present for growth to be initiated or to continue. The matrix is usually composed of sand, silt or organic matter, each type having distinctive vegetation. Within the British Isles the matrix tends to vary regionally: silt and clay are dominant in the south and east, sand in the west and organic matter in the northwest. Randall (1977) showed the plant species most commonly found with different shingle matrices. Regional climate also plays a highly significant part in species distribution

Water availability is another basic factor in the ecology of shingle foreshores. This is likely to be extremely low because of the high porosity and low water-retention of the substrate. Inefficient capillarity in shingle usually rules out the water table as a moisture source for all but the deepest rooted of shingle foreshore plants. Thus, the principal source of supply must be pendulant water from precipitation. However, the speed of water movement is again related to fine fraction content and diameter. Early workers suggested that further moisture supplies are obtained within shingle by internal dew formation but it was demonstrated that it was no more important than in sand. Of greater significance is the 'mulching' effect of large shingle particles on the soil surface, which cause a reduction in the evaporation of any water present in the upper layers (Fuller 1987).

There are a few plant species that are more characteristic of shingle than of other environments, most of them being associated with the extreme mobility of the foreshore zone. One species apparently exclusive to maritime shingle in Britain is *Suaeda vera*, which is limited climatically to the southeast. The plant is unusual in shingle foreshore habitats in that it is woody and upstanding, reaching over 1 m in height. It is also evergreen in the optimal parts of its range. Usually *S. vera* germinates in the driftline; rapidly sending long roots deep into the shingle, so stabilising the plant. Overwhelming by shingle in storm conditions forces the plant to a horizontal position from which it sends out new roots and new vertical shoots.

In contrast, *Mertensia maritima* is a northern element in British shingle foreshore habitats. Typically it grows as a low cushion on 'pebble-wrack-sand' beaches on the north and west coasts of Scotland, where grazing does not occur. Good examples are The Churchill Barrier, Orkney and around the Castle of May, Caithness. An interesting change in the distribution of this species over recent years has been the decline or disappearance of its more southerly sites, possibly a response to climatic change since a period of low winter temperatures is necessary to stimulate seed germination (Farrell & Randall 1992). The fact that this species is also highly susceptible to grazing and trampling may also play a part. These factors have certainly been significant in the changing distribution of *Lathyrus japonicus*. *Glaucium flavum* and *Crambe maritima* are other characteristic species of shingle foreshores.

Although there is considerable variation in the assemblages of species found in shingle foreshore habitats, lists compiled from widely separated sites show some floristic pattern. Fringing beaches and the seaward slopes of spits and bars show constancy of several species, in particular *Tripleurospermum maritimum*, *Silene maritima*, *Atriplex glabriuscula*, *Rumex crispus* ssp. *littoreus* and, in the north, *Galium aparine*. Other species that are common in this habitat include *Festuca rubra*, *Beta maritima* and *Honckenya peploides*. Less common but still locally important are *Potentilla anserina*, *Sonchus arvensis*, *Rumex acetosa*, *Elytrigia* spp., *Sedum acre* and *Senecio* spp. It will be noticed from this list of species that the majority, whether annual or perennial, are open ground nitrophiles. Their communities fall within two Habitats Directive Annex 1 habitats - the annual vegetation of drift lines and perennial vegetation of stony banks. However, as with more terrestrial shingle vegetation Sneddon & Randall (1993) showed that the communities around Britain are more complex than this twofold division suggests.

Landward slopes of spits and bars contrast with seaward slopes in that they are usually less mobile and have different nutrient inputs. Bars and spits, which have a poverty of drift material, are not so rich in flowering plants and many of the nutrient-hungry species are absent. On the north and west coasts where water-tables may be higher, *Iris pseudacorus* and *Filipendula ulmaria* are common, whereas in drier conditions in the south and east *Geranium robertianum* and *Solanum dulcamara* occur in their coastal ecotypic form. On wider fringing beaches and on some spits and bars on lower energy coasts, *Tamarix gallica* and *Lupinus arboreus* have been introduced into this habitat. These species act as good protection for exhausted migrant birds such as linnet *Acanthis cannabina* or spotted flycatcher *Muscicapa striata*. In other areas, especially where spits are adjacent to salt-marsh, the reduced mobility and much-increased organic matter content of the substrate gives rise to narrow bands of halophytes: *Sarcocornia perennis*, *Salicornia* spp., *Suaeda maritima*, *Puccinellia maritima* and *Atriplex portulacoides* being the most frequent. Details of the variation around England, Scotland and Wales can be seen in Sneddon & Randall (1993, 1994).

