EA-NORTH WEST Box 8

ENVIRONMENT AGENCY

DEVELOPMENT OF DATA AND INFORMATION SOURCES ON NATURA 2000 ESTUARINE SITES IN THE NORTH WEST

Duddon Estuary: Final Report

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1 Introduction

1.1 Background to Project

A number of sites in the UK are designated as special protection areas (SPA) and/or candidate special areas for conservation (cSAC) and thus enjoy protection at an international (European) level. These sites together comprise the Natura 2000 network of sites throughout Europe. The Environment Agency, as competent authority in England and Wales, has a responsibility to safeguard the interest features of Natura 2000 sites through its function in regulating a number of activities that take place in and around these sites. In response to this, the Agency is undertaking a review of consents (authorisations to discharge effluent, abstract water, release atmospheric emissions etc.) process. All consents that could potentially influence protected species and/or habitats at Natura 2000 sites are being reviewed, a process that can involve many thousands of consents at a single site. In order to carry out this task, the Agency identified that it needed an up to date source of information on scientific knowledge for a number of the sites. This project provides that resource for Morecambe Bay SPA/cSAC in north west England.

Related projects have been undertaken for Ribble and Alt Estuaries SPA and Duddon Estuary SPA (Fig. 1). These, together with the phase 1 project for Ribble and Alt estuaries, have developed a database of information, the North West Natura 2000 database (version 2). Section 2 provides an overview of the database, including instructions for use.

1.2 Objectives

With an overall aim of providing a resource to assist with the review of consents process, the specific objectives were as follows:

1. Identify sources of information
2. Obtain information and consult with information holders
3. Develop a database for the Information Directory
4. Review and Summarise Existing Information
5. Identify Gaps in current knowledge
6. Suggest projects to fill gaps

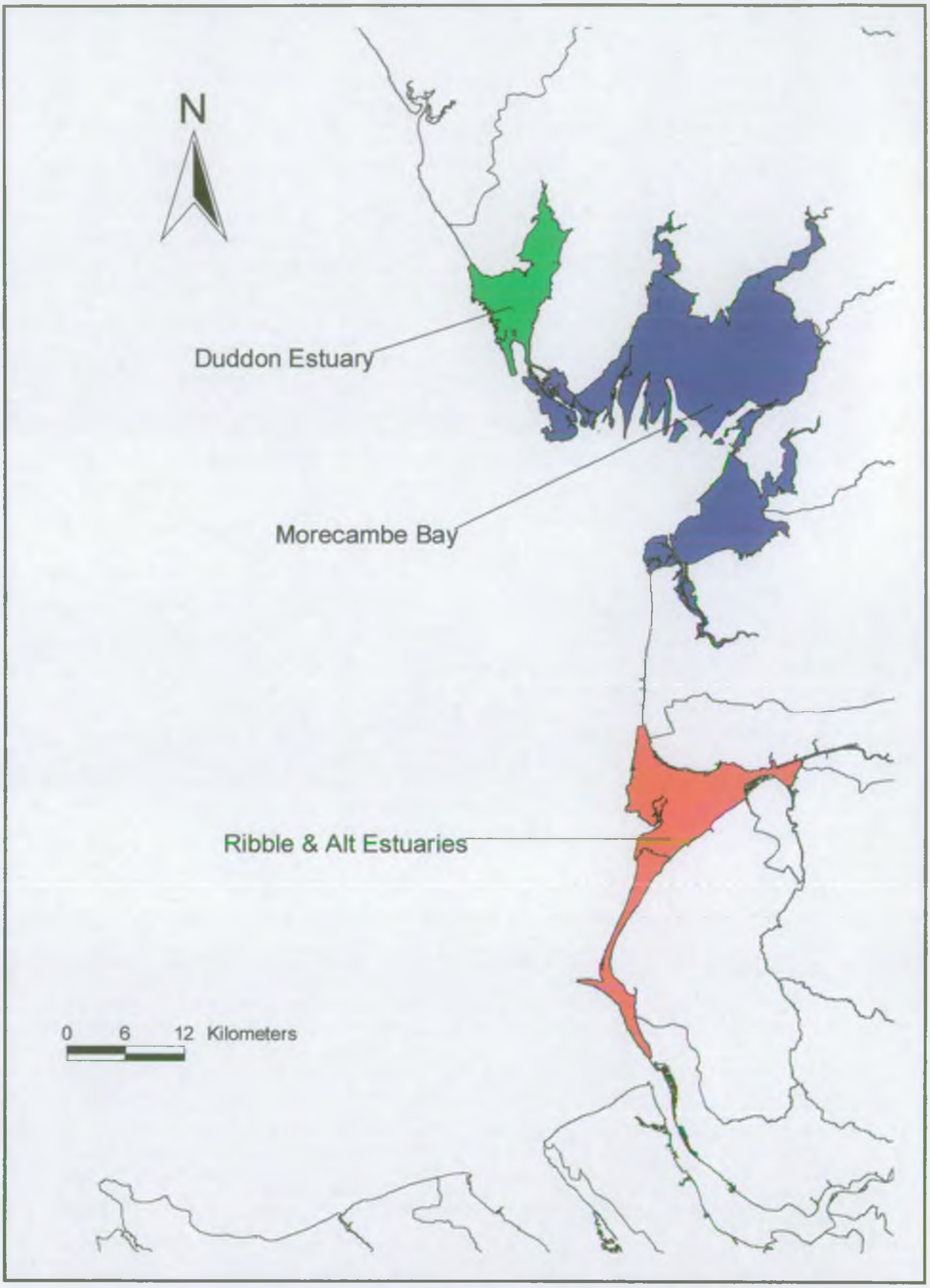


Figure 1 SPA Sites covered by the North West Natura 2000 Information Collation Project

1.3 Morecambe Bay

Morecambe Bay, located in north west England (Fig. 1), is a complex of the estuaries of 4 main rivers, the Wyre, Lune, Kent and Leven (Fig. 2). It is the second largest embayment in the UK after the Wash and is a wide, shallow feature with depths mostly < 10m. The majority of the Bay consists of intertidal sand and mudflats, there are also important mussel beds and localised stony outcrops, or scars. The soft intertidal sediments in particular are prime habitats for invertebrate communities that in turn support bird populations of major conservation importance. Fringing areas of saltmarsh, freshwater wetlands, saline lagoons and shingle banks provide additional feeding for some bird species and also vitally important roosting grounds for the large numbers of birds that feed in the intertidal areas.

The Bay is a very dynamic system. Erosion and accretion occur side by side, the composition of bird and invertebrate communities fluctuate over varying spatial and temporal scales and major channels shift. All such processes are influenced by both natural and anthropogenic factors, although identifying the cause of change is a complex and uncertain process.

Large numbers of wading birds use the site as a temporary feeding ground during spring and autumn migrations. The site is also of importance throughout the year, for breeding populations of terns for example while large numbers of waterfowl (waders and wildfowl) overwinter on Morecambe Bay.

Morecambe Bay is a key wildlife conservation area with both national and international conservation designations. At the European level it is both a Special Protection Area (SPA, Figure 2) and candidate marine Special Area of Conservation (cSAC, Figure 3).

The presence of the following Annex I habitats are the primary reason for selection of the site as a cSAC:

- Estuaries
- Mudflats and sandflats not covered by seawater at low tide
- Large shallow inlets and bays
- Perennial vegetation of stony banks
- Glasswort *Salicornia* spp. and other annuals colonising mud and sand
- Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)
- Shifting dunes along the shoreline with *Ammophila arenaria* ('white dunes')
- Fixed dunes with herbaceous vegetation ('grey dunes')
- Humid dune slacks

Other habitats of conservation interest include reefs to the north of Heysham constructed by *Sabellaria alveolata* the honeycombe worm which is nationally rare. These biogenic reefs are protected as Annex 1 features under the Habitats Directive. The shallow inshore waters are important spawning and nursery areas for commercially important demersal and pelagic fish species while a designated bass nursery area exists close to Heysham nuclear power station. Cockle and mussel fishing and trawling for brown shrimp occurs in the intertidal areas and within channels of the Bay.

