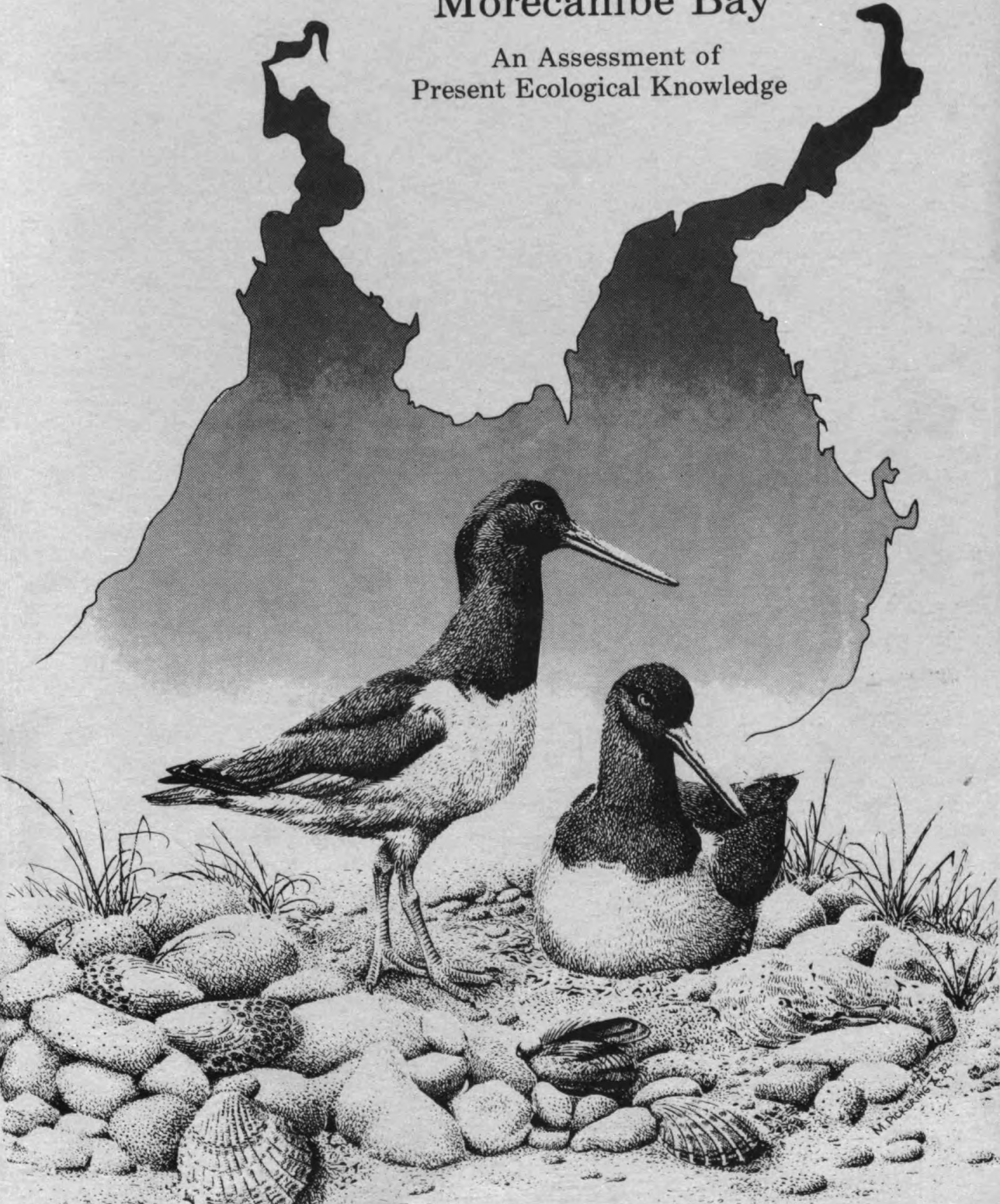
Morecambe Bay

An Assessment of Present Ecological Knowledge



Morecambe Bay Study Group
in conjunction with
Centre for North West Regional Studies, University of Lancaster

MORECAMBE BAY:
An Assessment of Present Ecological Knowledge

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Published as a Resource Paper
of the
Centre for North-West Regional Studies
in conjunction with the
Morecambe Bay Study Group
1987

ISBN 0 901 272 34 5

Printed by the University of Lancaster Central Printing Unit

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Preface

This book aims to assess present ecological knowledge of Morecambe Bay. Members of the Morecambe Bay Study Group prepared their individual contributions in 1980/81 for publication in 1982 by the Natural Environment Research Council in their Series C on British bays and estuaries. Regretably NERC was then affected by serious financial cut-backs and reorganization, which caused repeated delays in the appearance of this publication. When the Series C was terminated in 1986, the unpublished manuscript was returned to us and we immediately sought another publisher. We are grateful to the University of Lancaster's Centre for North-West Regional Studies for accepting it for their Resource Paper Series and we are pleased to acknowledge the substantial financial aid provided towards the cost by NERC and the Estuarine and Brackish-Water Sciences Association.

As about five years had elapsed after the chapters were written initially, authors were given a short period of time towards the end of 1986 in which to up-date their contributions if they so wished. In fact all chapters underwent minor revision except for Chapter 9, Birds and Chapter 11, Phytoplankton. N.A. Robinson edited the original version of the book for publication by NERC, but had ceased to be a member of the Morecambe Bay Study Group by 1986. I therefore have edited this revised version.

