SECTION 2 BACKGROUND TO THE REPORT

2.1 The Need for the Study

2.1.1 As indicated in Section 1.1.1, the coincidence of two issues of current national concern has made the further investigation of the retreat option and the production of this report particularly appropriate at this time. The first of these issues is the international debate about the changes in climate anticipated as a result of global warming. This possibility has prompted bodies such as the Nature Conservancy Council (Doody and Burd, 1990), Worldwide Fund for Nature (Hollis et al, 1990) and the Natural Environment Research Council (Boorman et al, 1989) to investigate the likely effects, particularly those associated with sea level rise, on the British nature conservation resource.

The second concern is reflected in recent reports assessing the extent of past coastal habitat loss in Britain. The RSPB's publication "Turning the Tide" (RSPB, 1990a) and the Nature Conservancy Council's Coastwatch Programme, Estuaries Review, and Coastal Habitat Inventories (NCC, 1989; 1991) have all demonstrated that the natural resources of the British coast have been severely depleted, largely as a result of human activities, over recent decades.

Section 2.2 of the report therefore reviews the climatic change debate. Section 2.3 assesses the current status of different coastal habitats and investigates the likely impacts upon these habitats of climate change and sea level rise. Appendix A2.1 provides additional details in respect of the objectives and status of ongoing research dealing with various relevant climatic change and/or habitat related projects.

2.2 The Climatic Change Debate

2.2.1 Past Sea Level Rise

The Intergovernmental Panel on Climate Change (IPCC) "Business-as-Usual" scenario for emission of greenhouse gases predicts a rate of increase for global mean temperature during the next century of about 0.3°C per decade (with an uncertainty range of 0.2°C to 0.5°C per decade; IPCC, 1990). This is a greater rate of increase than the world has seen over the past 10,000 years and will result in a likely increase in global mean temperature of about 1°C above the present value by 2025 and 3°C above today's temperature before the end of the next century.

Mean sea level has risen by 10-20cm during the last 100 years (Warrick, 1986). To date, however, there is no evidence of an acceleration in the rate of sea level rise. Observations show that the planet has warmed by 0.5 ± 0.2°C since the late nineteenth century (Warrick 1986), and six of the seven global-average warmest years on record have occurred since 1980. The extent of the warming is broadly consistent with the predictions of global climate models produced in recent years, but it is also of the same magnitude as natural climatic variability. The observed increase in temperature could therefore be due largely to this natural variability. The lack of reliability of these models at the regional level also means that the expected signal from greenhouse warming is not yet well defined and the ideal modelling experiments required to define the signal have not yet been carried out. The shortage of available instrumental records means that little is known about the low frequency characteristics of natural variability for many climate events. The detection of the enhanced greenhouse effect from observations cannot be guaranteed for more than a decade (Wigley and Barnett, 1990).

There is a long-term trend demonstrating rising ocean levels occurring for 6,000 years since the end of the ice age. The shrinking of alpine glaciers may account for one-third to one-half of the observed rise (Warrick and Jones 1988). The contribution by thermal expansion of the oceans and by Greenland ice-sheet melt is less certain. Peltier and Tushingham (1989) refer to work that suggests 25% of recent sea level rise is explicable by this steric effect. Although it does seem likely that recent sea level changes are related to climatic change, as with the changes in global mean temperatures it is not possible to confidently ascribe this past sea level rise to the greenhouse effect.

2.2.2 Predicted Sea Level Rise associated with Global Warming

As a result of the predicted rates of increase for global mean temperature under the IPCC Business-as-Usual scenario, sea level is expected to rise by between 8cm and 29cm by the year 2030, with a 'best-estimate' of 18cm. The projected range for the year 2070 is 21-71cm, with a best-estimate of 44cm (IPCC, 1990). The point is made, however, that projections this far into the future should be treated with caution as they are subject to many uncertainties (Warrick and Oerlemans, 1990).

The Report of Working Group 1 of the IPCC provides the most authoritative current estimates of climate change and sea level rise. Its findings have therefore been adopted for use in this report.

2.2.3 Contributions Towards Projected Sea Level Rise

The effect of increasing global temperatures on land ice will vary depending on the temperature range where the ice is situated. Ice mass balance increases (i.e. accumulation exceeds ablation) with temperature until annual temperatures higher than -15 to -10°C when ablation occurs. The Greenland ice sheet and most glaciers are in the warmer regions of the planet where any increased temperature will result in increased ablation. Hulton (personal communication, 1990), in work completed during his thesis but as yet unpublished, has studied Greenland ice sheet dynamics and expects accumulation in the centre of Greenland while ablation may occur at the edges. This will steepen the profile of the ice sheet but the ice mass balance will still decrease slightly under a scenario of global warming.