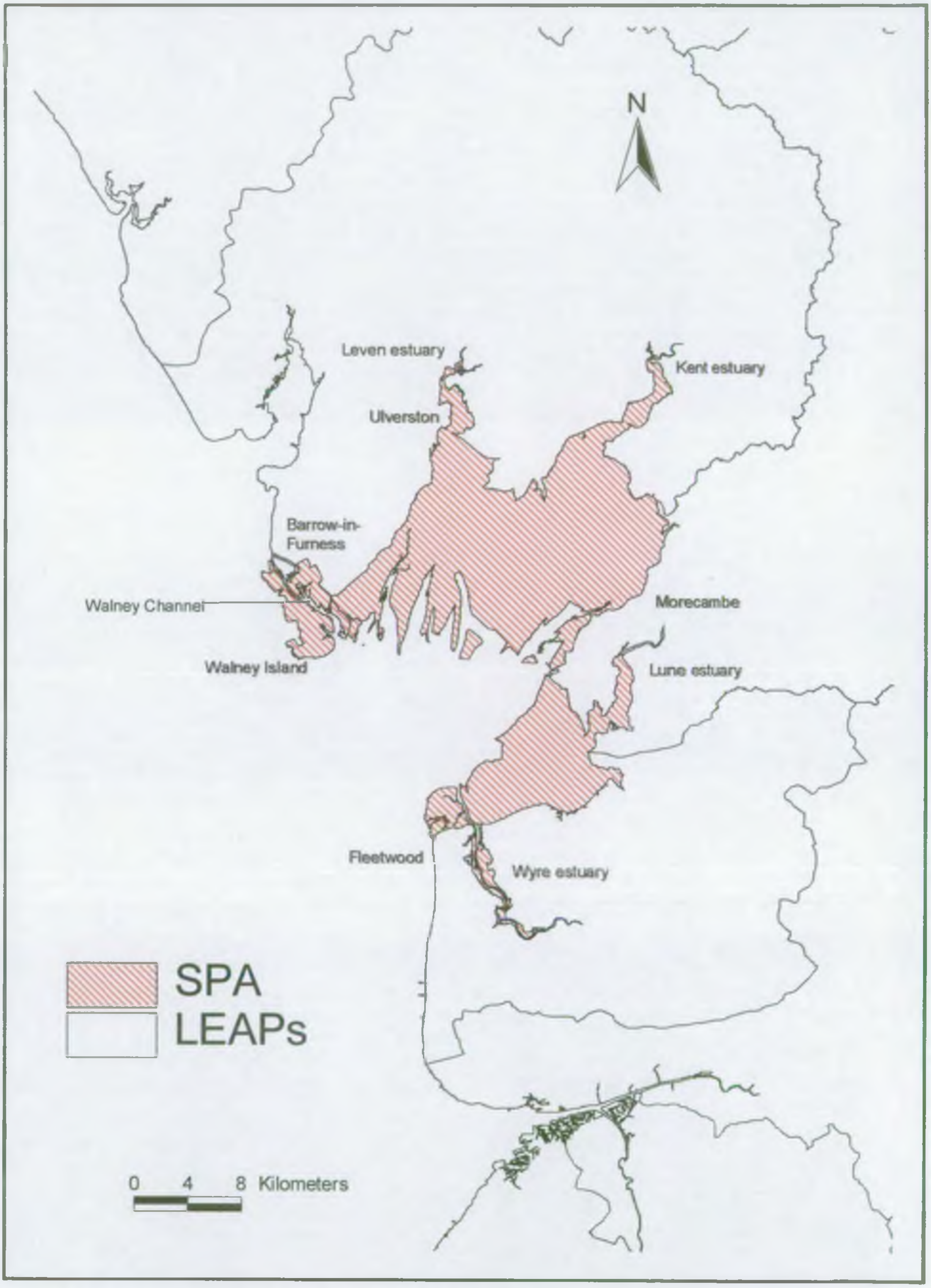


Figure 2 Morecambe Bay Site Map Showing SPA Boundaries

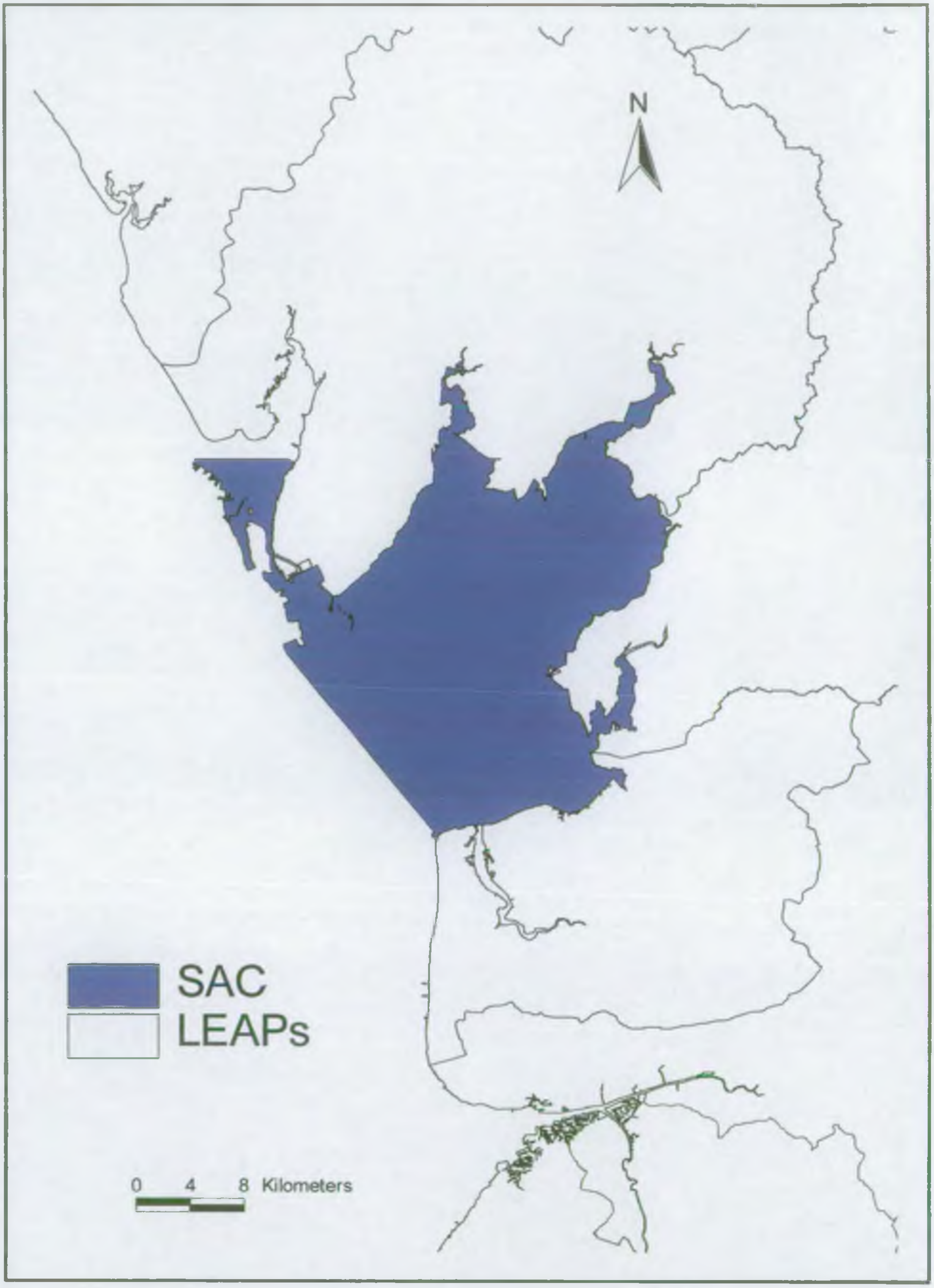


Figure 3 Morecambe Bay Site Map Showing SAC Boundaries

The SPA designation is based upon:

- Populations of European importance of the following species listed on Annex I of the Directive:

During the breeding season; Little Tern *Sterna albifrons* and Sandwich Tern *Sterna sandvicensis*. Over winter; Bar-tailed Godwit *Limosa lapponica*, Golden Plover *Pluvialis apricaria*.

- Populations of European importance of the following migratory species:

During the breeding season; Herring Gull *Larus argentatus*, Lesser Black-backed Gull *Larus fuscus*. On passage; Ringed Plover *Charadrius hiaticula*, Sanderling *Calidris alba*. Over winter; Curlew *Numenius arquata*, Dunlin *Calidris alpina alpina*, Grey Plover *Pluvialis squatarola*, Knot *Calidris canutus*, Oystercatcher *Haematopus ostralegus*, Pink-footed Goose *Anser brachyrhynchus*, Pintail *Anas acuta*, Redshank *Tringa totanus*, Shelduck *Tadorna tadorna*, Turnstone *Arenaria interpres*.

- A seabird assemblage of international importance (by regularly supporting at least 20,000 seabirds).

During the breeding season, the area regularly supports 61,858 individual seabirds including: Herring Gull *Larus argentatus*, Lesser Black-backed Gull *Larus fuscus*, Little Tern *Sterna albifrons*, Sandwich Tern *Sterna sandvicensis*.

- Regularly supporting at least 20,000 waterfowl (a Wetland of International Importance)

Over winter, the area regularly supports waterfowl including: Great Crested Grebe *Podiceps cristatus*, Bar-tailed Godwit *Limosa lapponica*, Pink-footed Goose *Anser brachyrhynchus*, Shelduck *Tadorna tadorna*, Pintail *Anas acuta*, Oystercatcher *Haematopus ostralegus*, Grey Plover *Pluvialis squatarola*, Knot *Calidris canutus*, Dunlin *Calidris alpina alpina*, Curlew *Numenius arquata*, Golden Plover *Pluvialis apricaria*, Turnstone *Arenaria interpres*, Black-tailed Godwit *Limosa limosa islandica*, Cormorant *Phalacrocorax carbo*, Wigeon *Anas penelope*, Teal *Anas crecca*, Mallard *Anas platyrhynchos*, Eider *Somateria mollissima*, Goldeneye *Bucephala clangula*, Red-breasted Merganser *Mergus serrator*, Ringed Plover *Charadrius hiaticula*, Lapwing *Vanellus vanellus*, Sanderling *Calidris alba*, Redshank *Tringa totanus*, Whimbrel *Numenius phaeopus*.

2 Study Methods

The project was carried out in 5 distinct phases:

1. identification of information sources;
2. consultation with Agency staff/external organisations
3. development of information directory (database);
4. summarising findings of key studies;
5. identification of significant gaps in knowledge and projects required for bridging.

2.1 Identification of Information Sources

A list of known and potential sources of information was prepared. This list comprised the consultees who included statutory bodies, Environment Agency and English Nature; academic researchers; conservation groups; local authorities; industry and consultancies.

The initial list was expanded as further sources became known to the project team. All organisations consulted during the information collation exercise for Morecambe Bay are indicated in the information directory (Section 3 this report and Database Directory).

2.2 Consultations

Key consultees were visited by members of the project team. This was the case for The Agency and English Nature whose information archives were searched as part of the study. Other consultees with significant information archives were also visited and materials loaned or photocopied. The remaining consultations were by written letter with follow up phone calls and/or emails as necessary. Information was requested on research, reports, programmes of survey and monitoring, scientific models, and management strategies/plans. Only existing interpreted material was included, raw datasets were beyond the scope of this study.

The geographical limit applied to the information collection exercise was taken as the boundaries of the SPA and cSAC as set out by English Nature (2000) in their Regulation 33 Advice. However, information from outwith this immediate area was obtained if it contributed to the study. This was especially the case for water quality information where pollution from both landward and seaward sources can affect the study site.

We attempted to collate all available information sources dating from 1990. However, there was pertinent material that pre-dated 1990, this was incorporated where it added significantly to the value of the project.

Where specific information was not available for Morecambe Bay itself, relevant studies from other sites were considered. This aspect is developed further in Section 5 (Identification of Gaps and Projects Required for Bridging).

In order to ensure that information reviewed could be accessed again in future by the Agency, full details of authorship/ownership was to be collated. In many cases, hard copies of reports, scientific papers etc. were obtained.

2.3 Information Directory

A MS Access 1997 database was constructed to maintain records of:

- People: key contacts with any organisational affiliations shown
- Organisations: key organisations with contact persons indicated
- References: reports, papers, theses, dissertations etc. linked to people and organisations to indicate availability.
- Models: summary of scientific models applied to the site with details on output, propriety products used, availability, costs for use and an assessment of quality.
- Programmes: research programmes, monitoring programmes and other resources, such as databases, with availability indicated.

The information database is shared by several related projects. There have been related studies for Ribble and Alt Estuaries SPA and Duddon Estuary SPA. Information within the database is assigned descriptive keywords that include site identifiers, these are provided in Appendix 1.

Information already available internally within the Agency is clearly identified within the database.

Further information on the design and use of the database is provided in Section 3.

2.4 Summary of Key Studies

The review of key studies (Section 4) seeks to build into a description of the 'ecosystem' linkages of the site and the adjacent river catchment use and coastal/marine properties where these affect the site. All material used is references in the information directory, often there are additional notes alongside individual records that provide further details and summaries.

2.5 Identification of Gaps and Projects Required for Bridging

The structured approach adopted in the summary of key studies (Section 4) has facilitated identification of gaps in knowledge. Where gaps were suspected, the database was queried for relevant information before a gap was confirmed.

Outlines of potential projects to fill gaps are given in Section 5. When recommending such work, it has been borne in mind that the review of consents process is underway and limited time will be available for future studies to deliver results that can be incorporated into the process.