Ada W. Pringle
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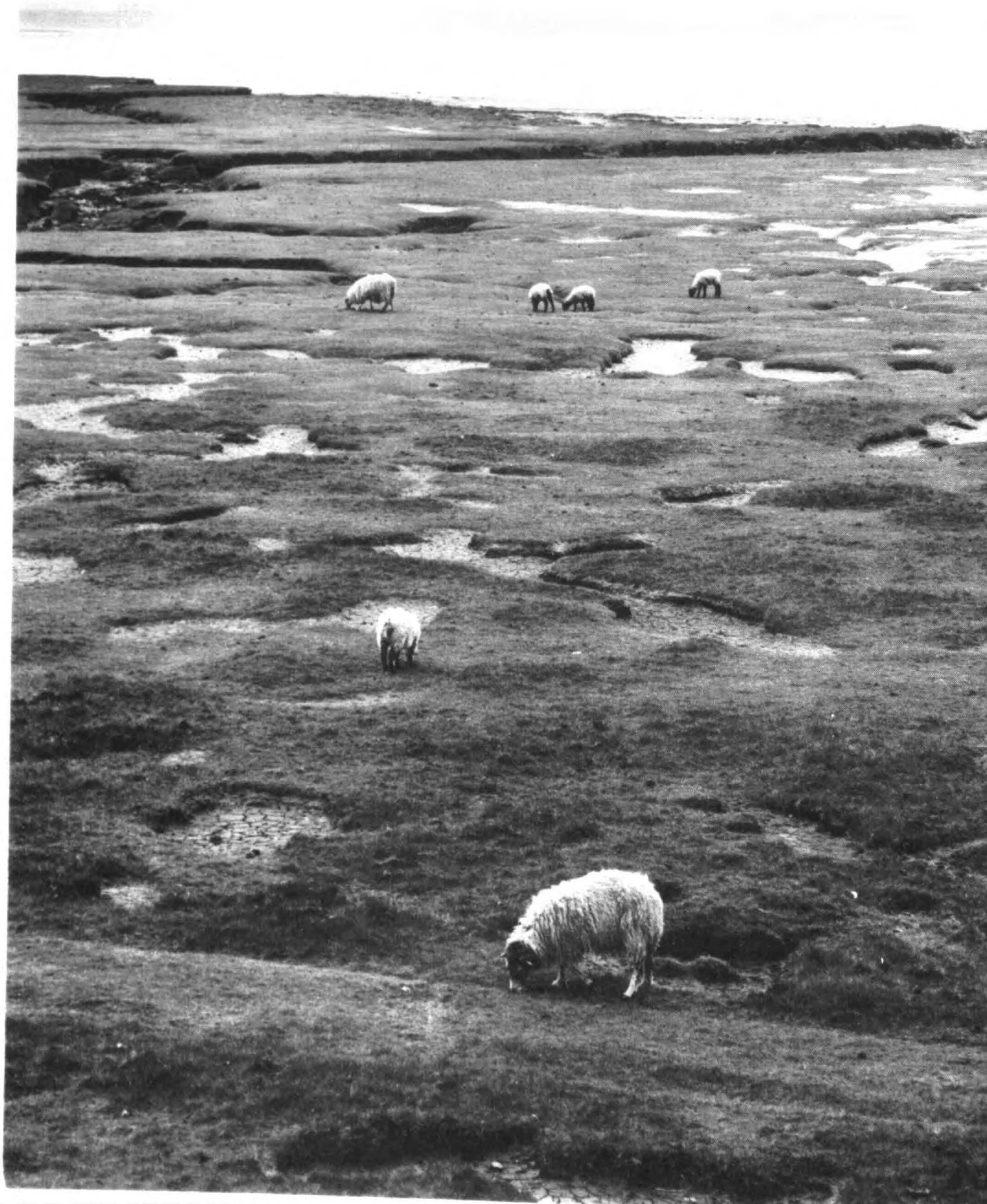
June 1987

Overleaf:
Silverdale Marsh: intensively sheep-grazed, species - poor saltmarsh (reproduced by courtesy of the Nature Conservancy Council).



Chapter 1

MAN AND THE BAY

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Settlement Pattern

Fleetwood, Morecambe and Grange-over-Sands are the only towns with actual frontages onto the Bay and these are all 19th century developments owing their origins to the advent of the railways. Barrow-in-Furness, concealed behind Walney Island, is also a 19th century creation, owing its stimulus mainly to the iron industry. Earlier settlements were small fishing villages and anchorages which have either been absorbed in recent developments, as in the case of Morecambe and Barrow, or have become separated from the Bay over the centuries by reclamation, expansion of saltmarshes and siltation of estuaries (a classic example being the fishing village of Flookburgh left high and dry by the reclamation of Winder Moor), with the result that Heysham Head, with its 10th century Anglian Church near the rock-cut graves of an earlier Celtic foundation, is one of the few really ancient settlement sites which still looks directly onto the Bay.

Morecambe and Grange are flourishing holiday resorts, but the fact that the beaches are generally muddy rather than sandy has probably helped to protect the Bay from further developments of this sort, and the provisions of the Structure Plans (see below) make it unlikely that there will be any significant change in the settlement pattern, and particularly any expansion of urbanisation, in the future. In spite of their apparent size when viewed on a map, Fleetwood, Morecambe (and Grange) seem to have little effect on the wildlife of the Bay - their most significant effect has probably been the discharge of sewage effluent.