The Antarctic ice sheet with its much colder climate may experience an increase in accumulation, possibly reducing the rate of sea level rise (Hekstra, 1989). Warmer air over Antarctica can hold more moisture and therefore produce greater snowfall (Meier, 1990). There is great uncertainty about the response of the crucial Antarctic ice sheet, but with its geometry and the regional climatic characteristics, it is unlikely to contribute to global sea level rise in the short term (Warrick and Oerlemans, 1990). Drewry (1990), however, points out that it is crucial to understand ice sheet dynamics to estimate the effects of global warming. Ablation of ice is not simply dependent on temperature. Direct ablation is a very slow process. The effects of ice shelves and floating ice at the margin's and the occurrence of calving on the rest of the ice sheet are more influential.

The melting of Arctic sea ice will not contribute to sea level rise since the ice is floating, displacing an amount of water roughly equal to that in the submerged ice (Titus, 1989).

Finally, Warrick and Oerlemans (1990) are among the scientists who expect more than half of the rise in sea level to be attributed simply to thermal expansion (rising sea surface temperatures decreasing the density of sea water and hence raising sea level).

2.2.4 Regional Variations in Global Sea Level Rise

Predictions of sea level rise on the global scale do not take into account vertical land movements due to natural isostatic movements, sedimentation, tectonic processes and even anthropogenic activities (eg. groundwater and oil extraction) (Alcock, 1990). Research has been carried out to determine what proportion of secular (long-term, observed) sea level rise in the UK is attributable to vertical land movements. However, there are inherent problems in estimating **actual** land movements rather than **relative** movements. The variable quality of the data available, the errors associated with tide gauge monitoring, and the temporary short nature of the record, all serve to complicate the research (Rossiter, 1972; Pugh and Faull, 1982). There is also a paucity of tide gauge data for mean sea level records in the UK. Although 34 tide gauges now make up the UK 'A Class' network of gauges, only four of them have sufficient data to provide time series of mean sea level for most of the twentieth century (Woodworth, 1987). Another way of determining regional variations in sea level changes due to vertical land movements is from stratigraphic data. Shennan (1987), for example, has estimated land movements on the east coast of England from analyses of sedimentary data and saltmarsh reclamations of different ages.

Despite the complications, it is widely accepted that the south of Britain particularly the south-east is subsiding, while the north of Britain is rising by the same amount (Valentin, 1953; Rossiter, 1967, 1972; Woodworth, 1987; Pugh 1990; Alcock, 1990; Boyle and Ardill, 1989). Estimates of the rates of subsidence and uplift in Britain are summarised in Table 2.2.1.

Table 2.2.1 Regional Vertical Land Movements

Subsidence	Rate of Subsidence	Reference
Southern England	1mm/year	Rossiter, 1972
Thames Estuary	2mm/year	Rossiter, 1972
Sea levels at Newlyn	Rising 1.3mm/year relative to Aberdeen	Woodworth, 1987
Sea levels at Sheerness	Rising 0.6 ± 0.2mm/year relative to Newlyn	Woodworth, 1987
South East England, East Anglia	1-2mm/year	Shennan, 1989
Humber Estuary	1-2mm/year	Posford Duvivier, 1991
Uplift	**Rate of Uplift**	**Reference**
East Scotland	0.5mm/year	Rossiter, 1972

Pugh (1990) has tabulated linear mean sea level trends relative to land for selected UK ports, based on Woodworth's work. Table 2.2.2 shows the land movement estimates based on the assumption of a eustatic (global) sea level rise of 1.5mm/year. As previously mentioned, however, a common data span only exists for four of the eight stations. Isostatic movements are modified in some areas by local tectonic effects, for example the Portsmouth area appears to be sinking fastest, probably due to subsidence associated with a geological feature known as the Hampshire-Dieppe Basin (Alcock, 1990). The apparent anomalous figure for North Shields is viewed by Rossiter (1967) as evidence of land subsidence from mining activity. Carter (1988) splits the British Isles into two provinces, one in the south east, the other in the north and north west, corresponding to the late Quaternary loading pattern.

Table 2.2.2 Vertical Land Movement in the British Isles

	Data Span	Estimated Vertical Land Movement (per annum)
Newlyn	1916-82	- 0.3mm
Portsmouth	1962-82	- 3.5mm
Sheerness/Southend	1916-82	- 0.4mm
Lowestoft	1956-82	+ 1.2mm
North Shields	1916-82	- 1.1mm
Douglas (I.O.M.)	1938-77	+ 1.2mm
Aberdeen	1916-82	+ 0.6mm
Lerwick	1958-82	+ 3.5mm

Source: Based on Pugh (1990)

2.2.5 The Role of Vertical Land Movement

It is difficult to make predictions of how regional vertical land movements in the UK will contribute to or counteract expected eustatic sea level rises from global warming. Longer term changes, over 100 years or so, cannot be reliably hind-cast from data over one or two decades, and the stratigraphic record indicates that some short-term variations in sea level will not have a significant effect on the development of the coastline (Shennan 1987). Further research is in progress to enable more accurate estimates of future sea levels in different UK regions. Consistent monitoring is essential and satellite altimeter data should enhance observations by tide gauge in the future.