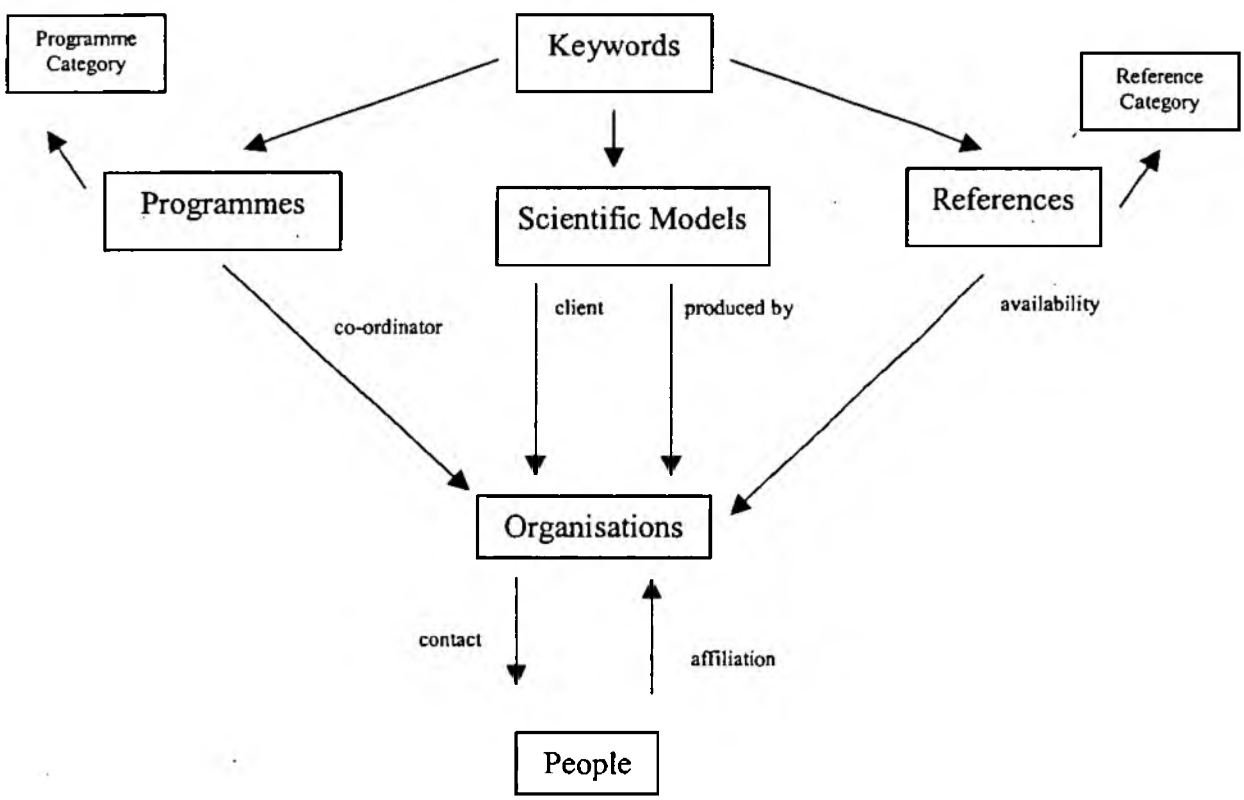
3 Database Information Directory

3.1 Overview of Database

The database is a directory of scientific information relevant to several estuarine Natura 2000 sites in North West England, namely Ribble and Alt Estuaries SPA, Morecambe Bay cSAC/SPA and Duddon Estuary SPA. At the core of the database are 5 tables containing information on scientific programmes (e.g. research and monitoring activities), scientific models, references (scientific papers, reports, plans etc.), organisations and people. There keywords that describe entries in the database according to geographical location and subject area. The same suite of keywords is shared throughout the database and forms the basis of searching outlined in Section 3.2. Further tables hold information on the category of programmes and references and the assessed quality of scientific models.

Links between the various tables permit relationships between information and people/organisations to be referenced. For example, the clients for whom scientific models were produced and the organisations who undertook the work can be seen on the form that describes each model. The main tables and relationships are summarised in Fig. 4.

Figure 4 Key tables and relationships (NB this is a simplified representation of the structural relationships within the database).



3.2 Using the Database

The database is provided in 'read only' format. This is necessary to ensure that the integrity of the database is maintained when it is accessed by multiple users. Database administrators are provided with a version that has both read and write capability, this must be updated centrally before new or amended records can appear in the database.

There are two main ways to find information in the database, custom search functions and MS Access's internal search capabilities. The custom search functions searches for specific occurrences or combinations of keywords in Programmes, References and Models and produce a report based on the selected sub-set of records that can be viewed or exported into another package, such as MS Word or Excel. The internal search function of Access can be used to find individual records by searching for any occurrence of text (or numbers) within a particular field in the database.

3.2.1 Custom Search Functions

Simple and advanced search options are provided within the database, accessed via the 'Search Database' from the main switchboard. These allow queries of References and Programmes to be made.

The simple search allows the user to enter a single keyword (cf. Appendix 1) to retrieve relevant records. The keyword must be entered in the correct format, namely:

Keyword

This will bring up all occurrences of references/programmes that are described by the particular keyword. Please note that keywords must be typed in *exactly* as in Appendix 1 and that the * before and after is essential.

The advanced search allows up to 3 keywords to be combined in a search in the format:

Keyword 1 AND *Keyword 2* AND *Keyword 3*

Automatic dialogue boxes guide the user through the process. If less than 3 keywords are required, simply enter * into the second and/or third dialogue box.

There is also an option to exclude a keyword in the final (fourth) dialogue box. The format is the same (*Keyword*). If there is no requirement to exclude a keyword, enter *none* in the box.

All these searches bring up a sub-set of forms which can be printed or exported into another package.

3.2.2 Access Search Functions

From the main switchboard go to the part of the database you wish to search.

Click in the field you wish to search in (e.g. 'Author' or 'Notes').

Use the 'Find' icon (below), or CTRL + F, to bring up the 'Find in Field' dialogue box

Set the options for search and match as required (typically search only current field and match any part of field provides results most readily).

Run the search until the desired record(s) is located.

The current (i.e. displayed) record can be printed, ensuring that 'current record' is checked to avoid printing all recorded.

3.3 Hard Copy of Database

Summaries of the database contents are provided in Appendix 2.

4 Information Review

4.1 Physical Environment

A summary of the geological environment of Morecambe Bay is provided by Pringle (1987). The following summary is from that source (unless otherwise referenced):

> The present coastline of Morecambe Bay (Figure 5) cuts across unconsolidated Pleistocene and Holocene deposits. Glacial and post-glacial deposits typically form the coastal margin with drumlin cliffs, scars (or skears) and saltmarshes the most frequent landforms. There are also some cliff and shore platforms in Carboniferous and Permo-Triassic rocks. These include outcrops of carboniferous limestone near Aldingham and at Sea Wood near Bardsea (South Furness) that form low cliffs (up to a few metres) and irregular shore platforms jutting out from beach shingles which are mostly derived from eroded limestones. Humphrey Head is the most dominant limestone feature, this is a cliff of up to 53m at the south west tip of the Cartmel peninsula.
>
> The coast between Silverdale and Arnside has extensive Carboniferous limestone cliffs backing rapidly eroding saltmarsh that provides some coastal protection. At Heysham Head there is a single Millstone Grit coastal outcrop and some small coastal outcrops of Permo-Triassic rocks at Roughholme Point, west of Humphrey Head, south of Heysham harbour at Red Nab and near Cockersand Abbey.
>
> Much of the coastline is comprised of cliffs cut in drumlins that rise to about 30m. The till is predominantly clay with locally derived limestone and sandstone and some erratics from Lake District and Scotland. At the foot of the cliffs are sometimes found larger erratics called scar (or skear) which represent the coarse fraction of the till that cannot be moved by waves except during extreme storms.
>
> Sand Dunes occur at the north west extremity of Morecambe Bay, although extraction of sand and gravel since 1878 has resulted in much disturbance and erosion. Dunes are also present at the south-west of the Bay in the Knott End and Fleetwood area.
>
> The large tidal and shallow depth (typically < 10m (English Nature 2000)) of much of the Bay means that more than half of bed area of Morecambe Bay is exposed at Low Water Spring Tides. This exposed area is predominantly intertidal sand, limited mudflats are present around Walney Island and Lune channel (JNCC 1993). Lune Deep is the major channel in the entrance to the Bay (depth up to 82m). This and other channels have greatest depth and width to seaward, there being very few ebb channels which demonstrates that it is tidal currents associated with flooding tides that mould the channel systems and sandbanks of the Bay. Both channels and banks are highly mobile features in the Bay (as can be seen from the channel changes outlined in Figure 5).
>
> Throughout the Bay, there is a general coarsening of sediment seawards, fine-very fine sands occur in channels, finer silts and clays are found at the heads of estuaries.

The total area of intertidal sand and mudflats has been estimated as 310 km^2 (English Nature, 2000). Net sediment transport is into the Bay (McLaren 1989).

It is understood that the current dominance of sandy sediments, particularly on beaches between Heysham and Morecambe, is a recent phenomenon. Pringle (1987) cites Phillips (1976, not seen) who stated these beaches were composed almost entirely of mud during the mid 1960s. The development of sandy substrate in this area was seen as a result of channel movements associated with Heysham Lake.

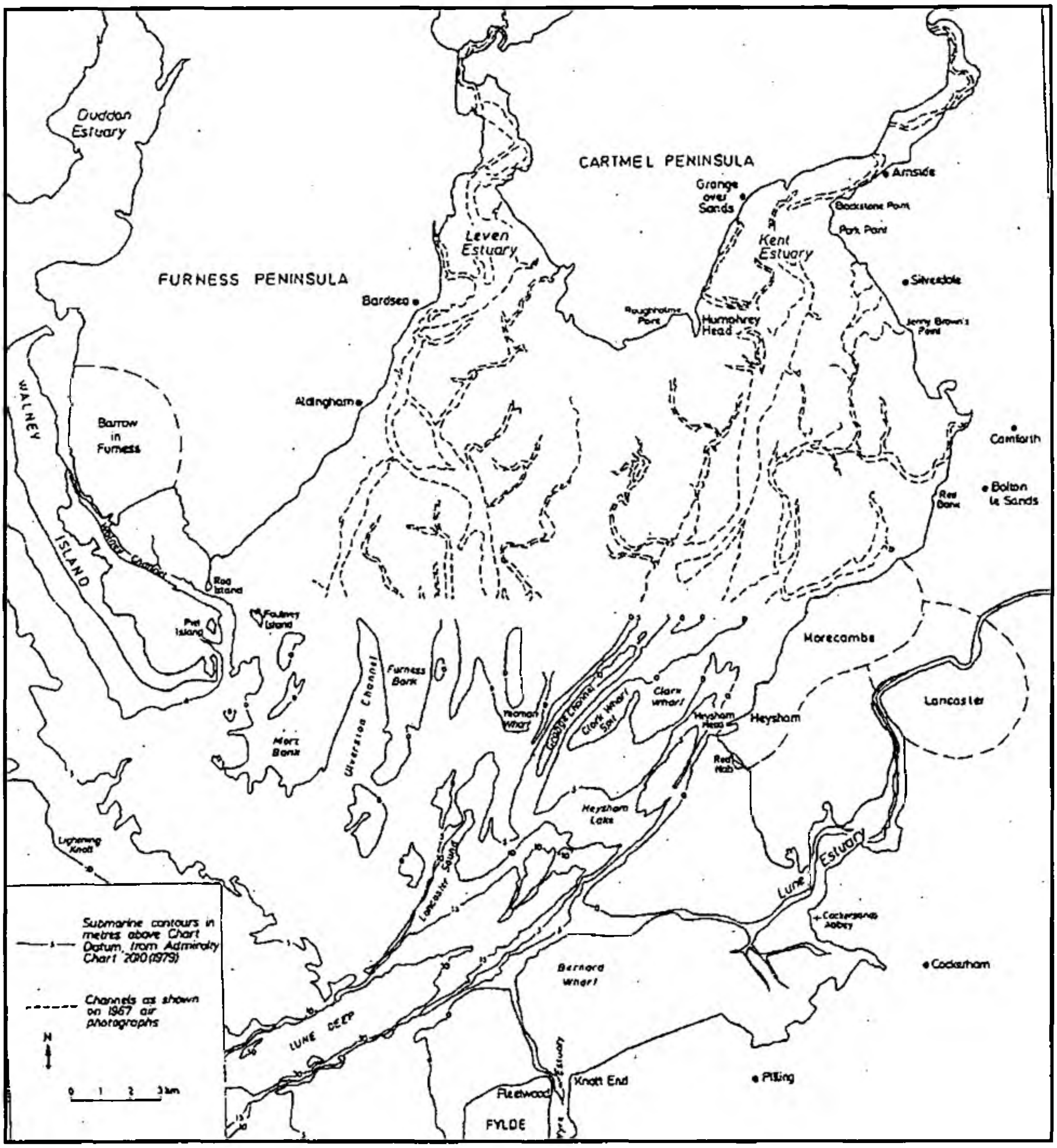


Figure 5 Coastline and bathymetry of Morecambe Bay (from Pringle 1987).