Road and Rail

Except where there are man-made promenades such as at Morecambe and Grange, and the stretch of the Furness coast from Newbiggin to

Rampside where the road runs along a sea defence revetment, roads avoid the exposed coast and run further inland, an exception to this being the A588 from Cockerham to Pilling which ran along the top of the saltmarsh (until brought behind a sea defence bank in 1980-81). Before the construction of proper roads the coastal peat bogs and steep rocky promontories made access to the Furness peninsula by land very difficult and the main highway was across the sands from Hest Bank near Morecambe to Kents Bank near Grange and then across the Leven estuary from Cark to Ulverston. With the advent of turnpike roads further inland the use of this exposed and dangerous route by coaches and carts ceased, but it is still a Public Right of Way and still has its Guide appointed by the Duchy of Lancaster who takes parties across on foot. Now only minor roads run near the coast and the general pattern of these is not to run along the coast but to approach it at right angles, frequently leading to dead-ends where there is little room for parking or development. As the main recreational means of reaching the coast is now by car, this has the effect of making access to large parts of the coast difficult or at least inconvenient. It must also have acted to a certain extent as a brake on development, but particularly by restricting public pressure it must have played a very significant part in maintaining the relatively undisturbed condition which applies to so much of the coast of Morecambe Bay. Remoteness is invaluable to wildlife.

Railways have had a great deal of indirect effect on Morecambe Bay by influencing the settlement pattern and determining the location of ports, but direct intrusion by construction is confined to the Furness coast. However they nearly had much more effect than this. In 1837 during the search for a main-line West Coast route George Stephenson proposed a line running on a barrage across the Bay in a segment of a circle from Poulton-by-the-Sands (now Morecambe) to Humphrey Head, then across the recently reclaimed Winder Moor and by another barrage across the Leven estuary via Chapel Island to Ulverston. The expense of crossing the sands was to be compensated for by the land reclaimed from the sea. In 1838 John Hague who had reclaimed part of the Lincolnshire coast produced an even more ambitious scheme for taking the line on a 17 km embankment straight across the Bay from Poulton to Aldingham on the Furness coast, and then on a 2.4 km embankment across the Duddon from

Roanhead to Hodbarrow. These two barrages would have reclaimed about 20,000 ha. of land in the two estuaries. Fortunately for the Bay, though unfortunately for the Cumberland coast towns of Whitehaven, Workington and Maryport which were promoting the scheme, in 1840 a Royal Commission which had been set up to look into the future of railway communication between England and Scotland gave its decision in favour of a direct route proposed by Joseph Locke through the Lune gorge. With a speed which puts motorway construction in the shade, work started in 1844 and in 1846 the Lancaster to Carlisle railway over Shap was opened to traffic. More recently George Stephenson's original concept of a bay crossing was revived by the Morecambe Bay Barrage Scheme of the 1960s, albeit without result.

By this time Ulverston and Barrow were linked to lines on the Cumberland coast but it was not until 1857 that the Furness Railway opened the line from Carnforth to Ulverston, linking the headlands by embankments and crossing the unstable sands of the Kent and Leven estuaries by long viaducts which were remarkable engineering feats for the time and which, incidentally, sealed the fate of Milnthorpe and Greenodd as ports. This line has had considerable effects on this segment of the coast. By linking headlands the embankments have straightened out the indented coastline and resulted in reclamation of the land behind, such as the Winster estuary between Meathop and Grange. The viaducts and approaching embankments have reduced tidal scour and increased accretion in the estuaries above them, leading to physiographic changes and reclamation of saltmarshes, particularly on the west side of the Kent around Meathop and on the east side of the Leven.

Ports and Harbours

Prior to the 19th century the small boats of the times plied to many anchorages around the Bay and penetrated a long way up the rivers. A pier at Hest Bank was used by boats from Liverpool and Glasgow (Ashmore 1969). Milnthorpe was the port of Westmorland vital to the trade of the wool, grain, gunpowder and snuff mills of the Kent valley and supplying coal to Kendal. Lancaster was a prosperous port trading with the West Indies, America and the Baltic, second in importance only to Liverpool (a claim however which seems to have been made by most of the west coast ports operating at that time). There were smaller anchorages at such unlikely places as Skippool Creek and Hambleton up the Wyre, Penny Bridge above Greenodd, and Wilson House near Lindale when John Wilkinson the Ironmaster had a foundry there. During the 19th century major changes took place. Increasing size of boats and siltation of the rivers caused anchorages to be moved progressively down from the inner to the outer reaches of the estuaries. Development of canals and then railways reduced minor coastal traffic, and competition from the Ports of Preston and Liverpool resulted in commerce being concentrated at the railway harbours of Fleetwood and Heysham, while Barrow developed as a construction as well as shipping dockyard in conjunction with iron and steel production. Of the minor harbours only Glasson Dock survives, but now mainly as a recreational centre.

The development of Fleetwood began in 1840 with the construction of a railway line from Preston, with ambitious plans for a port and holiday resort. The resort never prospered but the port gradually developed, particularly with Belfast and Isle of Man traffic, and it is still the home of the trawler fleet which has made 'Fleetwood' synonymous with 'fish' in north-west England. Visitors to the holiday resort of Morecambe would be surprised to learn that it started with aspirations of being a railway harbour in 1850 when the Midland Railway built the stone jetty which is now occupied by Marineland, but with the opening of the Furness Railway their Irish traffic was transferred to Barrow. The construction of Heysham Harbour by the Midland Railway in 1897-1904 brought the Irish traffic back, and Morecambe continued to develop as a holiday resort.

The waters within Morecambe Bay are shallow but the location of Fleetwood, Heysham and Barrow on headlands where access to navigable waters can readily be obtained without the need for major channel works means that they have had little impact on the physiography of the Bay - unlike the Ribble Estuary where training walls in connection with the Port of Preston have greatly accelerated accretion and reclamation, drastically changing the configuration of the estuary in a century. Training walls were constructed along some parts of the Lune in the mid-19th century when the Port of Lancaster was making a bid to survive, and this has resulted in considerable saltmarsh development in the narrower parts of the estuary upstream of Sunderland Point, but not in the lower reaches of the estuary.

