3.3.7 Grade and Drainage

The grade or slope of the land behind the defence will represent a significant control on habitat creation opportunities. If the profile is concave, there may only be a narrow area available for the creation of a new inter-tidal habitat before the land rises steeply. A gentler slope, on the other hand, might provide significant opportunities for developing a range of habitat types, for example mudflats through to upper saltmarsh and on to terrestrial habitats.

On a site specific basis, the micro-grade is also important in the establishment of many coastal habitats. With saltmarsh, for example, its major importance is in respect of surface drainage which should be adequate but not too rapid. Naturally accreting material will tend to evolve into suitable gradients, and will in time develop a creek system. Artificial fill may require manipulation. Pumped spoil can produce flat grades which are poor for drainage. Drainage may thus require management if the evolution of the site is to be speeded up. In some sites creeks have been mechanically excavated, often using aerial photographs to identify the orginal creek pattern at a site. A novel alternative solution suggested for use in the US has been to lay bales of hay along desired creek routes. In time the hay degrades, forming the required channel and providing valuable organic material to the soil. In general, however, the US Army Corps of Engineers' preferred strategy is to set up a site for nature to work with, and in these cases neither creek formation nor micro-scale grading is carried out.

3.3.8 Site Size

In general terms, the larger the site available for habitat creation or restoration initiatives, the greater the chance of success. Site size becomes increasingly important, however, as the isolation factor increases, as suggested by island biogeography theory (Begon et al., 1986). Work by the US Army Corps of Engineers suggests that it may be possible to create a shallow marsh or wetland habitat as small as 4 ha, as long as it is open to tidal ingress and hence to waterborne flora and fauna from nearby sites. The minimum viable size will, however, ultimately depend on the requirements of the species using the site. US experience suggests that isolated but accessible areas of marsh will be used by fish, and that isolated mudflats, in cases as small as 0.4 ha, will be used as resting areas by birds. Work at the University of California at Berkeley (J. Blanchfield, personal communication, 1990) on the other hand, suggests that a minimum size of nearer 80 ha may be required in order to ensure that the tidal prism (the amount of water entering or leaving a site) is large enough to maintain a natural cycle of sedimentation and erosion.

In Great Britain, the expansion of sites of existing nature conservation interest is a stated priority of several agencies (see Section 4.1). Section 3.4.2 demonstrates the importance of adjacent habitats as a source of flora, soil fauna and invertebrates. Given these dual requirements, size may become a secondary consideration in some retreat cases. If a site is created in isolation from existing habitats, however, it appears that site stability, sustainability and ecological diversity will all benefit from the development of the largest area possible.

3.4 **Biological and Chemical Considerations**

3.4.1 In addition to the physical parameters discussed in Section 3.3, successful habitat creation or restoration initiatives will require that a number of biological and chemical parameters must also be:

i. assessed, in order to determine the type of habitat which might be expected to develop as a result of natural processes following bank failure, and

ii. controlled, if a more environmentally desirable habitat is to be restored or created (see Section 4.1.4).

These factors will both require full consideration and evaluation at the pre-feasibility or planning stage of a project. Site surveys are likely to be required at the proposed project site, and also at other natural or semi-natural habitats in the vicinity to establish biological and soil/water characteristics. Further, close liaison with those undertaking the physical surveys will also be required as the inter-relationships between the physical, biological and chemical parameters will, in many cases, be complex.

The major biological considerations associated with the retreat option include the proximity of similar sites and the related availability of soil fauna, and also the preferred method of establishing vegetation cover. Primary chemical parameters relate to soil chemistry and the quality of the water entering and leaving the site.

3.4.2 **The Importance of Adjacent Habitats**

Irrespective of the type of resource being restored or created, many studies have shown that the proximity of a site with similar interest to that being proposed can be of critical importance to the success of the project. In five of six successful marsh restoration projects, examined in the San Francisco Bay area (BCDC, 1988), the fact that there was an adjacent marsh "source" of flora and fauna was cited as being among the reasons for success.

Nearby sites of a similar nature to a proposed creation or restoration project can provide a supply of seeds and vegetation which may subsequently take root, and also benthic organisms and soil invertebrates. This assumes, however, that the hydraulic connection between the new wetland and such sites is adequate to permit their passage.

Vegetation can be planted if the seed supply is inadequate or undesirable - the Nature Conservancy Council, for example, might prefer to see saltmarsh species such as Salicornia or Puccinellia planted, rather than allowing Spartina to colonise. The artificial introduction of soil organisms, on the other hand, is not generally as successful because of the complexity of their life cycles and habitat requirements, and natural migration is therefore essential.

3.4.3 The Planting of Vegetation

There are essentially three options in respect of vegetating a restored or created site, assuming that controlling conditions such as drainage, elevation and salinity are acknowledged and have been met:-

- predicting what will grow and providing the correct physical conditions to encourage natural colonisation of desired species
- seeding or planting of desired species
- waiting to see what, if anything, might colonise the site.