4.2 Coastal Processes

Pringle (1987) reviewed information available at the time on tides and currents in the Bay and a further brief summary is provided by Comber & Hansom (1994). The most up to date information on wind, wave, tides and tidal currents is provided by various models that are detailed in the information directory (e.g. Bullen Consultants wave refraction model for Barrow-in-Furness Borough Council (database ref. 52) and WL Delft's Morecambe Bay model for ABP (database ref. 61). The general summary below is based on Holt et al. 2000 and Pringle 1987:

> Morecambe Bay has the largest tidal range in the northern Irish Sea, the maximum spring tides have a 10.4 m range, minimum neap tides 3.4 m range (NRA 1992, cited in Holt et al. 2000). Currents at the mouth of the Bay are typically 1 knot at spring tides, increasing up to approximately 4 knots on spring tides in channels such as Walney and Lune Deep. Tidal streams are asymmetric with ebb tides running approximately 40 minutes longer than flood tides at Heysham.
>
> Wave heights are restricted both by the shallowness and enclosed nature of the Bay. The maximum fetch (approximately 225 km from the south west (Pringle, 1987) is also the direction of the strongest winds Strong winds from the south west can raise both high and low water levels by around 1m, strong easterly winds can reverse this (Phillips and Rollinson, cited in Pringle, 1987).

Mason et al. (1999) studied intertidal sediment transfer in Morecambe Bay. Land-sea boundaries and corresponding heights were determined using remote sensing and hydrodynamic modelling; differences in heights were used to determine sediment erosion/accretion over the 5 year period between 1992 and 1997. During this period, the authors estimated that 16 million m^3 of sediment was eroded from the intertidal area of the Bay, almost all the change being reflected by a significant decrease between mean sea level and the low water mark (no estimate of accretion provided).

Mason and Garg (2001) followed up this work by constructing a morphodynamic model for the same intertidal region, employing remote sensing and hydrodynamic modelling. The model consisted of a set of linked modules for predicting 2D depth-averaged tidal currents, waves, sediment transport rates and sediment budgets. Sediment volume changes during the period 1992–1997 were measured over the intertidal zone at a resolution of 240 m. The total volume of sediment eroded was estimated as 102 ($\pm$16) $\times 10^6$ m^3, and the total volume accreted 107 ($\pm$15) $\times 10^6$ m^3, i.e. the follow up analysis suggests that there was slight net accretion in the area. Tidal asymmetry was shown to be the dominant agent of sediment transport in the intertidal zone, with waves being of secondary importance; a close correlation was found between the computed directions of tidal asymmetry and observed sediment transport paths.

The saltmarsh at Silverdale has recently undergone a period of rapid erosion (Pers. Obs.). Such activity may simply reflect the natural cycle of erosion and accretion in low-lying coastal areas; however, this does have implications for wildlife interest features that use the site (cf. Section 4.8).

Further information on wave conditions is provided in Section 4.5.

4.3 Designated Species Information

The presence of the following species at the site has resulted in SPA designation:

Bar-tailed Godwit *Limosa lapponica*
Black-tailed Godwit *Limosa limosa islandica*
Cormorant *Phalacrocorax carbo*
Curlew *Numenius arquata*
Dunlin *Calidris alpina alpina*
Eider *Somateria mollissima*
Golden Plover *Pluvialis apricaria*
Goldeneye *Bucephala clangula*
Great Crested Grebe *Podiceps cristatus*
Grey Plover *Pluvialis squatarola*
Herring Gull *Larus argentatus*
Knot *Calidris canutus*
Lapwing *Vanellus vanellus*
Lesser Black-backed Gull *Larus fuscus*
Little Tern *Sterna albifrons*
Mallard *Anas platyrhynchos*
Oystercatcher *Haematopus ostralegus*
Pink-footed Goose *Anser brachyrhynchus*
Pintail *Anas acuta*
Red-breasted Merganser *Mergus serrator*
Redshank *Tringa totanus*
Ringed Plover *Charadrius hiaticula*
Sanderling *Calidris alba*
Sandwich Tern *Sterna sandvicensis*
Shelduck *Tadorna tadorna*
Turnstone *Arenaria interpres*
Whimbrel *Numenius phaeopus*
Wigeon *Anas penelope*
Teal *Anas crecca*

English Nature uses annual counts for qualifying bird species, in the context of 5 year peak means, together with available information on UK population and distribution trends, to assess whether the SPA is continuing to make an appropriate contribution towards Favourable Conservation Status of the species across Europe (English Nature 2001). Much information is available on the abundance and distribution of birds in Morecambe Bay and is readily available and summarised elsewhere (e.g. Morecambe Bay Partnership, 1995; English Nature, 2000).

Key factors supporting the presence of the above bird species are food supply and the presence of secure roosting sites. For some species, e.g. pink-footed goose, golden plover and lapwing, adjacent land, often agricultural, provides very important feeding areas outside of the SPA. The highest total number of birds, however, are dependant upon the expansive intertidal sand and mudflats which provide invertebrate prey. The key prey and forage species in the Bay were identified by Morecambe Bay Partnership (1995) as (Table 1):

Table 1 Key prey and forage species for birds in Morecambe Bay (from Morecambe Bay Partnership, 1995)

Group	Taxa
Bivalves	*Mytilus edulis, Macoma balthica, Tellina* sp., *Cerastoderma* sp.
Gastropods	*Hydrobia ulvae, Littorina* spp.
Crustacea	*Carcinus maenas, Corophium* spp., *Balanus* spp.
Polychaetes	*Hediste* (=Nereis) *diversicolor*
Insects	Larvae of Tipulidae and Lepidoptera
Saltmarsh plants	*Puccinellia maritima, Salicornia* spp.
Algae	*Enteromorpha* spp.
Fish	Various species (e.g. sandeel and sprat)

Holt *et al.* (2000) note that *Zostera* is eaten by wildfowl (Teal and Wigeon) that occur in important numbers in Morecambe Bay.

Known relationships between invertebrate prey and bird predators are further expanded in Section 4.10.

4.4 Other Species and Groups

4.4.1 Invertebrates

The intertidal invertebrate fauna, particularly of soft sediment sand and mudflats, is of key significance to the bird species of conservation importance; however, surprisingly little work has been undertaken on this subject in Morecambe Bay. The most recent available review of information on intertidal invertebrates is provided by Adams (1987) which is summarised within the Information Directory itself. This is based largely on work undertaken in the 1970s and early 1980s. More recent studies that have considered invertebrates have typically been localised impact assessment studies (e.g. Spurrier *et al.*, 1997). Furthermore, the Environment Agency have not included Morecambe Bay's benthic communities in their National Marine Monitoring Programme (Mazik *et al.* 2001). English Nature recognises the importance of benthic invertebrates in their Conservation Objectives for SSSIs within the European Site. Invertebrate (birds prey) biomass targets are set for intertidal mudflats, sandflats and intertidal and subtidal boulder and cobble skears that aim for no significant reduction in presence and abundance of prey species in relation to reference level. The invertebrates will include *Hydrobia*, *Macoma*, *Mytilus/Cerastoderma* spat, *Corophium* and Nereis (English Nature, 2000).

4.4.2 Fish and Fisheries

Morecambe Bay is home to commercially important finfish and shellfish fisheries. Mussels, cockles and brown shrimp are the main commercial fisheries. Some other fishing takes place for the following species but is not of such commercial importance (further details in Morecambe Bay Partnership 1995 and Mazik *et al.*, 2001): eel, bass, flounder, plaice, rays, sole, whitebait, mullet (Holt *et al.*, 2000).

4.5 Scientific Models

A range of mathematical models have been developed, in particular to describe and predict physical processes including wave characteristics, tidal conditions, sediment transport and dispersal of pollutants. The type, ownership and availability, operation and outputs of scientific models that have been applied to Morecambe Bay is detailed within the information directory. The following is a brief summary of scientific models applicable to Morecambe Bay (information directory IDs noted in brackets):

A variety of mainly hydrodynamic models have been developed for various programmes in and around the Bay. These include models that seek to describe the movement of radionuclides from BNFL Sellafield in the eastern Irish Sea (7, 8, 63); a number of models based on Met office predictions of offshore wave conditions in the Irish Sea (49) that derive inshore conditions relevant to Morecambe Bay (50, 51 & 52). A further wave prediction model was developed for the proposed offshore windfarm at Barrow to predict wave conditions between the site and Heysham (55).

The Meteorological Office's Wave Prediction Model (Database ref. 49) quite often provides the only estimate of offshore wave conditions available. This is a commercial product (1 year costs £600; 5 years costs £2225. Every additional year costs £300 thereafter.) The nearest points inshore for which conditions are available relevant to Morecambe Bay are: 3°35'W, 54°00'N; 3°35'W, 54°25'N. The model archive consists of the hindcast fields of wind and waves produced during the operation of the atmospheric and wave model forecast suite. To produce the best possible analysis of surface wind, all available reports of surface pressure, wind speed and direction (from ships, buoys, platforms and land stations) are subjected to a range of consistency checks before being assimilated into the model's analysis. The resulting wind field is then used to modify the wave field derived from earlier time steps. For each of the 16 directional and 13 frequency bands, the changes in wave energy are computed at each grid point, using the local wind energy input, and allowing for propagation, dissipation and transfer between spectral bands. The model is a so-called 'Second Generation' model, where the spectral shape is empirically defined, rather than being calculated in run time. For this section of the Irish Sea the model does not include the effects of Anglesey or the Isle of Man. No summary of trends in the data produced has been found.

The Morecambe Bay Shoreline Management Partnership used the ABP multigrid model (50), which is part based on Meteorological Office data, along with expert assessment to provide information on inshore wave conditions. Summarised information from the shoreline management plan relating to wave conditions along the coast is provided in Table 2.