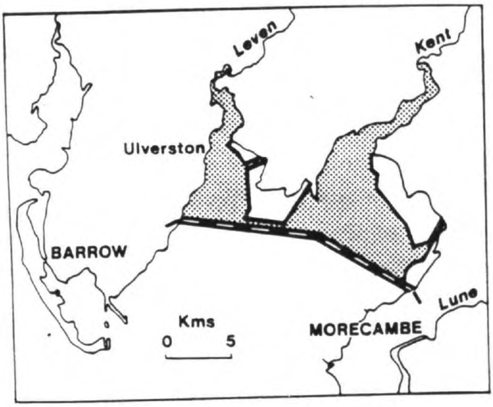
Industry

With the absence of coal the only local mineral resource exploitable on a scale of national importance has been iron ore, which led to heavy but temporary industrialisation of parts of the Furness area in the 19th century. The only intrusion into the Bay from this period of activity is the remains of the slag bank of the old Carnforth ironworks. With the exception of salt deposits at Preesall utilised by ICI, industry around the Bay depends on imported raw materials with the result that major industrialisation is confined to the immediate vicinity of the three ports described above, again, by good fortune, reducing the impact on the Bay. However, when Ulverston was chosen after World War II as the site for Glaxo's penicillin factory one of the reasons was that the work's effluent could be discharged into the Bay without, it was considered at the time, the need for treatment. Sand and gravel have not been extracted on a significant scale from the intertidal areas, though extensive workable resources exist in Morecambe Bay and the Lune Estuary. Aggregate was formerly extracted on a large scale from South End Haws on Walney Island and in 1982 planning permission was granted for the resumption of extraction on a more limited scale and subject to conditions to protect the wildlife of the area.

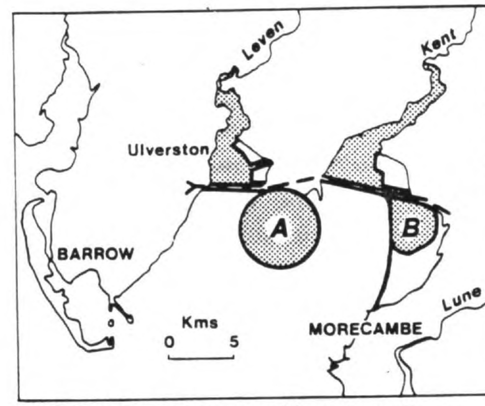
The power industry has a number of key installations around the Bay. The Central Electricity Generating Board's Heysham Nuclear Power Station consists of two stations: Heysham A which is in operation and Heysham B which is under construction. Each will take cooling water from the Bay at a rate of about 50 cumecs and return it with the temperature raised by about 8°C and with a small amount of residual chlorine. This will have some very localised effects but it is not anticipated that it will affect the ecology of the Bay as a whole. In the 1970s geophysical investigations were pursued for potential sites for an offshore nuclear power station complex on the Middleton and Pilling-Cockerham sands. The Morecambe Bay Gas Field lies outside the confines of the Bay as defined for this report, but Cockerham and Pilling, two possible sites for the Terminal out of several considered by the British Gas Corporation, would have involved laying the landfall pipelines through long approaches of unstable sediments in the Lune Estuary. Construction of the Terminal at the chosen location: Westfield Point at Barrow, has been achieved without any significant effects on the Bay as the landfall pipes approach from the open sea by crossing Walney Island and Piel Channel. However there is a real possibility that gas, or even oil, could be found by further explorations within the Bay, requiring facilities which could change the present scene completely.

The water industry probably has the greatest potential capacity for changing Morecambe Bay. In the 1960s, at a time when ideas for estuarial barrages combining road crossings with water storage were in vogue all over the country, the Water Resources Board conducted the Morecambe Bay Barrage Feasibility Study, culminating in their report of 1972: Morecambe Bay Estuary Storage. The report assessed the merits and implications of the four schemes shown in Figure 1.1. By this time it was apparent that the 'Full Barrage', which would also be the most damaging environmentally, was virtually eliminated on cost grounds, but no action was taken to develop any of the schemes in any case. In the 1970s the concept of bunded reservoirs in Morecambe Bay, though on a much smaller scale, was revived in the North West Water Authority's Environmental Appraisal of Four Alternative Water Resource Schemes, the other three being for inland sites at Haweswater (Cumbria), Borrow Beck and Hellifield. Their Report of the Environmental Impact Study, November 1978 assessed the implications of various permutations of two bunded reservoirs: one on Cartmel Wharf immediately south of Flookburgh and the other on the east side of the Bay, variously off Hest Bank, Red Band or Carnforth (Keermouth). Subsequently the NWWA decided that, if the need for a new major source should arise, the Authority's strategy would be based on regulation of the River Lune from either Haweswater or Borrow Beck, with however estuarial development not being entirely ruled out, but that on present demand forecasts no new major source is likely to be required for some twenty years. Thus the prospect of use for water storage, which would certainly have far-reaching effects on Morecambe Bay, has receded but not entirely disappeared. Although they have not brought about any changes in the Bay, these two major investigations have played a significant role in advancing studies of the ecosystem. The original Barrage Feasibility Study promoted the collection of a great deal of data on the physical aspects and flora and fauna, especially the vegetation of the salt-marshes, and invertebrates of the mudflats and the numbers,