At present, the process of drawing the most reliably researched predictions of global sea level rise together with estimations of regional land movements provides the best guide to the expected rates of sea level rise in the UK. In general, the north of Britain is uplifting by a rate of 0.75-1mm/year while the south of Britain is subsiding by 0.5-1mm/year. As Woodworth and Rossiter concluded, the rate of sinking in the south east (Sheerness) and the Thames area appears faster than in the south west (Newlyn). The south east corner of Britain and the East Anglian region are therefore subsiding at a rate of around 1mm/year to 2mm/year (Shennan, 1989). There are other anomalies in localised areas, however, such as the Portsmouth example where subsidence of the rate 3-4mm/year may be occurring.

2.2.6 Storminess under a Scenario of Global Warming

While the implications of climatic change on global sea levels have been modelled and discussed extensively, the effects on storms, winds and disturbances is less certain. There have been many statements suggesting that storms will increase in intensity and frequency at mid latitudes generally and more specifically around Britain. Kelly (cited in Gribben, 1990) suspects that intense storms will be more likely to occur at temperate latitudes as the world begins to warm. Kelly points out that the pattern of warming is expected to be uneven, generating strong temperature gradients. Sinclair (1990) expects increasingly intense storms as warmer temperatures stimulate weather systems into greater activity. A report produced by the Ark Foundation in 1989 also predicts the occurrence of more frequent and violent storms in the UK. Finally, Carter and Draper (1988) reveal that several authors have concluded that wave conditions over the North Sea and North Atlantic have become more severe in recent years. There is, however, no evidence to suggest that this is more than just natural variability.

IPCC (1990) point out that current climate models have limited success in simulating storm tracks of low frequency variability. Results from the current models at least, only give an indication of the likely changes in winds and disturbances. The Report explains that mid-latitude storms, such as those which track across the North Atlantic, are driven by the equator-to-pole temperature gradient. In a warmer world, this gradient would probably be weakened, and it might therefore be argued that mid-latitude storms will weaken or change their tracks. There is some indication of a general reduction in day-to-day and interannual variability in the winter storm tracks, though the patterns of change vary from model to model.

Further research with higher resolution models is needed to assess changes in storminess with any assurance. As storm tracks also depend on global conditions there is a need to run 'General Circulation Models' (based on a global scale) and regional high resolution models together. Hekstra (1989) accepts that a decreasing temperature gradient between the equator and poles should result in fewer and weaker depressions, but he also warns that the effect on specific regions and locations is less easily foreseen.

Alcock (1990) suggests that an increase in mean sea level, and hence water depth, would tend to decrease the effect of wind stress, resulting in smaller surges. He warns, however, that locally generated wind-waves will encounter less resistance from the bottom and grow higher.

2.2.7 Impact of Sea Level Rise on River Discharge Characteristics

Sea level rise will also have a subtle effect on estuaries and the tidal rivers that feed them. Law (1989) notes that recent dredging of the River Thames has moved its saline sector much further upstream. In Louisiana, researchers have been able to see the characteristics of saline intrusion as the Mississippi River deltaic plain subsides and eustatic sea level rises. Vegetation maps indicate a northward movement of saline marsh types in some areas and anthropogenic activities have also accelerated the rates of saline intrustion (Salinas, DeLaune and Patrick, 1986; McKee and Mendelssohn, 1989; Day and Templet, 1989; Schroeder, 1989).

Where the freshwater discharge down a river is large it takes time for the effect of salinity to move upstream, but if the flow of freshwater drops away in times of drought, the sea will move in to make up the shortfall (Law, 1989). A rise in sea level will increase the intrusion of saline water because of the increase in water depths and the increase in tidal flood volumes (Volker, 1987). Titus (1986) refers to De Sylva's comments (1984) that a rise in sea level increases the salinity of an estuary by altering the balance between freshwater and saltwater forces. During droughts the salt water penetrates upstream, while during the rainy season low salinity levels prevail. A rise in sea level has an impact similar to decreasing the freshwater flow. The implications of drought conditions for saline intrusion up tidal rivers and drainage ditches are made more serious by the predictions of the effect of global warming on precipitation. Climatic models cited by IPCC Working Group 1 agree that Britain could expect a change in the seasonality of its rainfall, with wetter winters accompanied by drier summers. The unreliability of models in making regional predictions at high resolution, however, lends suspicion to further quantitative predictions beyond this general pattern.