We are also aware of the following models; however, no summary information on outputs, trends identified etc. has been available:

Sediment transport analysis by GeoSea Consulting for United Utilities (53) provides an assessment of the coastal zone sediment transport regime from Liverpool Bay to the Walney Island. The principal aim of the Morecambe Bay analysis was to assess the sediment transport regime with particular attention to the relationships between the Irish Sea; the Lune Deep and Morecambe Bay itself.

A Wyre estuary hydrodynamic model describes tides and sediment transport in terms of erosion and deposition patterns (56) while the output from a Lune estuary model (57) includes waves, currents, sediment transport and a prediction of coastal evolution along the tidal Lune.

ABP Marine Environmental Research Ltd have developed 500m grid of tidal flows in the Irish Sea (59) that has good coverage for Morecambe Bay.

Several models to describe wave conditions and tidal flows in Walney channel and Morecambe Bay related to waste water discharges, bathing water quality and sediment dispersal (60, 61 & 62). The layout grid for the Delft Hydraulics Morecambe Bay Model (Database ref. 61) produced for ABP is provided in Figure 6.

In addition to that work described in the directory, it is understood that modelling work has been undertaken in relation to the gas installations at Heysham and Barrow but no further information has been received from contacts.

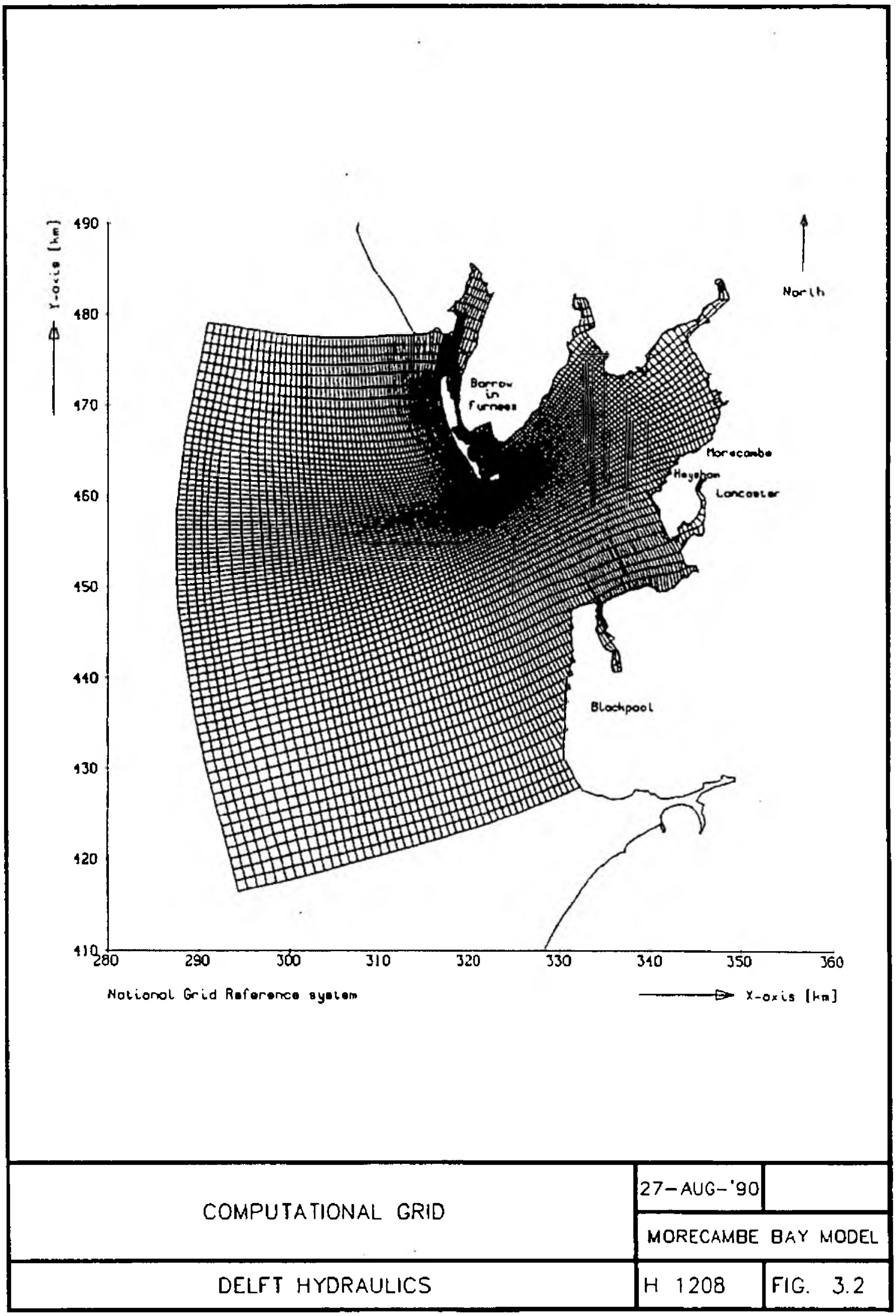


Fig. 6 Layout of WL Delft Hydraulics Morecambe Bay Model (Database ref. 61) produced for ABP.

Table 2 Morecambe Bay Wave Conditions

Information drawn from Morecambe Bay Shoreline Management Plan (database ref: 517). Management units progress southwards along the coast and are detailed in the plan provided within the SMP, available using the hyperlink in Reference 517.

SMP Unit	Comments
1 / 11 Piel Island	The island is directly exposed to wave directions from east of south and the south east facing corner of the island, where the castle is situated, has therefore been more vulnerable to erosion than the other sheltered sides. Larger waves from west of south may also be diffracted around the head of Walney Island to impact the shoreline head on.
2 / 1 Rampside to Roa Island	Foulney Embankment provides some shelter to the mainland section of frontage from south to south east waves with Walney Island providing shelter from west to south. Direct wave exposure is therefore limited to locally generated offshore directional waves from across Morecambe Bay.
2 / 3 Newbiggin to Aldingham	The scalloped nature of the shoreline compared with the general orientation of shoreline (and) the prevailing wave direction results in edge wave effects occurring which sweep energy along the frontage in addition to the typical incident exposure energy and thereby beach levels are drawn down along certain sections of coastal defence. In addition the shoreline is subject to altered exposure conditions with channel changes offshore. The low water channels in this part of Morecambe Bay provide passageways through which wave energy can pass more easily and therefore be more significant where it impacts the shoreline nearest to such channels.
2 / 4 Aldingham	This section of shoreline is most vulnerable to extreme tide/wave conditions with normal conditions causing little problems. Sediment movement which is minor is in a net south westerly direction.
2 / 5 Aldingham to Sea Wood	The shoreline has evolved as a result of bank/channel interaction, however with no direct pathway for waves to propagate and impact the shoreline if exposure conditions are medium to low.
2 / 6 Sea Wood to Bardsea	Under normal conditions exposure is limited and it is only under extreme wave and tidal behaviour that the natural cliff is affected.
3 / 1 Bardsea to Canal Foot	Future evolution along this section of shoreline depends on changes to exposure conditions and channel behaviour further upstream, specifically on the north side of the railway viaduct. Alterations to the meandering of the channel here could dramatically alter the behaviour of the channels along this frontage and also the ability for waves to propagate to the shoreline.
3 / 3 Leven Viaduct to Cark	The future integrity of this section of shoreline relies on two distinct elements. Firstly the saltmarsh providing a coastal defence role in reducing the wave energy impacting the shoreline and secondly the upstream breakwater continuing to hold the Leven Channel away from the eastern bank as it passes through the viaduct.
4 CARTMEL PENINSULA (CARK TO HUMPHREY	..it is noticeable that the intertidal zone does not play a significant role in normal circumstances with regard to any wave energy reflection or tidal energy diversion.

HEAD)	
4 / 1 Cark to Cowpren Point	The future integrity of this section of shoreline relies on two distinct elements. Firstly the saltmarsh providing a coastal defence role in reducing the wave energy impacting the shoreline and secondly the upstream breakwater continuing to hold the Leven Channel away from the eastern bank as it passes through the viaduct.
4 / 2 Cowpren Point to Humphrey Head	..the basis for evaluation of losses within the management unit is high water levels with associated wave action leading to overtopping and potential breaching of defences with flooding to the low-lying hinterland.
Management Unit No. 5 / 2 Arnside	The basis for evaluation of losses within the management unit is generally a combination of extreme water levels and associated wave conditions causing overtopping of existing structures. Additionally there is the potential risk of channel movement causing undermining of existing defences and the potential for shoreline recession. Crest levels of existing defences vary along the frontage with some levels only providing a level of protection against tides and waves of < 1 in 10 years.
7 MORECAMBE / HEYSHAM	The coastal processes are not entirely uniform across the frontage with changes caused from human intervention at the Stone Jetty in the middle of Morecambe township more importantly influenced from the movement of significant low water channel features offshore allowing different deep water pathways for waves entering the Bay to move into the shoreline here. However in the case of this latter variation of exposure it is possible over decades for the channels to change position and thereby shift the exposure within the limits of this coastal process unit hereby supporting its discrete identification. This represents quite a complicated coastal process unit with changes in foreshore sediment characteristics evident from the intervention at the Stone Jetty. However wave conditions are reasonably consistent especially during extreme events with the waves approaching the shoreline obliquely and energy levels being influenced from the offshore channel geometries.
7 / 1 Hest Bank to Throbshaw Point	Evolution of the Morecambe shoreline frontage over the past 150 years has been a function of natural process/human intervention interaction, with the development of Heysham Harbour having a major effect on shoreline exposure conditions. This development changed the littoral drift driven by wave activity along the Morecambe shoreline and may have altered the balance of silt to sand to shingle that constitutes the shoreline materials in evidence today. During the last century and up until the 1960's, Council approved extraction of shingle took place from the foreshore along the Morecambe frontage. This artificial lowering of the foreshore allowed for increased tidal volumes resulting in increased water depths and concomitant high levels of wave energy impacting the shoreline. Locally the creation of the Stone Jetty provided man made shelter for the frontage allied with natural protection provided by existing foreshore features e.g. the shingle spit at the Battery. Over the years however reclamation of land from the sea by the erection of hard defences and the continued extraction of shingle from the foreshore prejudiced protection of the frontage. Strategically the frontage's behaviour is governed by the movement of offshore channels the arrangement of which alters the exposure to storm activity. In 1989 Lancaster City Council embarked on a strategy of upgrading their defences using a combination of rock breakwaters, beach nourishment and sea