Planting can be expensive but may be recommended if there is a known risk of alien or undesirable species invading the site. The most common (desirable) species used for planting/transplanting/seeding operations in British coastal habitat creation and restoration initiatives are listed on Table 3.4.1.

Table 3.4.1 British Coastal Vegetation Species suitable for Planting/Transplanting

Habitat	Species
Saltmarsh	Pioneer saltmarsh species include Salicornia and Puccinellia.
Sand Dunes	Main species for planting include Ammophila arenaria (Marram grass); Leymus arenaria and Elymus farcutus.
Shingle	No records of artificial planting: natural colonisation is slow because of shingle mobility, and limited nutrient/organic matter/sediment supply.
Reedbeds	Phragmites australis and Carex sp. are most commonly planted.
Grazing Marsh	Appropriate herb or flower-rich seed mix according to soil type, salinity, nutrient status, etc.

In general, transplanting vegetation has been found to be more successful than seeding because transplants are better able to adapt to a wider range of conditions. Seeding, however, is a rapid and economic route to achieving vegetation cover - if the seeds can survive the exposure to wave energy and, frequently, the instability of the substrate. Woodhouse et al (1972) also found that seed storage is difficult because viability is lost if seed is stored in damp, cool, saline conditions.

In all cases, it should be noted that perennial species of vegetation will not bind sediments on a long term basis. Any planting should therefore be undertaken using pioneer species which will allow a natural progression to, for example, higher marsh species (e.g. sea lavender and sea purslane). Similarly, the timing of planting is very important in relation to climatic conditions. Frost might cause serious damage, but summer heat and drought can also cause stress to young plants. Spring planting is desirable, as autumn planting may expose the relatively young plants to winter storms and hence erosion.

Work undertaken by the US Army Corps of Engineers has demonstrated that the health of plants is very important and this may, in some cases, dictate whether planting is preferred to natural colonisation (e.g. if the existing or adjacent stock is of poor quality artificial planting may be preferred). The Corps have also demonstrated that seeded areas, seedlings, or young plants may require protection in the form of a breakwater to prevent washing out, particularly in a high energy environment. Experiments undertaken for this purpose include:-

- floating tyre breakwaters (research into the use of old tyres in the UK has shown that toxins may be released from the tyres, causing local pollution).
- sand bags which ultimately degrade and release the sand
- fibrous or organic erosion control mats
- artificial plant rolls (artificially cultivated carpets of vegetation planted in consolidated clays).

The cost of these techniques varies significantly, from the cost of little more than installation only for old car tyres, to around $340 (£170) per linear metre for the plant rolls (1990 costs).

In Norfolk, England, where reed rhizomes were planted under geotextile matting, problems were encountered in establishing vegetation growth in the inter-tidal zone (see Table A3.5.3, Appendix A). In this case, however, the grazing of young shoots by waterfowl contributed to the problem and a string of floats had to be installed to keep the birds away from the site (Brooke and Ash, 1988).

A further problem encountered in establishing sand dune or saltmarsh vegetation relates to people pressure. BCDC (1988) found that pressure from recreational users caused severe damage to the developing salt marsh communities, for example. Once vegetation is established, the physical conditions required to ensure that the vegetation cover is self sustaining (including access) must be closely monitored and, if necessary, controlled.

3.4.4 Soil Conditions

Soil conditions provide a further control on successful habitat creation. There are generally two sediment supply options unless a restoration option simply involves re-vegetating an existing site (e.g. with selected salt marsh or sand dune species). The first option is the use of the existing soil (e.g. former agricultural land or land used for some other development purpose). The second involves the use of dredged material or similar as fill to raise the elevation of a site. A range of issues in respect of the latter option are dealt with in detail in Sections 3.4.7 and 3.4.8; the soil issues are dealt with below.

The particular soil characteristics of relevance to habitat creation or restoration are as follows:-

- nutrient status
- degree of contamination (if any)
- structure (including compaction)
- sediment size
- bulk density
- plasticity
- permeability

Present land-use will affect the type of habitat which develops or can be created. Plants, in general, are unlikely to grow on heavily contaminated soil. Several mitigation schemes in the United States and elsewhere have failed because previous land-uses have rendered the soil toxic. Depending on the type of habitat required, potential toxins include excessive salinity, excessive nutrients, heavy metals and/or pesticides. Salinity might be a problem if material is dredged in seawater for use in the creation or restoration of reedbeds or brackish seasonal wetlands. Over time, however, an adequate freshwater input might be expected to leach excess salts out of the soil. In other circumstances, however, a high residual saline content in agricultural soils may prove to be beneficial if the desired habitat is salt marsh. Where sites have been in agricultural use for a relatively short time, there may still be enough salt in the soil to develop salt marsh species following winter rains. Much British low-lying land has been in agricultural use for several hundred years, and around the Wash land claim for agricultural purposes started in the 14th Century (Doody, 1991). At Porlock Bay in North Somerset and in part of the Norfolk Broads area, however, regular salt water flooding already leads to the frequent occurrence of salt tolerant species in low intensity grazed agricultural areas.