2.2.8 Saline Intrusion

Though less dramatic than inundation by salt water as a result of sea level rise, the likely intrusion of saline water further inland is an important factor in the sea level rise debate. The most publicised threat from saline intrusion is the effect on aquifers and groundwater supplies near to the coastal zone. If the shoreline moves landward under a scenario of rising sea levels, the boundary between fresh and saltwater in a coastal aquifer will move inland and rise nearer to the surface (Barth and Titus, 1984). The displacement of freshwater by denser saltwater provides the greatest danger to coastal aquifers where existing water levels are within a few metres of mean sea level and the implications are particularly serious if salt water migrates up an estuary that recharges an aquifer (Kana et al., 1984; Sorensen et al., 1984). Titus (1987) references Hull and Tortonello's (1979) work showing that since the last ice age, as sea level rose approximately one hundred metres, freshwater rivers such as the Susquehanna have evolved into estuaries like the Chesapeake Bay. A decrease in the flow of a river or an increase in the volume of water allows salt to migrate upstream. An increase in sea level of only 13cm could result in salt concentrations in the Delaware River migrating 2-4km upstream. A rise of one meter could cause salt concentrations to migrate over 20km, possibly enough to threaten part of Philadephia's water supply during a drought (Barth and Titus, 1984) and the Delaware River Basin Commission, for example, has responded to salt water intrusion by constructing reservoirs that release water during droughts, maintaining a minimum flow (Barth and Titus, 1984).

Law (1989) suggests that rises in mean sea level will also increase seepage into the ditches behind tidal embankments and Volker (1987) agrees that such seepage of sea water will increase with changes in the difference between the level of the land to that of the sea. Finally, one further potential problem anticipated by Law, is the impact of saline water becoming trapped upstream of a fixed weir. Either of these scenarios could have potentially serious implications not only for human use of the affected land and water (e.g. agriculture, fisheries), but also for the natural ecosystems in those areas.

2.2.9 Impact of Sea Level Rise on Sediment Supply

Any reduction in river discharge in summer has potential implications not only for saline intrusion but also for sediment supply. The expected change in seasonal rainfall patterns (discussed in Section 2.2.7) could lead to a demand for new reservoirs to provide greater potential for water storage. Reservoirs interrupt the natural sediment supply to the river mouth. Dams and other barriers to salt water intrusion can protect water supplies and fresh water habitats, but such structures can retain sediments which in turn can increase erosion of coastal headlands and impair the ability of deltaic wetlands to keep pace with sea level rise (Coastal Zone Management Subgroup, IPCC, 1990).

Law (1989) expects higher sea levels to instigate suspended sediment movements to areas that currently receive negligible material. He refers to the Wash tidal sluice records in dry years, where sediment has been deposited on the seaward face of the sluice gates to such an extent that they would be hard to open on the first autumn flood to illustrate this potential impact.

2.3 Nature Conservation in the Coastal Zone

2.3.1 Coastal Habitats

Britain's coastline, with its outstanding diversity of landscapes and habitats, has been shaped by the islands' complex geological history, by changes in sea level, and by continuous erosion and deposition. Habitats in low lying coastal areas include sand dunes, saltmarshes, mud and sand flats, shingle features, coastal lagoons, reedbeds and grazing marshes. All of these landscapes and habitats have now been affected to a greater or lesser extent by human activities. Land claim for agricultural or industrial use has caused major losses of coastal habitat. Development immediately behind sand dunes and shingle ridges has inhibited their natural migration inland, particularly under storm conditions, and the building of seawalls and other structures has similarly prevented the natural retreat landwards of saltmarshes and coastal wetland features.

Table 2.3.1 demonstrates the current extent of each of the major types of coastal habitat in England and Wales. Figure 2.3.1 shows the distribution of three of these habitats - saltmarsh, shingle and sand dunes. The most valuable examples of all these habitats around the English and Welsh coast are designated as National Nature Reserves (NNR). The primary habitats in the coastal NNRs are shown in Table 2.3.2, and all the NNRs listed are highlighted on Figure 2.3.2.

The recent publication of documents such as Turning the Tide (RSPB, 1990a), together with the NCC Estuaries Review (1991), demonstrate quite clearly the extent and significance of coastal habitat loss. The recent introduction of legislation requiring an Environmental Assessment to be carried out on certain development projects, combined with the nature conservation objectives set out in the recent White Paper "This Common Inheritance" (HMSO, 1990a), indicate that the nation is beginning to take a more positive approach to environmental protection. But, in the short-term at least, more of our coastal habitats will be lost. Some will be lost as the result of development or planning pressures as discussed above. Some will be damaged or degraded because of pollution. Over the longer term, however, increased rates of sea level rise, increased storminess, and saline intrusion, even of the relatively small magnitudes discussed in Section 2.2, could have a major adverse effect on our remaining coastal wildlife resource. The possible environmental impacts of such changes in climate on low-lying coastal areas are discussed in Sections 2.3.5 onwards.