	wall re-profiling. Much of the length of frontage to this unit has been defended by the first five phases of construction constructed to date. Prior to the construction of the new coastal defences the frontage was vulnerable to wave overtopping on storm conditions due to lowering foreshore levels fronting structures, with crest levels of structures generally less than 1.0m above the predicted 1 in 100 yr SWL. To the north of the Stone Jetty sea bed levels create a channel running in from the main Kent Channel that passes the Stone Jetty and eastward to near Scalestones Point. Wave studies showed that historically , particularly from a westerly direction, waves penetrated into this channel and reached the shoreline. Construction of a new breakwater opposite the Town hall in 1989/1990 and armouring of the frontage at Scalestones Point has removed this threat.
7 / 2 Throbshaw Point to South End of Half Moon Bay	Future evolution of this length is governed by environmental conditions. The hard rock outcrops to the north end of the unit will control exposure conditions here whilst the softer shoreline to the south is protected from south of west wave exposure by the Port of Heysham but is more vulnerable to wave forcing from waves north of west.
8 HEYSHAM TO POTTS CORNER	This frontage enjoys greater protection arising from the harbour intervention in part but also because the intertidal zone starts to broaden extensively now providing large areas for friction dissipation of incoming wave energy.
9 LUNE ESTUARY	..wave effects are significant downstream of the boundary, still water level is the primary criteria governing exposure further upstream.
9 / 1a Sunderland Brows Farm to Sunderland Village	Over the last 150 years evidence suggests that the high water mark at the Point itself has moved gradually to seaward with the position of the low water channel and the roughness of Hall End Skear, off the Point, controlling the wave exposure conditions. Notwithstanding this the Point has been eroding over the past century and a half, and probably for centuries before that. It is vulnerable to extreme wave and water level conditions which currently are causing erosion at an average rate of 0.5m per annum. For a westerly wave field the present relationship of mean high water mark to the west of Sunderland Point and the low water channel orientation is such that the wave field is effectively compressed between the two features and focussed on the Point giving rise to progressive acceleration of erosion over the last 90 years or so since the Port of Heysham influenced shoreline evolution. This arises from the function of the intertidal zone above MHW in turning the waves to be more south of west by wave diffraction. The waves further to the south are propagating faster along the channel and then being swung northward due to channel orientation causing wave crest compression and increased height for wave fronts incident along the Point especially the eastern flank. In the future ongoing erosion of the Point will continue until the it gains protection behind the sand shoal on the western flank. This will lead to the following : S increased exposure of the village due to increased wave energy entering the estuary, as a result of cliff erosion, and the possibility at a certain stage of Point erosion of an edge wave developing resulting in a significant increase to wave overtopping at the village for a given

	sea state.
9 / 6 Fishnet Point to Plover Scar	There is a marked change in shoreline exposure upstream of Crook Farm from that existing downstream and this results mainly from the shelter provided by the estuary shorelines from offshore wave energies as one moves further upstream.
10 PILLING AND COCKERHAM MARSH	Most of the coastal defences in this unit are only subjected to significant activity during extreme events with many tide wave conditions not reaching much of the formed shoreline.
10 / 3 Bank End to Fluke Hall	The Lune Deep affords some protection to much of the south-east coast of Morecambe Bay from wave action, and in particular the Pilling and Cockerham embankment, since it refracts much of the severe wave activity (large wave periods) northwards. Waves of low period do not feel the effect of the deep channel and are able to propagate towards the coastline. The Pilling and Cockerham embankment may be subjected to waves of up to 5 second period generated from either strong local winds or from Irish Sea storms. However, in either case the maximum wave heights would be limited by the depth of water fronting the embankments due to the flat foreshore conditions.
11 PREESALL	Fetch lengths available support depth limited wave heights for normal tide conditions.
11 / 1 Fluke Hall to Knott End	Little protection is provided by the Lune Deep for the Preesall section of the coastline under both long and short period waves. Refraction analyses suggest also that the wave heights reaching the foreshore region may well be in excess of half of the offshore values. However, in view of the very flat foreshore conditions, large waves will be broken down to their depth limited 'equilibrium' height before impinging on the shoreline. It is necessary to assume that these 'depth limited' conditions will occur under all significant surge events as the evidence of the 1977 and 1983 storms would suggest that meteorological conditions giving rise to the surge are likely to have associated with them wind fields adequate to generate sea states of sufficient intensity. Wave conditions appropriate to the Preesall embankment under surge conditions, are, therefore, considered to be waves of depth limited height from inshore sea states with typical annual conditions of the order of 1.0m in height but under extreme surge conditions potentially double that value.

4.6 Water Quality and Water Resource Information

Freshwater inputs arrive in the Bay from 4 main estuaries: the Lune, Kent, Leven and Wyre. Of these, the Lune is believed to contribute around 50% of the total freshwater input to the Bay while the Kent and Leven together contribute 15%, the remainder coming from the Wyre, Crake, Bela and Keer in that order (Crawshaw, 1987). Low flows are an issue in the Wyre catchment (Environment Agency 1997). Historical abstraction rights belong to United Utilities (public supply) and British Waterways to maintain levels in the Lancaster Canal. Surface and groundwater abstractions have led to reduced flows in that catchment. Holt et al. (2000) pointed out that it was unclear to what degree abstraction in the Wyre affected the freshwater budget of Morecambe Bay, noting that water extracted for public supply would ultimately reach the Bay via rivers or long sea outfalls. Given the relatively small contribution the Wyre makes to total freshwater inputs to the Bay, it is likely that the influence of low flows in this river on the Bay is at most local to that estuary.

Salinity in the Bay is influenced by the freshwater riverine inputs that reduce salinity in the north eastern Irish Sea as a whole (Lee & Ramster 1981, cited in Holt *et al.*, 2000). These authors note that mid-Bay surface salinity averages less than 31 ppt in winter and 32 ppt in summer, suggesting a slight influence from freshwater (i.e. riverine) inputs. 'One-off' studies have reported local salinity measurements in relation to other water quality parameters; Johnson & Hosford (2001), for example, investigated the likely impact of boiler clean effluent from Heysham power station and reported annual variation of pH, salinity and temperature at Kings Scar to be: pH (7.91 - 8.26); salinity (28 - 33.3 ppt); temperature (7-14 °C). For Sunderland Point the equivalent data were: pH (7.89 - 8.37); salinity (28.4 - 33.5 ppt); temperature (4.4 - 19.7 °C). There appears to have been no analysis of the salinity regime beyond this, including any available assessment of the Environment Agency's own water quality data from the main estuaries discharging into the Bay. Our assessment is that salinity is not likely to be an important issue for the review of consents process. The shallow (principally < 10m) depth of the Bay means that there is a large exchange of water during the tidal cycle with the Bay at low tide being mostly exposed sand and mud. The salinity regime in the Bay can therefore reasonably be expected to reflect that in the adjacent coastal zone with relatively limited freshwater influence, as evidenced by the above mid-Bay data.

Morecambe Bay coastline is not highly developed; human impacts comprise sea defence, waste discharges (sewage, industrial, agricultural, thermal and domestic waste), commercial fisheries and tourism (Buck 1993). Major chemical industries are at Ulverston, Fleetwood and Brine Wells. There are ports and docks at Barrow-in-Furness, Heysham, Glasson and Fleetwood. Power generation at Heysham and Roosecote, both discharge chlorinated cooling water. Capital and maintenance dredging and commercial aggregate extraction that have the potential to raise turbidity occur in parts of to Bay, notably south of Barrow-in-Furness and at the ports of Heysham and Fleetwood and on their approaches.

In general, levels of contamination in the waters and sediments of Morecambe Bay have not been reported as high, especially in comparison with other sites such as Liverpool Bay. Water within the estuary is typically Grade A (Buck 1993) except Walney Channel and an area between Grange-over-Sands and Humphrey Head which has been classified as B. Levels of metals are relatively low (e.g. Mercury 370 μ k kg^{-1}, zinc 96 mg kg^{-1} (MPMMG 1998)). Levels of organic compounds, including PCBs, PAH and pesticides are also seen to be low in this study.

Johnson and Hosford (2001) also provide some information on metal levels in Morecambe Bay. The authors used data from the Environment Agency (chromium, copper and nickel at Plover Scar and Lune Deep) and reviews by OSPAR 2000 (copper, zinc, cadmium and lead) and Laslet 1995 (copper, manganese and nickel). No metal was present at levels that raised concern to the authors

Wrench & Loney (1989), in a study based on 203 locations in and around the Bay, generally found no elevated levels except for lead which was found at higher than expected levels across much of the area. WS Atkins (1994) concluded that there were no water quality concerns regarding lead, chromium, zinc, copper, nickel or arsenic. Mercury, cadmium and iron were omitted from the study and there was inadequate data for boron and vanadium.

Several studies have looked at mercury levels in fish tissues with respect to human health implications. Data collected over the period 1988-1990 Leah (1992) suggested that plaice and whiting from Lune Deep were amongst the least contaminated in the northern Irish Sea. The National Monitoring Programme reported comparable absolute mercury contaminant levels from more recent surveys of flatfish from a site off the Wyre and Lune estuaries (MPMMG, 1998); however, levels were reported to be higher in Liverpool and Morecambe Bay than other sites monitored around the UK. This same study reported mercury in mussels from the same location (0.8 mg/kg dry weight) to be the highest of any site in the UK. Pope *et al.* (1997) have also reported raised mercury levels in water and sediments and some biota from Knott End (Wyre Estuary). Metal concentrations were generally not too high, but exclusion of some invertebrate species was inferred and *Mytilus* was noted as the most sensitive taxon. The Environment Agency also have extensive records of cadmium and mercury levels in *Mytilus* from samples collected as part of the Dangerous Substances Directive.

Table 3, below, summarises metal concentration in dredged materials reported by CEFAS (2000). This data suggests elevated levels of zinc, lead and mercury (exceeding OSPAR guidelines) around Barrow-in-Furness.

Table 3. Metal concentrations in dredged materials (mg Kg-1 wet weight) for sites in Morecambe Bay. From CEFAS 2000)

	Heysham		**Lune/Wyre**	**Barrow-in-Furness**	
	1996	1997	1996	1996	1997
Arsenic	6.44	4.9	6.12	17.1	5.32
Cadmium	0.16	0.28	0.12	0.56	0.12
Chromium	23.38	23.38	15.12	42	15.08
Copper	12.98	6.87	4.52	87	8.06
Mercury	0.26	0.14	0.08	2.44	0.03
Nickel	14.38	9.53	8.08	23	10.46
Lead	20.13	16.75	13.2	224.67	17.48
Zinc	69.25	48.75	40.4	370	38.8

Our overall assessment of the current status of water and sediment quality with respect to metal contamination is that there are still problems from historical pollution sources (e.g. lead from past mining operations) but that current inputs are low and the situation is improving.

British Energy use Chlorine to clean cooling water before it is discharged back to sea. This is to prevent fouling within the system by marine organisms. There have been a number of studies to assess whether there is any environmental risk associated with the production of chlorinated by-products (e.g. Johnson & Hosford, 2001; Jenner *et al.* 1997); the conclusion was that there is no significant risk. The discharged waters are believed to contain two orders of magnitude less Chlorine than results from an equivalent process used by sewage treatment plants. The cooling water system is also a cause of mortality for fish that are drawn into the powerful stream. There are a number of internal reports for British Energy on fish mortality, including earlier reports for its predecessor, Nuclear Electric. Icthyoplankton may pass right through the cooling system, whereas adults are removed by drums. The conclusion has been that the mortality of fish is not a significant influence on the overall population, particularly of key prey species for pisciverous birds, such as sandeel, and hence that there are not deleterious ecological consequences (Colin Taylor, British Energy, pers. comm.).