If retreat is to be considered for some areas which are currently in intensive agricultural use, excessive nutrients or herbicides/pesticides might cause problems for habitat creation initiatives. Conversely, a limited amount of nitrogen, phosphorous and potassium might be beneficial to plant development and careful soil testing would therefore be required. Finally, a thorough chemical analysis of any dredged materials to be used in habitat creation/restoration initiatives, or of the soils of former industrial land on which such projects are proposed, would also be required in order to ensure that contaminants are not likely to be made bio-available as a result of a project. Even if the habitat creation element of a project on contaminated material appears successful, contaminants (e.g. pesticides or heavy metals) could nevertheless enter the food chain with potentially serious consequences. In the United States, the Environmental Protection Agency sets limits above which sediments are defined as being polluted. The Dutch also set quality standards for the environmentally acceptable disposal of dredged materials (Davis et al., 1990) but similar guidelines for Great Britain have not yet been developed.

3.4.5 Soil Structure

Another consideration in respect of soil or sediment use is the degree to which the soil has changed through oxidization, subsidence or compaction. Land which has been in agricultural use for some time may have changed to the point where it will no longer support the desired natural habitats. In the Norfolk Broads area, for example, the installation of deep land drains to improve drainage for intensive agricultural production led to a process known as saline deflocculation in the Wallasea soil series. Saline deflocculation destroys the soil structure, and there are now limited areas in which nothing will grow because the clay soils become waterlogged during the winter months, but dry out completely leading to extreme cracking in summer. It is not yet clear whether simply raising the water table back to its former position will encourage vegetation to return.

Compaction during the placing and grading of fill might also cause problems with soil structure and subsequent habitat development.

Finally, it should be noted that the development of interesting wetland ecosystems have been recorded on both contaminated and inert sediments. In the United States, a site for the disposal of contaminated dredgings monitored by the University of Wisconsin has recently been designated as being of environmental importance, and on the river Fal in Cornwall, salt marshes have developed on inert china clay waste. In the latter case, the clay material provided a substrate on which nutrient-rich sediment subsequently settled and this was followed by colonisation by various salt marsh species (NCC, personal communication, 1991).

3.4.6 Water Quality

The quality of water supplying or surrounding a proposed habitat creation or restoration project will be of particular significance in determining viable habitat types. Heavily polluted waters (e.g. oil slicks, chemical leaks) can cause problems for most types of coastal habitat, although British coastal waters are rarely chronically polluted to the point of damaging habitats on a day-to-day basis. Three water quality issues are, however, likely to be of importance in identifying appropriate coastal habitat creation initiatives:-

- Many vegetation types are sensitive to salinity levels. Reeds, for example, will not survive if salinity levels regularly exceed five parts per thousand. Certain sand dune grasses will tolerate salinities up to 35 parts per thousand and British salt marsh species prefer salinity in the range 5 to 38 parts per thousand.

- Large areas of stagnant water are not desirable in coastal regions and, although Britain does not yet have the same type of problems with mosquitoes and other insects as many of our European neighbours, care should nevertheless be taken to ensure that water circulation objectives are achieved.

- Eutrophic conditions (i.e. nutrient-enriched) such as those occurring around some sewage outfalls may lead to the excessive growth of algae which will, in turn, deter the development of vegetation, notably salt marsh species.

3.4.7 The Beneficial Use of Dredged Material

As discussed throughout the report, a great deal of practical research has been carried out, notably in the United States, into the potential beneficial uses of dredged material in habitat creation and restoration. The US Army Corps of Engineers, for example, has experimented using both clean and contaminated sediments for such initiatives in both the sub-tidal and intertidal environments. The 1988 publication "The Beneficial Uses of Dredged Material" (USACE, 1988a) sets out a wide range of options extending well beyond the coastal zone, and gives details in respect of the physical and biological needs of a particular habitat. On the whole, this publication and others simply use dredged material as a substrate. If sediment is uncontaminated, the criteria set out in Section 3.4.5 in respect of soil conditions (e.g. structure, nutrient status, etc.) apply equally to the use of dredged material. There are, however, a number of extra considerations in terms of the testing, use and monitoring of sites where contaminated or potentially contaminated dredged materials are used. Some of these issues are therefore discussed below.

3.4.8 Chemical Considerations Associated with the Use of Dredged Material

In recent years, considerable attention has focused on the possible release of sediment-bound toxic metals as a consequence of both dredging and dredged material disposal (Smith, 1976a; Lee, 1976). The pH and redox potential (degree of oxidation or reduction) of soils, sediments and surface waters alike are among the factors regulating the chemical forms of toxic metals and affecting their bioavailability. The pH and oxidation-reduction status of bottom sediments containing potentially toxic substances may be altered by the dredging process and by the subsequent disposal of the dredged material. A change in these parameters may result in chemical transformations, influencing the bioavailability of metals in dredged sediments by directly affecting the chemical speciation of a metal (i.e. altering valence charge) or by affecting the presence of ligands which regulate the mobilisation or immobilisation of toxic heavy metals.