Table 2.3.1 **Areas and Lengths of Coastal Habitats in England and Wales**

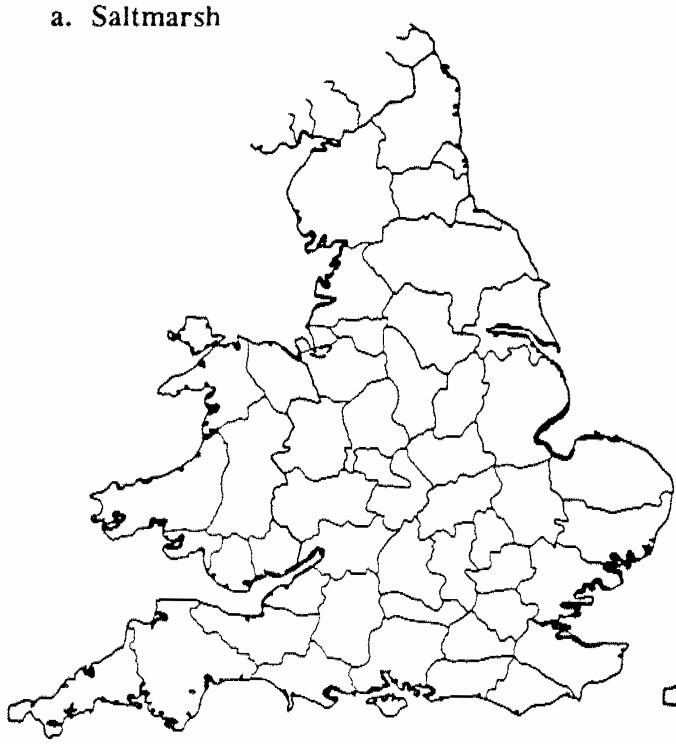
Coastal Habitats	Area (ha)
Intertidal Flats*	181,705
Saltmarsh	33,794
Sand Dune	16,334
Vegetated Shingle	3,527
Total Area	**235,360**
Foreshore Habitats	**Length (km) (Measured at Mean High Water)**
Mud	1,513
Sand	1,305
Rocky Shore	1,038
Shingle	640
Mixed Sediment	1,107
Saltmarsh	1,607
No intertidal area	325
Total Length (MHW)	**7,535**
Terrestrial Habitats	**Length (km)**
Sand Dune	474
Cliffs	1,605
Shingle Vegetation	358
Artificial Embankment	1,945
Other habitat	2,679
Total Length (Terrestrial)	**7,061**

Source: Coastal resources Survey, Chief Scientist Directorate; Nature Conservancy Council, Peterborough, UK. December, 1990.

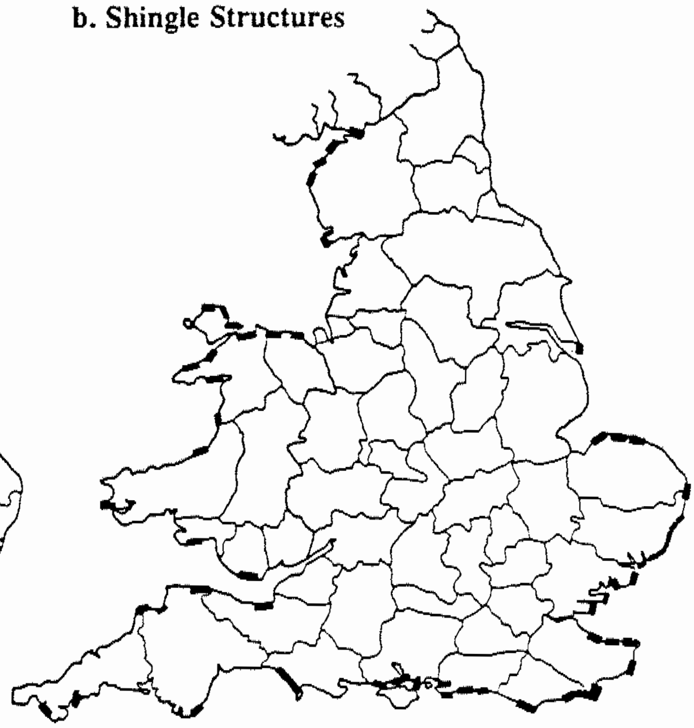
* There is no strict definition of intertidal flats but it is taken to mean areas of intertidal muds and sands.