Chlorine and other chemicals including corrosion inhibitors are also used to flush boilers at Heysham. Although this process was not subject to appropriate assessment, a number of studies have investigated potential toxicological effects (e.g. Cole *et al.* 2001; Mazik et al. 2001). These have calculated the dilution factors that must be used before effluent can safely be discharged into the sea.

Organic inputs to the Bay potentially originate from a number of sources. These include point source discharge directly into the Bay from sewage treatment plants, diffuse inputs from the land, predominantly agricultural runoff, and inputs from seaward. There is strong pressure to upgrade sewage treatment works from the EU Urban Waste Water Treatment Directive and further pressure as a number of beaches locally (e.g. Morecambe) have recently failed Bathing Water standards.

There is a potential conflict of interest between the need to meet new water quality standards and the likely benefit to current conservation interest of a degree of organic enrichment that boosts invertebrate productivity. However, Holt *et al.* (2000) suggested that dramatic detrimental effects of reduced organic loadings in Morecambe Bay were unlikely since organic enrichment in the Bay is not at a comparable level to other estuaries where reduction in wading bird numbers following estuary clean up has been reported. This view is partially supported by a recent study by the British Trust for Ornithology (Burton et al. 2002) which reviewed the research on the effects of organic and nutrient loading on the distribution of biota, especially invertebrates, fish and birds, within coastal and estuarine areas. This review concluded that reductions in the organic and nutrient load of discharges may have a negative impact on bird populations in all but the most grossly contaminated sites. However, there are clearly strong imperatives to tackle organic pollution of waterbodies and it needs to be understood that organic enrichment can lead to the maintenance of artificially high densities of organisms. Reduced organic loadings may lead to diminished numbers of some species but this should be compensated for by increased diversity, and of course reduced risk of non-compliance with bathing water standards.

A comprehensive review of nutrient levels in Morecambe Bay in relation to potential eutrophication is provided by Holt *et al.* (2001). Although waters in Morecambe Bay do not generally exceed 10 μg/l chlorophyll in summer (indicating hypernutrified waters (CSST, 1997, cited in Holt et al. 2001)), there is still potential for them to do so since there is a general and widespread increase in nutrient loading throughout the Irish Sea. Algal blooms do occasionally occur, almost always during periods of calm and/or following river spates (Evans 1987). These tend to be less intense and occur later than blooms in Liverpool Bay but Involve the same species *Phaeocystis pouchetti* and the dynoflagellates *Gyrodimium auroleum* and *Noctiluca scintillans*. The Bay is vulnerable to algal blooms which pose a risk to all organisms within the Bay through water column deoxygenation while general eutrophication could lead to increased benthic algal growth that could smother other benthic flora and fauna. However, although there is potential for deleterious effects and it will be important to continue monitoring nutrient levels, nutrient enrichment and eutrophication are currently not major problems in the Bay.

Heysham and Sellafield nuclear installations discharge liquid effluent into the Irish Sea. This has been the subject of much monitoring by DEFRA (MAFF), BNFL, The Environment Agency and Lancaster City Council. Routine monitoring programmes have focused on public health concerns and report that dose rates for key groups (such as fishermen working in the intertidal zone) are well within limits permitted for members of the public. Relatively little data is available for the wildlife implications of radionuclide dispersal in the environment. Woodhead (1998) provides a review of the impact of radioactive discharges on native wildlife and the implications for environmental protection. The most significant discharge is that of Sellafield and research has focused on the possible incremental effect of radiation on marine organisms. Exposures from anthropogenic sources are generally below the natural background; however, exceptions are Sellafield and the Drigg Sand Dunes site (see Duddon estuary report) both of which are detectable at 1 - 2 orders of magnitude higher than the likely natural background exposure. The overall conclusion of Woodhead (1998) was that there are unlikely to be any significant effects in populations of freshwater and coastal/marine organisms at dose rates below approximately 400 μGy/h (Woodhead, 1998 citing: IAEA 1976,1992; Myers 1989; NRCP 1991 &

UNSCEAR 1996). This figure takes into account most radiosensitive organisms; however, there are considerable uncertainties, for example, currently available samples represent only limited fraction of the exposed population.

4.7 Biological Effects of Exposure to Persistent Contaminants

It has previously been noted (Table 2, Section 4.6) that levels of lead and mercury can exceed recommended levels within Morecambe Bay sediments. The ecological significance of metals in estuaries was reviewed by Bryan and Langston (1992). The authors noted that concentrations and bioavailability of metals in estuarine sediments depend on many different processes, e.g.:

1. mobilisation of metals to the interstitial water and their speciation;
2. transformation, e.g. methylation, of metals including As, Hg, Pb and Sn;
3. binding to oxides of Fe and organics;
4. competition between metals for uptake sites in organisms;
5. influence of bioturbation, salinity, redox and pH on these processes.

Bryan and Langston (1992) considered it likely that the combination of metals in many estuaries that are only moderately contaminated contributes to the overall stress on organisms caused by substances requiring detoxification. Sublethal effects on sediment infaunal populations are as important as direct toxicity if, for example, prey species disappear from a mudflat. This is also a risk for sites contaminated with TBT which has been shown to have deleterious effects on the recruitment of several species of bivalve. Bryan and Langston (1992) also pointed out that some bird species, e.g. dunlin, can adapt to a wide variety of prey species whereas other are less flexible. Knot feed primarily on bivalves and may therefore be especially vulnerable.

Although there are very few instances in which deleterious effects can unequivocally be attributed to metals or their compounds, the Mersey bird kill in the late 1970s is believed to have been caused by ingestion of invertebrate prey species contaminated with alkyllead from industrial sources. Bull *et al.* (1983) suggested that bioconcentration of alklyC-lead residues in *Macoma balthica* was chiefly responsible.

Lack of evidence for other metals may simply reflect the limited research that has been undertaken and it is dangerous to rule out the possibility that there are potentially damaging effects from accumulations of Ag, As, Cr, Cu and Zn, especially on juveniles and individuals subject to, for example, food-shortage stress.

McLusky *et al.* 1986 demonstrated that exposure to contaminants that have sub-lethal effects under optimal conditions may reduce temperature and salinity tolerance under sub-optimal conditions. There is therefore the *potential* for invertebrates, and therefore birds, to be affected by contamination of the environment.

Certain invertebrates have been shown capable of developing resistance to pollutants. For example, Nedwell (1997) demonstrated that *Nereis diversicolor* and *Corophium volutator* collected from contaminated sediments had a much higher resistance to copper and zinc than animals from clean sediments. In the tolerant populations, metals were being sequestered in a non-toxic way. Walker et al. (1997) described how toxicity can be reduced by the production of metallothionein, a protein that binds to metals to reduce their availability or monooxygenases which enhance metabolism of a pollutant to increase its solubility and excretion.

Estuarine fishes can be susceptible to accumulation of contaminants; marine fishes, through their greater mobility and exposure to lower levels of contaminants in the open sea typically show lesser effects. In Morecambe Bay, the intertidal wetland and subtidal sand bank areas are important habitat for sandeel which support several pisciverous bird species (Elliot *et al.* 1998).

Overall, the conclusion is that Morecambe Bay currently supports an abundant bird fauna that is to a large degree dependant upon the presence of an plentiful supply of intertidal invertebrates. Contamination from persistent pollutants is generally decreasing as a result of legislative pressures, improvements in industrial practice and the decline of old industries such as mining. There should, therefore, be limited risk to the interest features of the site; however, there is a degree of uncertainty because of the limited research that has taken place. This is equally the case with radionuclide contamination which has received very little attention as a potential hazard to wildlife.

4.8 Habitat Requirements of Protected Species and Sensitivities of Species and Communities

Saltmarsh is an important habitat for birds on the site. In particular, it provides feeding opportunities for wildfowl that graze saltmarsh vegetation, undisturbed roosts over the high tide period for both waders and wildfowl and breeding habitat for a number of species, such as redshank. Much of the saltmarsh in Morecambe Bay is grazed by cattle and sheep. A range of grazing types and pressures leads to a mosaic of sub-habitats, for example short-sward, dry marsh on sheep grazed areas, tussocky sward, wet marsh on cattle grazed areas and a rank sward on ungrazed areas. Wintering wildfowl and breeding birds exhibit preferences within this diversity of sub-habitats which is therefore important to allow maximum diversity of species of breeding birds and wintering wildfowl.

The condition of saltmarsh on the site is the subject of a study by ERC, University of Liverpool on behalf of English Nature. This will be reporting in Spring 2003 to support condition assessments and provide management recommendations in relation to grazing on the SPA/cSAC. Preliminary findings from the study indicate that there are a range of grazing types and pressures that, in general, provide a the diverse habitat structure required by the avian interest features. There are some localised issues, in particular the rapid erosion of Silverdale marsh and its high intensity use for recreational walking has rendered this once significant area of saltmarsh of limited current value.

Waders require large areas of undisturbed, invertebrate-rich , low tide mudflat to feed and secure (i.e. largely predator and disturbance free) high tide roosts which may be located along the seaward edge of saltmarsh areas (Lambert 1998).

Little information was available on specific habitat requirements of the protected (bird) species for Morecambe Bay. The distributions, of birds in Morecambe Bay were reviewed by Wilson and Marsh (1987) from which some inferences of habitat requirements can be made. The descriptions from that report, summarised below, are not complete but together with other information sources confirm the importance to waterfowl of both suitable feeding and roosting areas (and breeding sites for those species which breed at the site). Trends in habitat use, feeding behaviour etc. do vary and so the following should be used only as a guide:

WADERS

Morecambe Bay is important as wintering area, spring and autumn passage area and moulting area in late summer. Several species breed in small numbers, the Bay also serves as a summering area for small numbers of immature birds. Disturbance through human activity limits use of many preferred roosting areas which would normally be as near as possible to the feeding grounds. The following information was available for waders cited in the SPA designation:

Oystercatcher

Breeding: on shingle beaches and saltmarsh at south half of Walney, Foulney Island, Carnforth Marsh and Lune Estuary shingle beds.
Passage & Wintering: Loss of cockles in 1962-63 winter severely affected passage and wintering populations. Also feeds on earthworms inland, previously linked to decline in cockle populations in the Bay although the habit persisted after intertidal feeding improved. Kent and Leven estuaries are key feeding areas August - October. Winter population is centred on several large mussel beds in the lower Bay.
Cease feeding once feeding grounds are covered by the tide and gather to roost nearby.

Ringed Plover
Breeding: mostly nesting on shingle beeches, sometimes on saltmarsh. South Walney, Foulney and Lune Estuary.
Passage & Wintering: mainly a passage migrant when it is well distributed throughout the Bay, lowest numbers in upper estuaries. Small wintering population concentrated mainly between Bardsea to Walney and Hesk Bank.

Golden Plover
Not normally intertidal- low-lying fields and saltmarsh important. Uses shingle and mussel skears around the Bay as nocturnal roosts.

Grey Plover
Mainly confined to the Lune, small numbers in the Keer areas.

Lapwing
Breeding: on saltmarshes.
Wintering: on fields around the Bay, occurring on the intertidal during autumn migration with largest numbers on the upper Leven, Lune and Kent.

Knot
Passage & Wintering: on arrival in late summer moult on the Bay, confined mostly to the Lune estuary. Lune and Keer regularly hold wintering and spring passage populations.