The sediment characteristics that most affect mobility and biological availability in dredged materials are particle size, organic matter content, amount and type of ions, amount of iron and manganese, oxidation/reduction potential, pH and salinity. When the physical and/or chemical environment of a contaminated sediment is altered by removal and placement, the chemical and biological processes important to mobilisation or immobilisation of potentially toxic materials may be affected.

Considerable information is available from the agricultural literature on toxic heavy metals uptake by crop plants from contaminated or sludge amended soils (Dowdy and Larson, 1975; Cunningham et al., 1975; Jones et al., 1975). However, much less is known about factors influencing metal uptake by marsh plants from wetland soils or dredged sediments. A strong pH influence on trace metal availability to plants is supported by the agricultural literature, and an increase in acidity may also favour the plant uptake of these materials. Laboratory studies have further demonstrated that the availability and subsequent accumulation of irons, manganese, and zinc in rice and marsh plants is strongly influenced by both pH and oxidation intensity (Jones and Etherington, 1970).

The DoE Intergovernmental Committee on the Redevelopment of Contaminated Land (ICRCL) issues threshold values and action trigger values for heavy metals in contaminated soils. They emphasise, however, the need to assess the soil's phytotoxicity properties in terms of increasing soil acidity (ICRCL, 1987). Of the potentially toxic metals, more cadmium is mobilised to readily bioavailable forms by moderate changes in pH and redox-potential than other metals, and the gradual oxidation of dredged material applied to land for habitat development could significantly increase the mobility and subsequent plant availability of sediment-bound cadmium.

In conclusion, therefore, it has been demonstrated in laboratory studies that both pH and redox potential affect the geochemical distribution and bioavailability of potentially toxic metals in sediment water systems. These parameters have also been found to affect the accumulation of some of these metals in above ground marsh plant tissue. Minimal increases in the plant availability of some metals may occur as the pH/redox potential environment of a sediment water system is altered following wetland deposition, but substantial increases in bioavailability and subsequent plant uptake may occur for other metals. It may, however, be possible to manage disposal methods, predominant plant species, and possibly the physicochemical parameters of dredged material applied to land in order to minimise plant uptake of toxic metals from contaminated sediment.

3.5 Restoration and Creation

3.5.1 Review of Projects Already Undertaken

Sections 3.3 and 3.4 set out the various parameters which are likely to influence natural or managed coastal habitat development. If a resource is to be established which is both desirable in nature conservation terms (Section 4.1.4) and sustainable (Section 3.1.4), it will therefore be necessary to meet the relevant habitat's often very specific requirements in respect of each of these parameters. The remainder of Section 3.5 is devoted to a review of habitat creation and restoration initiatives undertaken both in Great Britain and internationally, and to the development of a series of tables setting out the limits within which each particular type of coastal habitat might be expected to survive.

As discussed earlier, it is not the purpose of this report to provide site specific technical guidelines for habitat creation or restoration. The report's objective is to highlight the factors which must be considered if such projects are to have a reasonable chance of success. Nevertheless, a great deal of technical information was examined during the preparation of the report and the manuals, reports and other papers dealing specifically with methods and techniques for restoration and creation have therefore been singled out. A list of these documents is presented in Table A3.5.1 in Appendix A. Discussion papers and other publications relating to specific creation and restoration projects were also reviewed and a detailed summary of these initiatives, which fall broadly into the categories listed in Table 3.5.1 below, is presented in Table A3.5.2, Appendix A. In both cases, the large number of projects undertaken in the United States (the US Army Corps of Engineers cited over one thousand examples of habitat creation schemes involving the use of dredged materials alone (USACE, 1988)) arises primarily from the mitigation requirements of Section 404 of the 1972 Clean Water Act. This is discussed in Section 5.5.3.

Table 3.5.1 Summary of Habitat Creation/Restoration Initiatives Reviewed (by Habitat Type)

Habitat	Number of Examples	Countries	Comments
Sand dunes	11	UK, USA, Australia, Netherlands	All restoration projects. Mostly successful.
Saltmarsh	24	UK, USA, France	Creation and restoration. Varying degrees of success.
Island Habitats	6	UK, USA	Most used dredged material or similar to create habitats for birds.
Mudflats	2	USA, France	Limited experience. Some success.
Reedbeds	3	UK	Generally successful.
Lagoons	3	UK	Produced valuable habitats for birds.
Sub-tidal habitats	9	UK, USA, USSR, Netherlands	Some notable successes especially for benthic communities/shellfish

Finally, as part of the Regional round-up of information undertaken during the preparation of this report, a review of British habitat creation and restoration initiatives was carried out, mainly because of concern that many such initiatives had not been formally documented. The results of this process are presented in Table A3.5.3, Appendix A, and the number and type of projects undertaken in each region is listed in Table 3.5.2 below. Two points should be noted. Firstly, that these lists are not intended to be exhaustive, and secondly that the overlap with schemes highlighted on Table A3.5.2 is, in fact, minimal.