SCHEME I
The Full Barrage

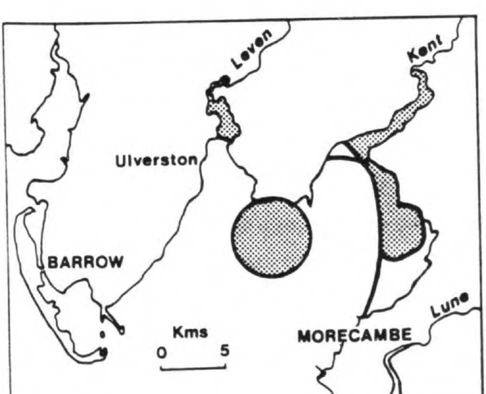


SCHEME II
Twin Barrages with Cartmel or Warton Reservoir



Additional storage at either A or B

SCHEME III
River Barriers with Cartmel and Silverdale Reservoirs



HYBRID SCHEME

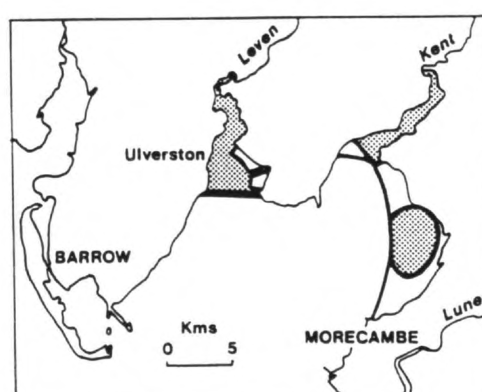


Figure 1.1: Morecambe Bay: Estuary Storage (Water Resources Board 1972).

distribution and feeding habits of wading birds; and the NWWA's project led to the formation of the Morecambe Bay Study Group.

Fishing and Agriculture

There is a long tradition of inshore fishing in Morecambe Bay (see Chapter 13), where boats still work from Morecambe, Glasson Dock and Sunderland Point, and shrimping rigs from Flookburgh. The fisheries are regulated by the byelaws of the North Western and North Wales Sea Fisheries Committee to conserve the marine fish and shellfish populations, and by the Salmon and Freshwater Fisheries 1975 and NWWA Fishery byelaws in the case of salmon, migratory trout and eels. A conflict between fishery and nature conservation arose in the 1950s when drastic decline in cockle takings was attributed to predation by Oystercatchers. At the instigation of the Sea Fisheries Committee the Oystercatcher was transferred to the Second Schedule of the Protection of Birds Act 1954 for Morecambe Bay and the Lune Estuary by the Wild Birds (Oystercatchers) Order 1956, and for several years the Committee's officers carried out culling on a large scale by cannon netting and shooting (Driver, 1977). Culling was resumed after further decline of the cockle industry resulting from the severe winter of 1962-3, but was abandoned in 1968 when it was apparent that it was not having any effect on the situation of the cockles - or the Oystercatchers. The Order was repealed on implementation of Part 1 of the Wildlife and Countryside Act 1981.

Virtually all the saltmarshes around the Bay are in agricultural use, being grazed by sheep or, in some places, cattle. This profoundly affects the vegetation: greatly reducing the diversity of plant species but if anything increasing its feeding value for wildfowl and not affecting the importance of saltmarsh margins as high-tide roosts for waders. More significant in bringing changes is the reclamation of saltmarshes by embankment and intensification of agricultural use following exclusion of the sea. Compared with the Ribble and Dee Estuaries the development of saltmarsh in Morecambe Bay has been relatively slight, and 19th century reclamations appear generally to have capitalised on opportunities resulting from railway construction, except for the ambitious and not entirely successful reclamation of

Winder Moor at Flookburgh. The only other attempt to thrust out into the Bay was to reclaim Carnforth Marsh by running the Carnforth Iron Works slag into an embankment heading for Jenny Brown's Point, where a stone breakwater was constructed which can still be seen. The embankment was never completed but the existence of these two structures must have played a large part in the development and stability of the saltmarsh between Carnforth and Silverdale.

The most recent reclamation, and indeed the only one so far in the 20th century, has been of 270 ha. of the Pilling-Cockerham Marshes by a sea defence bank constructed by the NWWA in 1980-81. Serious flooding by breaches of the tortuous old defences in November 1977 led to proposals for a straighter embankment further out on the saltmarsh, combining sea defence with agricultural reclamation. As originally proposed the embankment presented a conflict with nature conservation as it would have enclosed the entire saltmarsh including the Fluke Hall wader roost, the main roost for the Lune Estuary, but after lengthy consultation by the NWWA with the agricultural and nature conservation interests a modified line acceptable to all parties was adopted. It is possible that further proposals of this type will arise on other parts of the coast where the sea defences are antiquated. In this area a much larger reclamation, by running an embankment straight from Fluke Hall to Cockersands Point, was considered but not pursued in the 19th century.

Planning Designations and Structure Plans

Morecambe Bay, the Lune Estuary and a number of adjoining areas are in process of being notified as Sites of Special Scientific Interest by the Nature Conservancy Council under Section 28 of the Wildlife and countryside Act 1981. The Arnside-Silverdale Area of Outstanding Natural Beauty (AONB) (Figure 1.2) is designated by the Countryside Commission under Section 87 of the National Parks and Access to the Countryside Act 1949 and the Lake District National Park is designated under Section 5 of the same Act. The AONB is partly in Lancashire and partly in Cumbria, and extends considerably over the foreshore. The National Park only touches on the Bay, covering the upper reaches of the Leven estuary and extending across the Kent to abut with the AONB.