Sanderling
Passage & Wintering: Rarely winters, common on autumn passage when largely confined to the Lune area. Spring passage mainly at east and upper Bay. Feed and tide edges but are forced onto saltmarshes on spring tides.

Dunlin
Breeding: A few pairs on the larger marshes.
Passage & Wintering: Flookborough Marshes important roost area. Lune and Keer estuaries are important for passing birds that have wintered further south. A few hundred birds spend summer on the Bay.

Bar-tailed Godwit
Passage & Wintering: Summer arrivals present mainly on the Lune estuary. Most overwinter there with a few on the keer and Walney area.
Feeding: Bulk feed on the Lune very low down the tide, also feed at lower parts of Cartmel Wharf at low tide.

Curlew
Breeding: One or two pairs on saltmarshes.
Passage & Wintering: Large numbers in winter, spring and especially late summer. Numbers feed inland, especially in winter in the valleys of the Lune, Keer, Kent and Leven. Need low disturbance roosts so Carnforth marsh is important as are Flookborough marshes and the Lune area. 4-8000 overwinter (mostly Leven and Keer areas).

Redshank
Breeding: on saltmarshes, especially Carnforth marsh. Numbers believed to have declined due to sheep grazing.
Passage & Wintering: At times feeds inland, especially on flooded fields. No information on distribution within the Bay, assume widespread.

WILDFOWL

At high tide wildfowl congregate mainly offshore, may seek shelter inland during storms. The following describes the importance of different parts of the Bay to wildfowl included in the SPA designation:

Walney- Wigeon and Teal important. Eiders use the spit at high tide and are also present at Sheep and Piel Islands, although largest numbers are on Foulney which also supports goldeneye. The marsh between Foulney and Rampside supports many wigeon and shelduck..

Leven- off Aldingham, Priory Point and upper Leven there are numbers of shelduck, wigeon and mallard. Three saltmarshes south of Flookborough are also important some years, especially wigeon, pintail and mallard. The largest concentration of shelduck and wigeon are of West and East Plain marshes.

Kent- Much is within the RSPB sanctuary area. Large numbers of wigeon. Also Shelduck and pintail. Goldeneye off Morecambe Promenade.

Lune- Largest concentrations of wildfowl on the Bay, especially Pilling-Cockerham area (mallard, wigeon and shelduck). Pink foot geese roost on sand banks to the south of the Lune (Wyre/Lune Sanctuary).
GULLS AND TERNS

Lesser black-backed gull
Large colony on South End Hawes on Walney. Most migrate for winter but an increasing number are staying on the Bay.

Herring gull
Large numbers breed with the lesser black-backs on Walney. Rubbish tips, especially Salt Ayre and Walney, provide foraging for over-wintering birds.

Sandwich tern
Breeding sites at Walney (on a shingle spit) and Foulney. No other information of use provided.

Little tern
Breeds at Foulney Island. No further information provided.

OTHER SEABIRDS

Great crested grebe
Common winter visitor. Cavendish dock is an important habitat. No further information.

The UK Marine SACs project and Marine Habitat Review (Jones et al. 2000) provide a comprehensive assessment of the habitat/environmental requirements of Marine SAC habitats together with sensitivities to human activities. This applies generically to all UK Marine SACs. Holt *et al.* (2000) reviewed the known sensitivity issues of important species and communities within Morecambe Bay, drawing primarily on work by Davison (1998), Holt *et al.* (1995 & 1998), Hartnoll (1998) and Elliott *et al.* (1998).

4.9 Linkages Between Physical Features and Habitats/Species

Prey resources are important in determining the distribution and abundance of shorebirds during the non-breeding season (e.g. Goss-Custard *et al.* 1984). The summary below, Table 4, relates the known feeding preferences of birds cited in the SPA designation.

The importance of other factors, such as the role of sediment characteristics in influencing invertebrate populations that in turn drive wading bird distributions during feeding have been studied and reported for other sites, e.g. McLusky (1989). However, no direct work on Morecambe Bay is known of. Some modelling work that may be relevant has been undertaken by CEH, Dorset, notably on the Exe estuary and is included in the information directory (45, 46). The models developed by CEH have been applied to a number of UK sites (e.g. Menai Straights, Burry Inlet, Humber and Wash). They are all based on predicting the behaviour of individual birds (wading birds and wildfowl) and predicting their responses to varying environmental conditions. Thus it is theoretically possible to model for the effects of a wide range of factors such as disturbance that reduces feeding time and increases energy expenditure, reduced food resources, increased inter or intra-specific competition and climate change for example. NB Environment Agency is funding the development of a model of the shorebirds of Poole Harbour

Table 4. Overview of known dietary preferences of estuarine waterfowl. Data drawn from a variety of sources to act only as a guide to the general dietary preferences. Adapted from McLusky (1989); Goss-Custard et al. 1997; Goss-Custard et al. 1991; Wilson and Marsh (1987) and English Nature 2001.

	Polycheaetes*	Nereis	Oligochaeta	Arenicola	Tubifex	Crustaceans*7	Bathyporeia	Corophium	Gammarus	Crangon	Carcinus*6	Balanus	Cerastoderma	Macoma	Hydrobia	Mytilus	Tellina	Tipulidae*9	Puccinellia	Enteromorpha	Agrostis
Knot*1*5	•	•		•				•					•	•	•	•					
Dunlin*2	•	•	•			•		•		•	•		•	•	•						
Redshank*3*8	•	•	•			•		•		•	•			•	•						
Shelduck*3*5	•	•	•																		
Eider*4																•					
Bar-tailed godwit	•	•	•	•									•	•	•		•				
Grey plover*7	•	•		•		•															
Curlew	•	•									•										
Black-tailed godwit		•											•	•							
Oystercatcher			•	•						•	•		•	•		•					
Turnstone									•		•	•				•					
Ringed plover					•			•	•						•						
Sanderling							•	•							•	•					
Wigeon																			•	•	•
Pintail															•						
Mallard															•						
Shelduck		•						•							•						

*1 knot feed almost exclusively on bivalves; *2 dunlin adapt to a variety of prey species; *3 feed mainly on the intertidal zone at low water; *4 feed in shallow water at low tide; *5 knot and shelduck rely on re-emergence of Hydrobia as mudflats are covered by the rising tide; *6 *Carcinus* move offshore in winter so feature in shorebird diets only in summer; *7 not including Crangon and Carcinus; *8 feeding rate depends mainly on the density of the amphipod *Corophium volutato;* *9 from terrestrial feeding grounds.

5 Identification of Gaps and Projects Required for Bridging

The following outline the main gaps identified during this project and suggest potential projects to fill them.

Gap 1: *Differentiating anthropogenic and natural change*

Detail: In its current state, Morecambe Bay supports the interest features (i.e. community assemblages) that are protected through its designation as SPA/cSAC. At the same time, the Bay is a dynamic system that is subject to both natural and anthropogenically induced change; Jeffers (1990) points out that major events, triggered by global climate change, could eventually push the Bay into a 'new state'. Such changes, and other more subtle ones, may or may not favour the currently designated interest features.

Suggestion for filling: Site condition monitoring needs to be developed to have the capability to differentiate between natural and anthropogenically induced change. This is a difficult task that represents a challenge to management of all sites that are currently important for conservation.. However, the current approach whereby individual components of systems (e.g. invertebrates, birds, water quality) are measured in isolation is doomed to fail as change will only be perceptible once it has happened. Predictive ecological approaches are required and this will only be found through extensive collaboration between various interested parties; e.g. regulators, researchers and central governments at an international level.

NB Gap 1 is common to both Morecambe Bay and Duddon Estuary reports.

Gap 2: *Invertebrate monitoring*

Detail: Intertidal benthic invertebrates, together with undisturbed roosting areas, are central to the use of Morecambe Bay by the key protected bird species. Not withstanding comments in Gap 1, current knowledge of invertebrate populations in Morecambe Bay is based on dated surveys, a number of ad hoc studies and limited recent high quality surveys. Good knowledge of these communities would feed into solutions developing for Gap 1, above.

Suggestion for filling: Regular (minimum annual) surveys using standard (coring) techniques should be used to sample intertidal invertebrates at a series of sites. A number (minimum 3) should be fixed sites along the Bay. The remainder (2-5) should be flexible to allow samples to be taken from areas of high bird usage; these may be stable for several years but may shift rapidly if environmental conditions change. The assessment of invertebrate community status should include estimates of both production and biomass, in addition to diversity and abundance that are normally measured.

NB Gap 2 is common to both Morecambe Bay and Duddon Estuary reports.

Gap 3: *Biological impacts of pollution*

Detail: Organisms provide the best indication of the *effective* environmental levels of various pollutants. Heavy metals are a remaining concern and uncertainty also exists around the potential impact of TBT around Barrow where high levels have been recorded.

Suggestion for filling: Monitoring of metal levels in flatfish and mussels, ideally at quarterly intervals to examine seasonal trends, should be carried out. A separate, potentially one-off study, to look at the possible effects of TBT on molluscs around Barrow should be carried out. If a problem is found then there is a possible implication for bird populations that depend on molluscan prey.

The wider impact of trace pollutants causing sub-lethal effects such as endocrine disruption is only recently coming to be understood as a potential environmental concern. There are current research programmes and these should be supported and applied to the site.

NB this gap is not necessarily a review of consents issue since passive dispersal of contaminant from ship hulls would clearly not be consented; however, activities such as hull washing or certain dredging activities that could result in TBT dispersal and contamination may require consents.

Gap 4: *Nutrient enrichment*

Detail: The Bay is threatened by elevated nutrient levels in the Irish Sea as a whole. Risks include eutrophication, toxic blooms and potential collapse of all or parts of the ecosystem. Inputs arise from outwith the immediate bounds of the Bay, including significant sources from THORP (Sellafield).

Suggestion for filling: The situation can only be addressed by increased knowledge of the problem and wider regulatory control of sources. A one-off project to establish an 'inputs budget' for the Bay would be very worthwhile and should also recommend appropriate action dependant upon results.

Gap 5: *Disturbance through major works*

Detail: Sea defences and other coastal works create inevitable disturbance to roosting and feeding birds.

Suggestion for filling: Commissioning of development of 'best practice' guidance for such activities and appropriate review of all such activities in light of potential impacts. This includes activities such as manual maintenance to installations such as outfalls.

6 References

All referenced are provided in the information directory.

Appendix 1

Keywords used in database:

Keyword	
Algae	Management
Alt Estuary	Mersey Estuary
Atmospheric Deposition	Metals
Birds	Microbiology
Conservation	Morecambe Bay
Currents	Nutrients
Dispersal	Plankton
Dredging	Radionuclide
Duddon Estuary	REQUIRED
Ecosystem	Residual Flows
Energy	Ribble Estuary
Environmental Assessment	River Flows
Environmental Change	Salinity
Fish	Saltmarsh
Flooding	Sand Dunes
Floodplain	Sandwinning
Freshwater	Sediment Contamination
Fylde	Sediments
Geomorphology	Sefton Coast
Groundwater	Survey
Habitats	Tidal Flows
Hydrodynamics	Vegetation
Hydrographic	Water Chemistry
Hydrology	Water Quality
Invertebrates	Waves