Much less common around Britain are the more terrestrial shingle formations of apposition beaches, cuspate forelands and offshore barrier islands. All these have typical foreshore habitats near the shoreline but further inland they are more stable. The largest apposition beach structures occur on the Isles of Arran and

Jura; Dungeness, Kent has the most complete cuspate foreland and Culbin Bar and Scolt Head Island are the most studied barrier islands. Ecologically these features are of most interest because of the differences in the time-scales of their stability.

Because beach mobility is less of an ecological consideration on these larger-scale formations, Scott (1963) recognized two vegetation classes relating to terrestrial shingle:

- Long-lived perennial species – beach subject to occasional inundation, lichens present;
- Heathland – beach entirely stable.

Vegetation succession

Understanding the factors determining the nature of vegetation succession is important when considering management and restoration options. This will be particularly significant when attempting to predict the outcome of a specific management operation. It is generally accepted that a greater expanse of shingle and a more stable formation result in a more complex ecological development over time. This has been studied by Ferry (2001) at Dungeness and Randall & Sneddon (2001) elsewhere in Britain. The quantity and composition of the matrix remains a vital factor throughout the successional sequence on stable shingle formations. It is of greatest importance at times of seed germination because, without it, enough moisture may not be present for growth to begin or to be sustained. The major difference between shingle foreshores and the larger, more terrestrial formations is that the latter do not have the advantage of external inputs of organic matter through tidal drift. Small quantities of nutritive material will be blown into these habitats by wind but most organic matter will be produced over long periods in situ, by the plants themselves. This hypothesis was first tested by Scott (1963) who later produced a tentative successional sequence based on Dungeness foreland (Scott 1965). Nine stages were recognized in an autogenic xerosere, ranging from bare shingle to climax woodland.

Scott identified a small-scale patterning of vegetation confined to the 'fulls' of shingle ridges, which support patches of dry, acid heath. This patchiness is recognized as supporting Whittaker's (1957) view of a sere as a general trend in vegetation change of 'loosely ordered complexity', conforming to Gleason's (1926) 'individualistic concept of the plant community'. Despite this, Scott notes a tendency for younger stages of succession to occur nearer the sea on more recently deposited shingle and older stages to landward, reflecting the known geomorphic sequence. Scott links the successional sequence to increasing humus within the shingle matrix, resulting from the dominant role of *Cytisus scoparius*, leading eventually to *Ilex aquifolium* woodland regarded as the climax.

Peterken & Hubbard (1972), also working at Dungeness, question the status of *Ilex* and propose modifications of Scott's model in which various heathland species may increase humus within the soil. Several scrub species are involved in the climax cycle dependent upon factors such as longevity, shade tolerance, fertility or dispersal mechanism.

Ferry et al. (1989) refute these deterministic models and highlight the importance of stochastic events. Randall (1992), working in New Zealand also doubted the applicability of linear species models and suggests an anastomosing successional sequence with a development from herb to low, then taller, shrubs while the species differ considerably in each locality.

Recently, researchers have tended to emphasize the mechanisms of succession, including 'facilitation' (Connell & Slatyer 1977), as being most significant, rather than the outmoded idea of climax. On shingle, pioneer vegetation has been shown to be particularly important in facilitation of the provision of shelter for later species in the sequence. It also helps to stabilize the system and provides humus. The adoption of an 'anastomosing' sequence of succession allows for the development of a partially deterministic model, yet admits the incorporation of stochastic events. This type of model offers the best means of developing a useful predictive tool with wide applicability for management purposes. Full details are given in Randall & Sneddon (2001).