Table 3.5.2 British Habitat Restoration/Creation Projects (by NRA Region)

Region	Number Restoration	Number Creation	Habitat Types Involved
Anglian	4	2	Saltmarsh; lagoons (for reedbeds and sand dunes see Table A3.5.2).
North West	5	2	Saltmarsh; sand dunes; lagoons.
Severn Trent	-	1	Marsh/brackish wetland (proposed).
Southern	4	7	Sand dunes; wetlands/scrapes; shingle island; shell beach.
South West	2	-	Sand dunes; boulder beaches.
Thames	-	-	
Welsh	2	2	Sand dunes; saltmarsh; scrapes; (proposed) mudflats.
Wessex	1	3	Lagoons; scrapes; reedbeds; saltmarsh.
Yorkshire and Northumbria	2	4	Lagoons; reedbeds; sand dunes; brackish wetlands.

3.5.2 Success Criteria

The physiology of a created site, its biodiversity and its long-term sustainability will determine its eventual success and it is this factor which has led authors such as Zedler (San Diego State University, personal communication, 1991) to question how often it will be possible to fully recreate a "natural", stable and functioning ecosystem. In particular, she points out that it may be very difficult to create habitats for endangered species because their range is limited, physical requirements are very specific and tolerance thresholds may be low (see, for example, Table 4.1.1).

The development of the soil physiology will, in many cases, affect the rate and extent of vegetation colonisation. If the soil invertebrates, algae and other organisms, nutrients and structure are not properly established, vegetation growth will be inhibited. Similar problems will be experienced if physical processes are not fully effective. A researcher at Stanford University, California (Philip Williams Associates, personal communication, 1990), reviewed the performance of restoration projects in the San Francisco Bay area and concluded that they were all "failures". Her criteria, however, related to vegetation establishment and plant cover, rather than to the hydrodynamic status of the site. Experience in the United States is now demonstrating that created marsh habitats take upwards of ten to twenty years to become properly established. The projects reviewed had generally been in place for much less than ten years and the soil (biological) and physical parameters on which the vegetation depends, may not have been fully functioning. In particular, soil invertebrates may not have become properly established following the change from freshwater to saline conditions, and the hydrological status of sites may not always have been properly considered at the planning stage of such early projects. It therefore seems that a key to successful habitat creation, from a biological as well as a physical viewpoint, is understanding and re-establishing natural processes, and then allowing enough time for the habitat to develop.

Determining viable habitats for a particular site will therefore depend to a large extent on the characteristics of the existing environment and the scope for manipulation. As discussed in Section 3.1.1, the selection of technically viable habitats at a given site should, however, be made with a number of ecological desirability criteria also in mind (Section 4.1.3/Table 4.1.1).

The importance of developing a sustainable habitat was discussed in Section 3.1.4. Site size was discussed in Section 3.3.8 and the extension of sites of existing interest is highlighted in Table 4.1.1. Of equal significance, however, is the "diversity" criterion listed on the same table. In this part of the report, sub-sections 3.5.3 to 3.5.8 deal with different coastal habitats in isolation. In reality, the creation of a single habitat type will rarely represent the optimum opportunity. A transition through different habitat types (e.g. sub-tidal to mudflats to saltmarsh, etc; see Tables 3.5.4 and 3.5.10) would usually be far more desirable and hence of greater value. Similarly, the existing habitat at the site in question should be reviewed and appropriate elements retained in any habitat creation/restoration proposals. These points are particularly important in selecting technically viable habitats to go forward to the evaluation process (Section 4).

3.5.3 Sand Dunes

All the examples of British sand dune restoration/creation initiatives investigated (see Table A3.5.3) relate to sites which already support, or are in the immediate vicinity of, an existing dune system. Dune creation on sites without any previous evidence of dune systems is apparently unprecedented and any proposal would therefore need to be fully assessed to determine whether or not the site's criteria meet the requirements of a self sustaining system.

Geographically, natural dune systems are most common on dissipative coasts with strong onshore winds and a plentiful sediment supply. Dune systems are classified into two main categories (Ranwell, 1972):-

- frontshore (offshore island, spit and ness dunes).
- hindshore (bay and hindshore dunes).

Assuming that restoration or creation initiatives are to be undertaken in the proximity of an existing dune system, it is important to identify and understand the topographical and climatic conditions which led to the formation of that particular dune system. Overall it should be noted that the parameters of dune formation are very site specific.

At Camber Sands, Sussex for example, an adequate littoral supply of sand sized material available for aeolian transport facilitated successful dune creation. Dune creation has also been successful at East Lothian in Scotland where an unstable system with low sand supply had to be considered, and creation was achieved by leaving the central hindshore unvegetated as a source of sediment supply. Sediment has to be effectively trapped in order to create and restore foredunes, but this may lead to the deterioration of the unvegetated inner dunes, as in the case of Braunton Burrows, Devon. In Portrush, County Antrim restoration resulted in undermining and scour because fences were too widely spaced given the low sand supplies. The planting of marram was also initially unsuccessful because the gradient of slope was too steep. Brooks (1979) recommends that slopes steeper than 27° should be contoured before planting: contouring was later tried at Portrush and proved successful. The porosity of fencing also influences sand-trapping success and at Camber Sands, mentioned earlier, successful sand accumulation was achieved when fence porosity was reduced from 69% to 42% (Metcalfe, 1977 cited in Ranwell and Boar, 1986).