Figure 2.3.1 General Distribution of Major Coastal Habitat Types around the Coastline of England and Wales

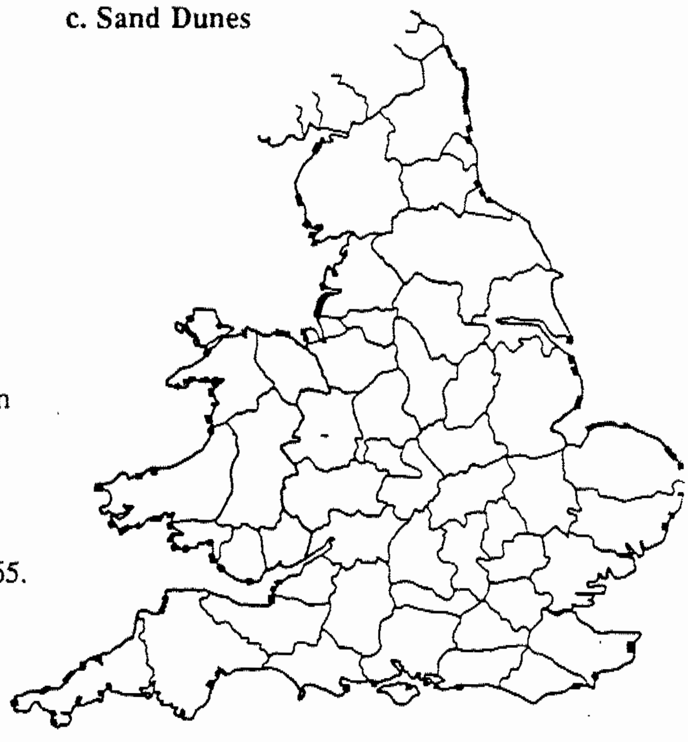
a. Saltmarsh



b. Shingle Structures



c. Sand Dunes



a. Source: based on a figure in Burd F. (1989) The Saltmarsh Survey of Great Britain : An Inventory of British Saltmarshes. Research and Survey in Nature Conservation Series No. 17, NCC, Peterborough.

b. Source: Based on figure provided by P. Sneddon (personal communication, 1990), Department of Geography, University of Cambridge.

c. Source: Based on figure in Doody, J.P. (1989) Management for Nature Conservation pp 247-265. In: Proceedings of the Royal Society of Edinburgh, 96b.

Table 2.3.2 Coastal National Nature Reserves and their Primary Habitat Interests

HABITAT	NATIONAL NATURE RESERVE (NNR)	OTHER ASSOCIATED HABITATS
Sand Dune	Winterton Dunes	Acid dune system
	Studland Heath	Lagoon and heathland
	Braunton Burrows	
	Morfa Harlech	
	Dyfi (Ynyslas Dunes)	Estuary and raised bog
	Ainsdale Sand Dunes	Slack and woodland
Sand Dune and Saltmarsh	Gibraltar Point	
	Oxwich	Freshwater marsh between wooded limestone headlands
	Whiteford	Foreshore
	Ynys Llanddwyn/Newborough Warren	Pools and rocky headlands
	Morfa Dyffryn	
Sand Dune, Saltmarsh and mudflats	Lindisfarne	
	Saltfleetby/Theddlethorpe Dunes	Freshwater marsh and sandflats
	Holkham	Sandflat and farmland
Sand dune, Shingle and Saltmarsh	Scolt Head Island	
Saltmarsh	North Solent	Grazing marsh
	Hartland Moor	Heathland inland

HABITAT	NATIONAL NATURE RESERVE (NNR)	OTHER ASSOCIATED HABITATS
Saltmarsh and Mudflats	Blackwater Estuary	Grazing marsh
	Colne Estuary	
	Dengie	Shingle
	Leigh	
	The Swale	Grazing marsh lagoons
	Arne	Heathland inland
	Ribble Marshes	
Shingle and Saltmarsh	Orfordness and Havergate Island	Havergate - lagooned island
Mudflats	Walberswick	Reedbeds, saltmarsh, woodland and heath island
	Hamford Water	Fringing saltmarsh
Sandflat and Shingle	Bridgwater Bay	Lagoons
Cliff	Axmouth and Lyme Regis Undercliffs	
	The Lizard	Complex of coastal cliff and heathland
	Gower Coast	Cliffs and foreshore
	Stackpole	Dunes, calcareous grassland and freshwater lakes
	Skomer	Rocky island
Island	Bardsey Island (Ynys Enlli)	

N.B. There are a total of 34 coastal NNRs (Gubbay, 1988). Saltmarsh is represented in at least 25 NNRs, sand dune systems in 15 NNRs and mudflats in 12. Shingle habitats are found in 3 NNRs while sandflats occur in only one. Many of these habitats also occur as fringing areas at other sites, adding to the general diversity of NNRs.