Distinct communities also occur around artificial pits created by excavation and around lagoons that have developed naturally on shingle. The areas support a completely different flora dependent upon whether the water table is affected by fluxes of seawater or tidally related fluctuations in freshwater level. Where seawater is able to seep through the shingle, lagoon waters are brackish and a limited number of salt marsh species occur. *Artemisia maritima*, *Aster tripolium*, *Limonium* spp. and *Atriplex portulacoides* are the most frequent in these conditions. Where the water is less brackish there is usually a zonal sequence from open-water species through *Phragmites australis* to *Triglochin palustris* near the water's edge. There are also 'shingle/salt-marsh communities' in western Scotland maintained by percolation of seawater through the storm-crest into shingle with a silt matrix. Here *Armeria maritima*, *Puccinellia maritima* and *Plantago maritima* form an intermittent, eroded turf over shingle.

A final community type is that of organic foreshores. These occur where, almost regardless of substrate, there is a very large algae deposit each winter, which does not fully decompose during the succeeding summer. Such conditions occur on high-energy coasts where the main constituent of the organic material is *Laminaria* spp. These areas mainly support communities of annual plants but some perennials can grow through further additions of organic debris. Over much of western Scotland *Atriplex glabriuscula* is the dominant species but *Potentilla anserina* is the major species in Mull. Such communities are dependent upon the chance input of seed and in different years many ruderal species may occur. The most frequent are: *Urtica urens*, *Poa* spp., *Polygonum* spp. and *Spergularia arvensis*. These strand communities are normally open, variable and ephemeral, without the more formal structure found elsewhere.

Invertebrate communities on shingle

Shardlow (in Packham et al. 2001) regards coastal shingle as a unique and fascinating habitat for invertebrates. He recognizes two distinct habitats: saline-shingle beaches and terrestrial shingle. Some 390 species of importance to conservation have been recorded on shingle, including 15 Priority species, 18 species of Conservation Concern and 114 Red Data Book species. At least 11 shingle-specialist taxa occur in the UK, four of which are endemic. The current key factor threatening shingle invertebrates is thought to be changes in coastal sediment dynamics, related to management of the coastline and sea-level rise.

Barnes (in Packham et al. 2001) and McArthur (in Packham et al. 2001) look particularly at the ecology of shingle-enclosed lagoons, which are a priority habitat under Annex 1 of the Habitats Directive. Most lagoons are protected under legislation for other purposes but there is concern that our scanty knowledge of the interrelationships between lagoonal organisms will make the long-term safeguarding of populations difficult.

Birds of coastal shingle and lagoons

Birds associated with shingle can be divided into three groups. The first occurs on dry open shingle and is largely composed of about nine breeding species: Oystercatcher, *Haematopus ostralegus*, Ringed plover, *Charadrius hiaticula*, Lapwing, *Vanellus vanellus*, Grey partridge, *Perdix perdix*, and six passerine birds. Most of these occur more abundantly elsewhere. Stone curlew, *Burhinus oedicnemus*, and Kentish plover, *Charadrius alexandrinus*, formerly bred on coastal shingle but are no longer present. Wintering snow buntings, *Plectrophenax nivalis*, use the east coast shingle beaches as a place to search for food.

Cadbury & Ausden (in Packham et al. 2001) regard shingle as more significant for two other groups: nesting colonial seabirds and waterfowl. Five species of gull, including the rare Mediterranean gull *Larus melanocephalus*, four terns, *Sterna* spp., and cormorant, *Phalacrocorax carbo,* all breed on shingle. Many sites are particularly important for tern nesting and Orfordness has one of Britain's largest colonies of lesser black-backed gull, *Larus fuscus,* and herring gull, *L. argentatus*. Among the waterfowl, avocet, *Recurvirostra avosetta,* is restricted as a breeding species to coastal lagoons. Nationally high numbers of little grebe, *Tachybaptus ruficollis*, gadwall, *Anas streptera*, and, at Dungeness, Smew, *Mergus albellus,* congregate on shingle water bodies in winter. Chesil Fleet is famous for its large flocks of Brent geese, *Branta bernicle,* and mute swans, *Cygnus olor,* which graze on the beds of *Ruppia* and *Zostera*.