The size of sediment required for forming sand dunes is loosely defined in most literature as "sand-sized". The International Classification describes sand as between 0.02 and 2.0mm and the United States Department of Agriculture (USDA), also in Fitzpatrick (1986), defines sand-sized as particles between 0.05mm and 2.0mm. Sediment characteristics are among the overall physical and biological requirements for sand dune creation/restoration set out in Table 3.5.3 below.

Table 3.5.3 Physical and Biological Requirements of Sand Dunes

Elevation	Above MHW. For vegetation establishment a minimum of 1m vertical distance above MHW (Adrinani and Terwindt, 1974, cited in Ranwell and Boar, 1986) is required or 2m to escape storm damage (Brooks, 1979).
Grade	For successful vegetation establishment, a slope of less than 27 degrees is required (Brooks, 1979).
Salinity	Marram tolerates 1% salinity. Lyme-grass and couch grass tolerate salinities up to 3.5% (seawater strength) provided inundation is only for a few hours (Ranwell and Boar, 1986).
Sediment Regime	Sufficient sediment supply of sand-sized material 0.02-2.0mm (Fitzpatrick, 1986) from coastal (beaches, cliffs), river and/or sea bed sources is essential to sustain dune building. Porosity and positioning of fencing needs to be carefully selected according to sand availability.
Waves	Dune face should not be exposed to wave action.
Currents	N/A
Importance of adjacent habitats	Provision of a seed bank is important, either in the water Cakile maritima (sea rocket) and Salsola kali (saltwort), or as seed and rhizome fragments in the strandline (e.g. dune-building grasses) (Ranwell and Boar, 1986).
Wind	Sufficient wind required to enable effective aeolian sand transport. A wind speed of 5m per second can lift sand grains (Brooks, 1979) and initiate movement and saltation.
Foreshore/Backshore	Adequate backshore above MHW will provide 80% of sand for dune building while the foreshore between MLW and MHW will provide 10-20% (Ranwell and Boar, 1986).

3.5.4 Saltmarshes

In Great Britain there are very few examples of saltmarsh creation. There are, however, a number of examples of restoration, and most schemes are either designed to stabilise an area of sediment or to re-establish a damaged marsh. Many involve turf transplants, in sheltered areas and on a small scale. At Farlington Marshes, Hampshire, thick Reno-mattresses were covered in dredged material and saltmarsh communities have developed in the sheltered sections. In Lancashire, on the Ribble Estuary, Puccinellia clods were thrown onto high level sand flats and saltmarsh subsequently developed. The planting of Spartina has also been used to repair denuded areas in Southampton Water although the use of this species may not be considered appropriate at many sites in the UK. In more exposed, coastal rather than estuarine, locations such as at Dengie in Essex, saltmarsh restoration projects have been undertaken using groynes and poldering systems to reduce wave energy (see Table A3.5.3). Some of these projects have been more successful than others, but the reasons for success or failure are not entirely clear.

In the United States an extensive programme of saltmarsh creation and restoration has been undertaken because of the requirement for mitigation in the form of habitat creation if a proposed development will damage an existing wetland habitat (Section 5.5.3). In 1988, the San Francisco Bay Conservation and Development Commission (BCDC) reviewed the successes and failures of fourteen mitigation projects involving habitat creation, mostly saltmarsh, and concluded that four factors were of particular importance in cases where marsh restoration was judged successful:-

- The site elevations achieved were suitable for the desired habitat.
- The site was adjacent to an existing "source" of flora, fauna, etc.
- Water circulation objectives were achieved and water quality was satisfactory.
- The sites had been the subject of careful planning and detailed design by suitably qualified personnel.

Suitable soil conditions, successful planting, and a requirement for ongoing monitoring and maintenance were also cited as contributing to successful projects.

Among the reasons given for the total or partial failure of projects were the following:-

- The project had simply not been completed.
- Problems with soil chemical composition or with soil structure (e.g. soil had been compacted during construction).
- Poor planning or unauthorised modification of the approved plan.
- The site elevation achieved was not suitable for the desired habitat.
- Adverse impacts of man (i.e. disturbance by all-terrain-vehicles, recreationalists, pets, etc.).

The lessons from the BCDC report are equally important in the British context, particularly given our relative lack of experience in creating "new" saltmarsh. The physical and biological requirements of saltmarsh, whether created or restored, are set out in Table 3.5.4.