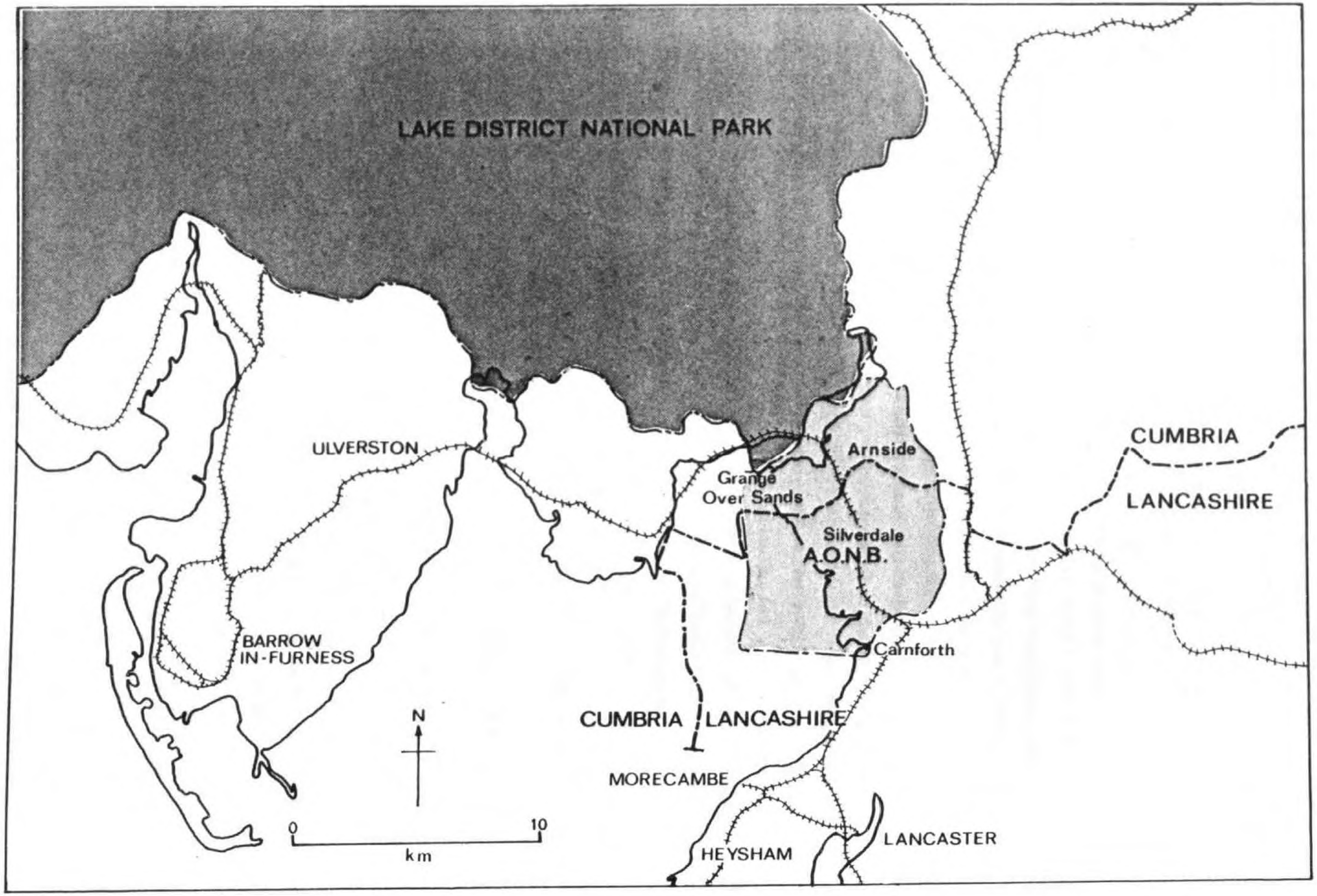


Figure 1.2: Statutory designations. (Figure 13.1 in Chapter 13 shows positions of Sites of Special Scientific Interest).

The Written Statement of the Central and North Lancashire Structure Plan (Lancashire County Council 1983) declares the following policy for AONBs (Policy 4): 'In the Forest of Bowland and Arnside/Silverdale Areas of Outstanding Natural Beauty the safe-guarding of the landscape and character of the area will be given particular emphasis in the consideration of proposals for development. Any development permitted will be required to be of a high standard of design and to use materials appropriate to the area.' Policy 7(a) states unequivocally that: 'There will be a general presumption against development on the remaining stretches of undeveloped coastline, including the river estuaries,' though 7(b) adds: 'Exceptions to this safeguarding may be permitted for fisheries, sea defence and coast protection, navigation purposes, or for informal recreation and amenity.' By comparison the Written Statement of the Cumbria and Lake District Joint Structure Plan (Cumbria County Council and Lake District Special Planning Board, February 1980) takes the more ambivalent line that for open countryside (which is defined as including unspoilt coastline) 'development will normally be resisted unless the social or economic benefits outweigh the environmental costs' (8.19), though strict development controls are proposed for the AONB (8.16). However Policy 5.5 states that 'new major industrial development should normally be located on land within or adjacent or urban areas' and 6.5: 'outside rural settlements new dwellings will normally only be permitted for those engaged in agriculture or forestry where such a dwelling is essential for the working of the farm or woodland'. From this combination of policies it may be deduced that any significant development along the coast is most likely to be concentrated in existing settlements.

The Future

This chapter describes a number of projects which would have wrought major changes in the Bay had they come about, and indeed the failure of so many of these projects is the somewhat accidental reason why the Bay has retained such a high degree of scientific interest. The high value which is now attached to its importance for nature conservation, landscape and amenity will no doubt weigh significantly in any future arguments about alternative uses, and the provisions of the two County Structure Plans clearly intend that the present character of the Bay should be preserved, at least as far as predictable developments are concerned, for the foreseeable future (i.e. the 20th century). In the longer term, the possibilities of water storage, nuclear or other power installations and gas and oil extraction in inshore locations cannot be ruled out, and indeed the discovery of oil or gas is not necessarily removed so far in time.