Guidelines for 'good practice' when working on beaches with vegetated shingle

Much vegetated shingle in Great Britain has already been lost to housing developments, agriculture and coastal defence while the remaining areas face a number of threats including trampling and unnatural enrichment of the shingle substrate. One of the main long-term threats to vegetated shingle is as a result of man's intervention in natural coastal processes, with coast protection work changing the accretion rate of shingle to coastal areas. Trapped between urban development on the landward side and rising sea levels on the seaward side, vegetated shingle is also threatened by 'coastal squeeze'.

Shingle banks form a natural coastal defence, which may require replenishment in order to maintain the bank crest height and width. With coastal protection techniques moving towards a more integrated approach allowing natural processes to work where possible and relying more on 'soft' defences rather than 'hard' structures such as sea walls, there is an opportunity to create new, stable areas of shingle. If planned with care, these could be used to create new areas of shingle vegetation.

Pioneer communities of vegetated shingle can begin to recover naturally from damage within a few years, as long as the seed bank remains intact and further damaging activities are halted. However, the more established communities, such as moss and lichen communities and closed-turf communities are unlikely to recover as they develop over many decades. Some can take hundreds of years to establish. Since planning for the long-term is unlikely to be profitable, it is important that these types of vegetated shingle communities are not damaged, as they are extremely rare.

Threats from coastal defence engineering works

Vegetated shingle can be damaged in a number of ways when coastal defence and other works are being carried out on the beach. It should be noted that damage could be done not only by vehicles and machinery but also by trampling, especially on the older communities. Damage can occur in a variety of forms including physical damage to individual plants or plant communities, disturbance of breeding birds, movement and compaction of shingle, destruction of the seed bank and nutrient enrichment through mixing of sediment layers or importation of unsuitable shingle.

Measures to prevent damage or to offset unavoidable damage

There are a number of measures that can be taken both before the commencement of coastal defence operations and while the work is being carried out. It is important that all contractors are informed in advance of the procedures that they must follow to limit any impact on the vegetated shingle. The number of beach access points for vehicles should be limited and clearly defined to avoid closed-turf, vegetated areas where possible. Particularly valuable or important areas of vegetation should be marked out and protected from vehicles, machinery and personnel. Any imported, marine-dredged shingle should be washed to avoid nutrient enrichment and should be of a similar type and size to that already present. Where possible vehicle movement should occur along beach below High Water Mark and above all, work should be limited to the period outside the bird nesting season (in the UK between March and August). Where damage is unavoidable it may be possible to create new areas of vegetated shingle elsewhere along the coast to ensure no net loss of this very rare habitat. Seed collection may be required prior to work to ensure that restoration can be attempted after works have been completed. Walmsley & Davy (2001) describe restoration procedures for vegetated shingle. Pioneer communities of vegetated shingle can begin to establish within a few years if there is a nearby seed source and an area of stable shingle. Sowing seed and planting container grown specimens can aid this process. The more stable, closed-turf communities are species-rich and take many decades to develop. However, species found in these communities can also be introduced by seeding and planting. Creation of this type of community can be attempted in phases over the medium to long term with each phase seeking to introduce a number of typical species, starting with those normally found in earlier successional communities and working towards species associated with later succession or climax communities. Lichen communities may also be attempted by translocation of pebbles, although there is little or no research available on this at present.

Traditional forms of management

Varying degrees of management intervention are required to conserve different successional stages of shingle structures. Though unlike other coastal habitats (notably salt marshes, sand dunes and sea cliffs) where grazing provides a significant determinant of the plant and animal communities, for vegetated shingle this influence is relatively limited. Minimum management is required to maintain scrub on woodland communities on shingle but heath, grassland and pioneer communities may require more active management. The presence of lichen heath is indicative of remote areas with limited public access (e.g. Orfordness, lee slopes of Chesil Beach). To allow the development of lichen or moss-rich heath, access should be restricted to such areas, thus protecting the fragile structure of these communities. *Calluna vulgaris* heath on the other hand may require grazing management to maintain age and species diversity.