Table 3.5.4 Physical and Biological Requirements of Saltmarshes

Elevation	Initial development between MHWN and MHW (Beeftink, 1977) may be critical to ±30cm. Contouring of topography will provide suitable elevations for most saltmarsh species (Zedler, 1984). Sedimentation should lead to development of upper saltmarsh and a transition through to terrestrial habitats.
Grade	1-3 degrees, relatively flat, reflecting the conditions under which marsh sediments are laid down. Steep and/or concave slopes will reduce the scope for (e.g. the width of) saltmarsh development. Adequate drainage is also important as the impoundment of water may prevent vegetation growth.
Salinity	5-38 parts per thousand (Beeftink, 1977). Salinities in excess of 50 parts per thousand may lead to high mortality of some Spartina species (Zedler, 1984). Lower salinities will lead to invasion by brackish and freshwater species.
Sediment Regime	Sufficient sediment in suspension to allow accretion to occur at a rate of between 3-10mm per annum (Beeftink, 1977). Accretion in excess of 25mm per annum could lead to smothering of some plants, particularly pioneer species. Sediment size is also important in determining viable plant species.
Waves	More exposed sites will require protection from wave attack particularly while young seedlings become established. UK literature suggests that fetch should be less than 2000m for initial colonisation of saltmarsh (Boorman, 1987). A mudflat or similar breakwater fronting the saltmarsh is important in reducing direct wave attack.
Currents	Must be sheltered site. Good tidal circulation is, however, essential.
Importance of adjacent habitats	Very important for provision of a seed bank for colonisation. Also a good indication of where a saltmarsh can grow. If saltmarsh is nearby it shows that conditions are or were generally acceptable.
Planting	Width of planting should be greater than 6m if marsh is to become self-sustaining.

3.5.5 Mud and Sand Flats

In the British context, mudflats are a particularly valuable coastal habitat because of their importance for migratory birds. Notwithstanding this, British experience in the deliberate creation or restoration of mud or sandflats is minimal (see Tables 3.5.1 and 3.5.2). Several proposals to create such sites to mitigate against anticipated losses are, however, currently under consideration.

Experience in the US is also limited, largely because mudflats do not qualify as wetlands under S.404 requirements and there is therefore no requirement for mitigation if existing sites are damaged or destroyed The only exception to this is if endangered species will be threatened by a particular development. The US Army Corps of Engineers have, however, carried out mudflat creation schemes using dredged material to create habitats for birds. In these instances, underwater placing has been used to raise the level of the sea bed. The main problems encountered have been littoral drift causing sediment loss and, in sites which were exposed to high wave energy, erosion. In the latter case, rip rap breakwaters have been placed to reduce wave energy and promote stability.

Some uncertainty exists over the potential for the colonising of created mud and sandflats by benthic organisms and, as these are transported on the tide, proximity to existing sites would appear to be important. Studies in France, where mudflat creation using dredged material is proposed for Le Harvre estuary, further suggest that mudflat stability is very sensitive to velocity. Velocities in the range 0.5 to 0.7 m/s are therefore being promoted as suitable to avoid excessive erosion while minimising the chance of excessive accretion leading to colonisation by pioneer saltmarsh species.

The physical and biological requirements for mud/sand flat creation or restoration, as far as these are known, are specified on Table 3.5.5.

Table 3.5.5 Physical and Biological Requirements of Mud or Sand Flats

Elevation	Below MHWN
Grade	Site specific. Little information available.
Salinity	N/A.
Sediment Regime	Site specific. Clearly important but little information documented.
Waves/Currents	Site must be protected to allow deposition of sediment and ensure minimal erosion. Related to sediment regime. Site specific understanding required.
Importance of adjacent habitat	Must be close enough for faunal colonisation.
Velocity	Velocities of 0.5m/s to 0.7m/s are suggested in Cellule de Suivi du Littoral Haut Normand, 1989.

3.5.6 Shingle Features

Experience in the creation or restoration of shingle features, both in the US and in Great Britain, is largely limited to beach recharge schemes. Creating or restoring shingle habitats is likely to be very difficult because of the mobility of the material and because of the sensitivity of shingle vegetation to disturbance.

3.5.7 Coastal Lagoon Features

British experience in creating or restoring lagoon-type habitats is limited, but several successful examples do exist. The extraction of gravel on Walney Island, Cumbria has led to lagoon creation for birds in former gravel pits (see Table A3.5.3). Careful control of water levels at Havergate Island, Suffolk has produced exceptional brackish lagoon habitat for breeding waders, wildfowl and terns on a former grazing marsh. Sluices and ditches help increase water circulation and control salinity levels in the lagoons. Trimley Marshes, also in Suffolk, contains created brackish and freshwater lagoons, with salinity being controlled by a combination of freshwater piped from an inland source and saline water brought in from the sea. Here, however, only the highest tides provide a supply of saline water because the lagoon elevation is higher than would be ideal.

Many islands in the USA created from dredged material incorporate lagoon systems created as to improve habitats for birds: Gaillard Island, Alabama (Table A3.5.2) is one such example.

Table 3.5.6 sets out the biological and physical requirements for the creation of coastal lagoons including both those linked to the open sea (3.5.6a) and those enclosed behind and bar or similar feature (3.5.6b).