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Chapter 2

SOLID GEOLOGY, STRUCTURE AND MINERALISATION

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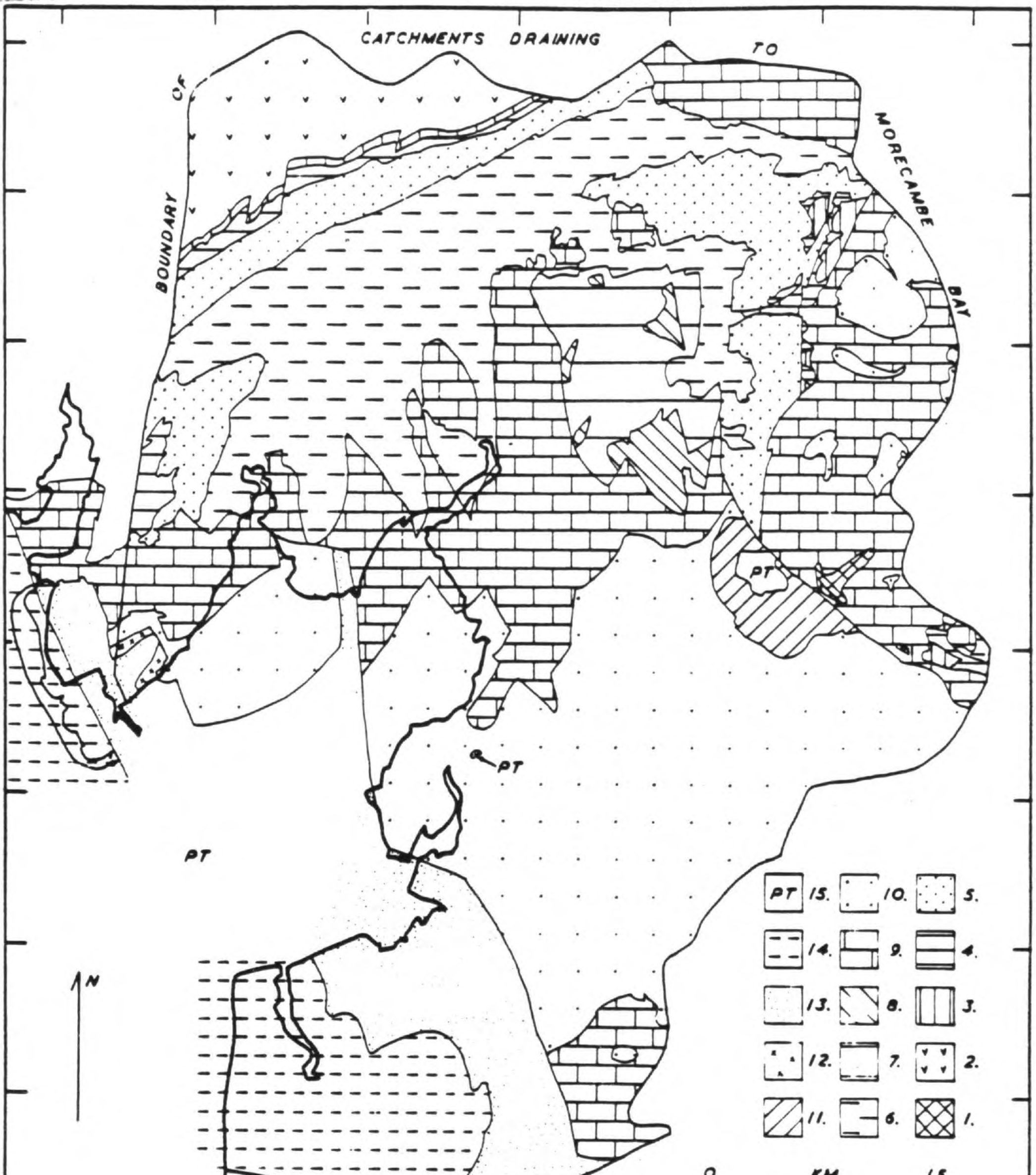
Solid Geology

The solid geology of the area around Morecambe Bay (Figure 2.1) was initially mapped by the Geological Survey during the second half of the 19th century. The details of the one-inch sheets of this Old Series are shown on Figure 2.2a. Only four memoirs were published (Aveline and Hughes 1872; Aveline et al. 1872; Aveline 1873; De Rance 1875). Parts of the area have been resurveyed by the Geological Survey (now the British Geological Survey), with production of the Barrow-in-Furness and Blackpool 1 : 50,000 geological maps for both the immediate Bay area and the adjacent catchments are shown in Figure 2.2b.

The geology of the area within Morecambe Bay was unknown until investigated by drilling and seismic survey as part of feasibility studies by the Water Resources Board for the Morecambe Bay Barrage (Gibb 1970), the Central Electricity Generating Board (1974) and in studies for the route of the pipeline from the Morecambe Bay Gasfield. A stratigraphic borehole has also been drilled at Humphrey Head (Institute of Geological Sciences 1974). These studies have provided information on the solid geology within the northern half of the Bay, north of a line from Heysham to Barrow (Gibb 1970) and within the south-east corner (CEGB 1974). This information has been incorporated in the British Geological Survey 1 : 250,000 sheets for the Lake District (Sheet 54°N - 04°W) and Liverpool Bay (Sheet 53°N - 04°W), and is shown in Figure 2.1. There are no direct data on the solid geology of the Outer Bay between lines from Heysham to Barrow and Fleetwood to Barrow, although the general geology has been inferred on the 1 : 250,000 sheets. To the west of the Barrow-Fleetwood line the solid geology is better known (Fletcher and Ransome 1978, Colter and Barr 1975, B.G.S. 1 : 250,000 sheets noted above).