Edaphic and environmental conditions peculiar to shingle seem to serve as natural limits on cover for *Calluna* (and other plant communities) in many locations, though active management measures may be needed to restrict scrub invasion. Maintenance of a variety of grassland communities requires clearance of invasive scrub and heath and continuance of grazing is required to maintain certain grassland assemblages such as the herb-rich *Holcus lanatus* grasslands of Arran. It must be remembered that, away from the driftline, shingle structures are usually highly nutrient-poor so that the introduction of grazing herbivores will almost always cause vegetation change and is potentially damaging. Locally, though, there may be enrichment from nesting birds, which will influence the vegetation composition.

Soil conservation on shingle is also highly significant. Mechanical clearance of scrub invasion as has been carried out at Slapton and Rye Harbour will bring about soil removal and a competitive advantage for ruderal species rather than earlier stages of shingle succession. Because of the long time scale of soil development on shingle, fire, whether accidental or deliberate can affect the full depth of the soil including any seed bank.

Control of alien plants

Because shingle structures are usually ‘open habitats’, it is easy for alien species to invade and establish in those areas where the abiotic environment is less harsh. This is particularly the case on the south and east coasts where houses and gardens abut the shingle and gardenplants spread. This can often be a sensitive issue as local people enjoy the showy species.

At Pagham LNR there are plans, in conjunction with English Nature, to determine the most effective way of controlling alien species by establishing trial plots / quadrats that will either be hand pulled or sprayed with herbicide. These will be compared to a control area where the plant will be left untouched. Once the methodology has been established and a clearance programme commences leaflets will be distributed to all Pagham Beach residents to make the case for selective vegetation control, and to forewarn them that work will be taking place immediately adjacent to their properties.

Harrowing

Cultivation with tractor and harrow has been used as a technique to knock back vegetation in areas where rampant vegetation is detrimental to ground-nesting bird species (Rye Harbour). Bare shingle is a favoured nesting habitat for several rare birds, notably terns; it can also host some rare and highly specialized plant communities and their associated invertebrates. Any decision to remove vegetation must be taken in the light of a full understanding of the conservation consequences including the geomorphic implications of removal of sediment from the shingle supply location.

This management technique also highlights another central dilemma for conservation particularly on vegetated shingle sites i.e. should management be for nesting birds or vegetation? Although successful in maintaining open areas of shingle it also results in an unnatural appearance to the topography and may seriously disturb plants and invertebrates that are also important on site.

Temporary fencing

Nesting sites for certain shingle species such as terns and oystercatchers are typically in beach locations much frequented by walkers and their dogs. Work at Rye Harbour LNR among others has shown the value of temporary fencing in these locations to reduce nest disturbance

Public access

The fragile nature of the shingle habitat makes it important that the public are directed in their movement as much as possible. Public access maps should be produced and explanations given why general access is not recommended. One successful way of limiting general public access is to provide an information board and a nature trail from the nearest parking site. Public access is limited to a certain extent by car-parking provision but in some areas off-road cycling and the illegal use of motorbikes and four-wheel drive vehicles over vulnerable areas of vegetated shingle may cause irreparable damage. Where this is a problem, such as at Orfordness and access points have been blocked, successful regeneration of rare plants can take place.

Best management practise on shingle beaches has not been published to date for other countries. English Nature have produced a guide (Doody & Randall 2003) and CD Rom for the management of coastal vegetated shingle, both of which will be found on their website:http://www.english-nature.org.uk/livingwith thesea/project_details/good_practice_guide/shingle CRR/shingleguide/Report.pdf)

Environmental education strategy

Shingle sites frequently have a 'wow' factor because of the dynamic nature of the site, the classic nature of the geomorphology and the unusual vegetation communities and birdlife that are present. They are important locations both for formal education (school visits) and for outreach to the general public. Where possible leaflets and interpretation boards should be produced and links made into local and regional networks.

Conclusions

It can be seen that there is a considerable and unique range of habitats on coastal shingle that reflects the complexity and age of the structures and the spatial range of the species. Only France and the UK have a wide-ranging knowledge of their shingle habitats (Randall & Doody 1995). Current EU initiatives fail to recognize shingle as a separate formation. In view of the rarity of the shingle habitat, the conservation of European shingle along the lines advocated above would lead to a more sustainable approach to coastal shingle management.

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