Figure 2.3.2 Coastal National Nature Reserves in England and Wales

Source: Based on a figure in Gubbay, S. (1988)
A Coastal Directory of Marine Nature Conservation
Marine Conservation Society, Ross-on-Wye

2.3.2 Coastal Habitat Functions and Services

Low-lying coastal habitats in Great Britain are of critical importance for nature conservation, both nationally and internationally. They provide feeding, breeding and roosting areas for many British bird species and act as wintering or stop over habitats for migratory species. In this latter role they are a vital link in the Eastern Atlantic Flyway - the ecological link between the breeding grounds of the northern tundras and the warmer wintering habitats of temperate Europe and tropical Africa. Coastal habitats are also a source of food and refuge for many British invertebrates, mammals, amphibians and reptiles and they are a favoured breeding ground for many marine invertebrates. The flora and fauna of coastal habitats therefore constitute a vital and highly productive part of Great Britain's natural wildlife resource

Primary productivity, a measure of the conversion of solar energy to a form of energy that may be used to power the biological processes that sustain life, gives rise to many other valuable functions (Larson, 1980). Coastal habitats are, for example, very important to fisheries resources which are currently suffering from both pollution and over-exploitation. The wetlands' rich nutrient supply and the sheltered conditions of estuaries are used seasonally, both by migratory fish and as spawning and nursery areas. Creek channels in particular are inhabited by several fish and shrimp species. Worldwide, over 50% of fishing is estuarine dependent (Asthana, 1989). Eighteen British fish species are dependent on estuaries for part or all of their life cycle. These include commercial species such as bass, flounder, and eel (NCC, 1991).

Coastal habitats provide many additional functions and services on which people depend to a greater or lesser extent. Some perform valuable flood defence and storm protection functions. Salt marsh, for example, acts as a buffer absorbing wave energy and hence preventing erosion. Reedbeds have a role in treating waste water; filtering water, retaining and removing nutrients and some heavy metals, and thus improving water quality. Other wetlands contribute to the groundwater recharge or discharge process; some provide a source of fuel. Most coastal habitats also provide an important recreational resource for walking, birdwatching, hunting and fishing. Many have protected or highly prized landscapes, and some are of considerable heritage value.

A number of authors have dealt in detail with the concept of wetland functions and services (e.g. Adamus and Stockwell, 1983; Larson, 1980; Gosselink et al., 1974) and it is not the purpose of this report to replicate their work. These functions and services are, however, of particular importance to this study in two respects. Firstly, the "success" of many habitat creation or restoration projects will ultimately be judged by the extent to which the natural characteristics of a particular habitat can be recreated. Secondly, a number of authors have attempted to place economic values on the services and functions provided by natural coastal wetlands, (e.g. King, 1990; Shabman and Batie, 1978). Some of these values may be of use in attempting to justify expenditure on habitat creation or restoration initiatives - if, of course, we can in fact duplicate the natural processes being evaluated. The economic valuation issue is discussed in detail in Section 4.

2.3.3 The Impacts of Climate Change and Sea Level Rise on the Coastal Resource

Mean sea level, tidal rise and fall, meteorological surges, tidal streams and other currents, and wave action are all important in shaping Britain's coastline. All of these factors may be modified to some extent by climate change, most particularly through the predicted rise in mean sea level and by the possible increase in the occurrence and severity of storms discussed in Section 2.2.

In the absence of other influences, a rise in mean sea level on a sloping shore will lead to a change in the position of the mean water line and thus an effective erosion. Before attempting to predict future changes, however, the possible impact of sea level rise on the other factors listed above must be assessed.

- **Tidal rise and fall**

Tides are driven by astronomical forces and are unaffected by weather conditions. They may, however, be influenced by a rise in sea level. The tidal range along many parts of the UK coast is large, the spring tide range being some thirteen metres in Bristol and more than three metres along most of the coast. The variations from place to place are a function of the shape of the coast, as well as the fact that the main tide in the North Atlantic reaches the south of England by passing around the north of Scotland and down the North Sea. The shape of the coast, particularly in Liverpool Bay and the Severn Estuary, can greatly amplify tidal range.

The effect on tides of an increase in sea level of the order of less than half a metre is not yet known. In particular, the impact on the high tidal ranges in estuaries such as the Severn is likely to be somewhat complicated. The overall increase in water level will reduce the significance of frictional losses as tides flow over the sea bed. The resonant characteristics of tidal estuaries may change and the tidal volume will increase if there is increased flooding of marshes. Pending further investigation into the subject, however, it is believed that changes in vertical tidal movement are not likely to be great. Tidal levels will of course be displaced upwards as a direct result of a rise in sea level. Recent analysis of long term tidal records at Immingham (Posford Duvivier, 1991), during which time sea level rose by some 0.25m, indicated that mean high water, mean water level and mean low water level had all risen by the same amount and at the same rate.