Table 3.5.6 Physical and Biological Requirements of Coastal Lagoons

a. Linked to the open sea	
Elevation	Below low water at centre of lagoon.
Grade	N/A.
Salinity	Varies, freshwater to saline.
Sediment Regime	Entrance must be stable in terms of tidal inflow/outflow and longshore drift (i.e. longshore drift should not cause closure). Low suspended sediment loads in both tidal water and freshwater inflow are essential to avoid excessive siltation and hence encourage habitat stability.
Waves	Protected site is desirable.
Currents	Protected site is desirable. Adequate tidal circulation is essential.
Importance of adjacent habitats	Requires faunal and floral colonisation from adjacent freshwater and saline habitats.
b. Not linked to sea	
Elevation	Low enough to ensure flooding (e.g. site should not dry out at low water). Water should not be too deep, or freshwater and saltwater may not mix.
Grade	N/A.
Salinity	Varies, freshwater to saline.
Sediment Regime	Needs stable ridge between lagoon and the sea. Sediment load of freshwater inflow should be low.
Waves	N/A.
Currents	N/A.
Importance of adjacent habitats	Requires faunal and floral colonisation from adjacent freshwater and saline habitats.

3.5.8 Reedbeds

There are some British examples of the planting of reeds within tidal river systems (Lewis and Williams, 1984). At Swinefleet, an estuarine site in the River Ouse, Yorkshire, reed rhizomes were planted at mean high water levels and have successfully colonised downslope. A major controlling factor on reed growth is, however, the salinity of the water.

Reeds are often planted along banks of rivers to prevent scour and trap silt. Rapid accumulation of silt may produce elevated land levels leading to a reduced frequency of flooding and the succession of plants such as Scirpus maritimus (sea clubrush), Atriplex spp. (Orache) and Agropyron pungens (sea couch) (Bibby and Lunn, 1982). As the site becomes drier, Salix spp. and other scrub species may invade. This tendency towards succession means that upper estuarine reedbed sites are particularly difficult to maintain unless there is a sufficient fresh water supply.

Reedbed creation and/or restoration requirements are set out in Table 3.5.7.

Table 3.5.7 Physical and Biological Requirements for Reedbeds

Elevation	Not documented but considered to be above MHW for planting.
Grade	N/A.
Salinity	<5 parts per thousand. Requires a regular freshwater input.
Sediment Regime	Excessive sediment supply and frequent inundation will lead to sediment accumulation, rapid heightening of land level and eventual habitat change (Bibby and Lunn, 1982). Low sediment content is therefore desirable.
Waves/Currents	Sheltered (relatively intolerant of water movement).
Importance of adjacent habitats	Not essential; can be planted.
Water Depth	Will grow in water up to 1m depth. Planting must be done out of water (Lewis and Williams, 1984) (Beeftink, 1977).

3.5.9 Sub-tidal Habitats and Bird Islands

As indicated in Section 2.3.15, opportunities for the development of new sub-tidal habitats are likely to become increasingly frequent if rates of sea level rise increase as predicted by IPCC (1990). Even in the short-term, a number of sites (notably in East Anglia) will offer the potential for creating sub-tidal habitats. This is because peat shrinkage, subsidence, or other vertical land movements (see Section 2.2.5) have combined with historic sea level rise to produce land, now protected by flood defences, which is already up to 2m below mean water level.

Much of the experience in the creation of sub-tidal and island habitats is once again found in the United States. The physical and biological requirements for two such habitats, seagrass beds and bird islands, are set out in Tables 3.5.8 and 3.5.9 respectively:

Table 3.5.8 Physical and Biological Requirements for Seagrass Beds

Elevation	MLW to -10m
Grade	N/A
Salinity	Most species require salinity greater than 20 parts per thousand; some species will tolerate 10-15 parts per thousand.
Sediment Regime	Seagrasses tolerate wide range of sediment size (sands to muds). Consolidation and retention may initially be a problem if dredged materials are used.
Waves/Currents	Low energy environment required but sufficient circulation/flushing to prevent development of lethal temperature extremes.
Light	Sufficient light penetration through water to support growth.
Time of Planting	Spring.

Table 3.5.9 Physical and Biological Requirements for Bird Islands

Elevation	Ideally 1m to 3m above MHW to prevent flooding of areas used for nesting while also reducing the risk of wind erosion.
Grade	Steep sides should be avoided.
Size	2 ha to 20 ha have been recorded.
Salinity	N/A.
Sediment Regime	Coarse materials (sand and shell) provide bird nesting substrates.
Location	Isolated from predators and human disturbance. Adequate food resources.
Timing	Build in autumn/winter in preparation for breeding season.

Finally, various other types of habitat which have been created, together with their environmental objectives and important parameters determining their success of failure, are summarised on Table 3.5.10 below:-

Table 3.5.10 Sub-Tidal Habitat Creation Initiatives

Habitat	Environmental Value	Critical Parameters
Topographic bottom features	Fish/shellfish "refuge"	Not enough known to target species for conservation
Eel grass beds (Zostera)	Precursor to saltmarsh development; encourages siltation	Sediment supply; waves/currents
Nearshore Berms	Benthic habitat; breakwater function	Grain size; consolidation and settlement; littoral drift characteristics
Feeder Berms	Beach recharge	Onshore migration; drift characteristics
Oyster beds	Commercial value	