In terms of the impacts on the coastal resource, the effect of a rise in tidal levels is likely to be most significant where it leads to the greatest change of the intertidal zone. For example, an area with a large tidal range such as the Severn Estuary could potentially be much less seriously affected than Poole Harbour, which has a spring tidal range of just 1.5m. In this latter case a rise in sea levels of 0.5m could destroy much of the salting and mudflat habitats in the absence of compensating accretion.

- **Meteorological Surges**

The most extreme high water levels around the coast of the UK are the result of a combination of high tides and surges. The latter are caused by meteorological effects - low pressure and strong winds. Any change in the occurrence and/or strength of storms is therefore likely to modify surges and consequently extreme high water levels. Until more is known about the degree of any increase in storminess, it is not possible to predict what the precise effect of sea level rise on surges may be.

A rise in sea level will also influence the generation and propagation of surges due to changes in hydrodynamics resulting from the increased water level. Information from Proudman Oceanographic Laboratory, however, suggests that any such changes are likely to be of minor significance.

- **Tidal Streams**

As discussed above, it is believed that changes in tidal levels other than those due simply to the direct impact of a higher mean sea level, will be minor. It follows that tidal streams will remain similar except where the tidal prism at a site is increased greatly by increased flooding. Such a situation is most likely to develop in enclosed tidal waters such as estuaries and creeks. The impact would be greatest when the increase in tidal volume is proportionally large, for example, where the rise in sea level is of a similar magnitude to the tidal range, or possibly when land presently protected is allowed to flood. Increased tidal volume will lead to a more energetic flow overall, and thus to some changes in the sea bed configuration particularly at the entrance to enclosed tidal waters.

- **Wave action**

In considering waves at the shore, two aspects need to be considered:-

- the offshore wave climate.
- the shallow water processes which transform offshore waves as they travel shorewards.

Offshore wave climate in the open sea will be largely unaffected by sea level rise but an increase in storminess has considerable potential for causing an increase in the severity of wave climate. Section 2.2.6 indicates that there is already evidence of such an increase, but because accurate wave records have only been kept for the last 25 years or so, the identification of statistically valid long term trends is not yet possible. A visual assessment by Carter and Draper (1988) does suggest a progressive rise in mean wave height offshore from south-west England of some 1-2% per year. Weather patterns show considerable year-on-year and decade-on-decade variability, however, so the existence of a trend over some 20 years is no evidence of anything longer term, let alone an indication of an impact of global warming. Nonetheless the potential effects could be serious, and IPCC (1990) therefore identified the importance of studying this topic in considerable detail.

Possible shallow water effects of sea level rise include such factors as wave breaking, wave height loss due to sea bed friction, wave refraction due to depth, shoaling, and wave refraction due to currents. Water depth is a major influence in the first four. An increase in sea level will therefore lead to a change in inshore wave climate by increasing water depths. This will for the most part take the form of an increase in wave height. Waves in shallow water travelling over a flat bed, for example, are limited in height by breaking to approximately 70% of the depth.

The largest waves to reach the UK's shores are generated over fetches several hundred miles long. Within estuaries, however, the shore may be protected to the extent that it is only exposed to waves generated over a fetch as little as a few hundred metres. In this case, a rise in sea level which leads to a greater flooded area at high water could significantly increase the fetch and thus the severity of wave climate at the shore.

2.3.4 The Dynamic Environment of the Coast

Before commencing discussion on the impact of global warming on defined habitats, it is prudent to set sea level rise in the context of the coastline as a dynamic environment. The natural tendency is for the coast to erode to the point where, by virtue of its profile, it becomes stable. Around 70% of the world's shores are currently eroding, to a large extent irrespective of any change in climate.

There is an underlying tendency for erosion to be influenced locally by a number of factors. Two key factors are the "hardness" of the coast - granite will erode much more slowly than sand and fine particles will stabilize at a far flatter slope than sand - and human intervention. Human interference might have the following impacts:-

- preventing erosion on one part of the coast may enhance erosion elsewhere.
- constructing dams may reduce the supply of riverborne material to the coast.
- dredging and extraction of materials from rivers and the coast may lead to erosion.
- building breakwaters and other major works might interrupt natural sediment transport patterns.

Furthermore the weather itself is variable, irrespective of long term changes. A single severe event (such as the 1953 floods) can be of major significance with respect to the evolution of a coast.

Finally, sea level is already rising and the rate at which it rises varies along the coast due to land movement. Land is sinking in the south east (see Section 2.2.4), to the extent that sea level rise in that region over the last century has already been greater than it is likely to be in the north west over the next century. In this respect there is clearly much to be learned from monitoring the impacts of past changes.

Both sea level rise and the potential increase in storminess are significant. The other factors discussed above do not alter this significance. They do, however, remind the reader that global warming should be viewed within the context of past and present changes.