Figure 2.1: Generalised solid geology of Morecambe Bay and adjacent catchments (Key: 1. "Ingletonian"; 2. Borrowdale Volcanic Group; 3. Coniston Limestone Group, Ashgill and Stockdale Shales; 4. Brathay Flags and Moor Flags; 8. Scout Hill Flags; 9. Carboniferous Limestone and St. Bees Shales; 13. Sherwood Sandstone Group; 14. Mercia Mudstone Group; 15. Undifferentiated Permo-Triassic rocks) (based on I.G.S. maps; Colter and Barr, 1975 and Gibb, 1970).



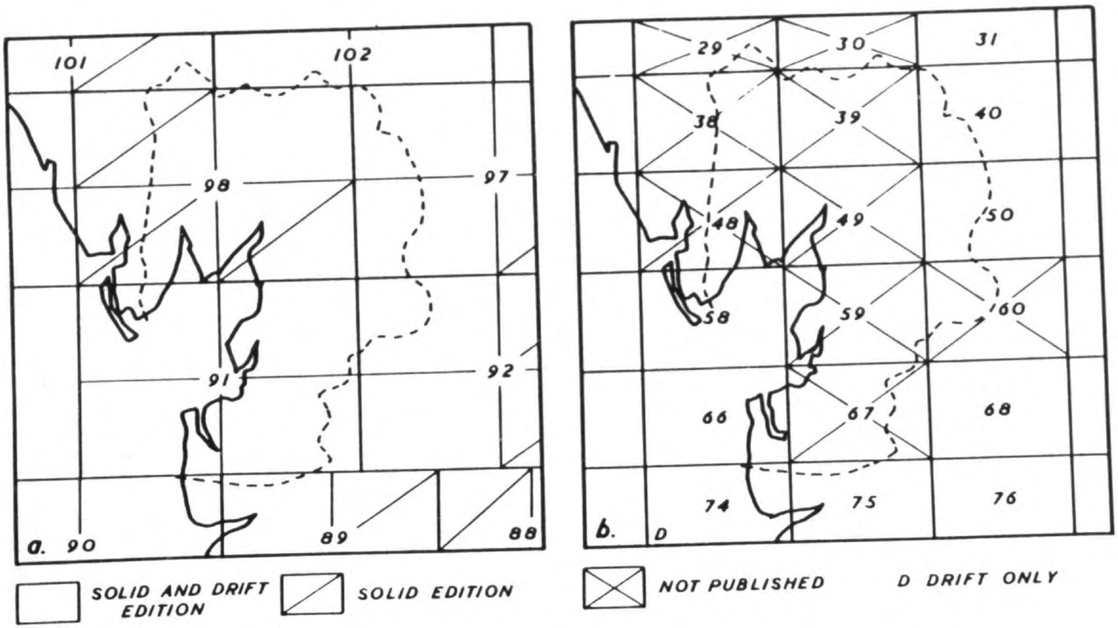


Figure 2.2: (a) Details of Old Series One-Inch geological maps,
(b) Details of New Series One-Inch and 1 : 50,000 geological maps (all published sheets in separate Solid and Drift editions except Sheet 74).

The stratigraphy of Morecambe Bay and its four main catchment areas is summarised in Table 2.1, and reviewed in Edwards and Trotter (1954), Taylor et al. (1971) and Moseley (1978), and the appropriate memoirs or sheet notes. References to more detailed discussions are given in the table.

The main stratigraphic problems in the area are within Morecambe Bay, along the east and south coasts and in the adjacent land areas covered by the Lancaster and Garstang sheets (Sheets 59 and 67 as shown in Figure 2.2b). These result from a lack of exposures, due to a variable cover of unconsolidated materials, sparse borehole information, problems in interpreting the detailed stratigraphy of the Millstone Grit and Permo-Triassic rocks, which occupy most of the area, and problems of distinguishing between them particularly when the former rocks have been stained red.

The catchment areas draining to Morecambe Bay expose rocks ranging from Ordovician to Triassic, and Quaternary and Recent. In each catchment the oldest rocks occur at the headwaters and become younger seawards. The catchments also show a progression in their geology clockwise from the Lower Palaeozoic dominated Leven-Crake catchment, via the Kent catchment with both Lower Palaeozoic and Carboniferous Limestone outcrops, to the predominantly Carboniferous rocks of the Lune catchment and the Carboniferous and (concealed) Permo-Triassic geology of the Wyre catchment.

The floor of Morecambe Bay contains rocks of Carboniferous and Permo-Triassic age. Two triangular areas of Carboniferous Limestone, continuous with the outcrops on land, occupy the mouths of the Leven and Kent estuaries. These are succeeded seaward by rectangular areas of Millstone Grit on the eastern and western sides of the northern half of the Bay, continuous with outcrops on land, and separated by a median area of Permian rocks. The Millstone Grit outcrops are known to finish at about the Heysham-Barrow line. To the south and west of this line the rocks are presumed to be entirely Permo-Triassic in age and continuous with the outcrops in the Fylde, Furness and under the Irish Sea.

Structure

Morecambe Bay lies between the three structurally distinct regions of the Lake District, the Ribblesdale Fold Belt and the Irish

Table 2.1 Summary of stratigraphy in Morecambe Bay and adjacent areas

TRIASSIC (Colter and Barr 1975, Rose and Dunham 1977)	
Mercia Mudstone Group. (formerly Keuper Marls)	Grey, red and green mudstones with halite beds (up to 250 m), overlain by 100 m halite.
Sherwood Sandstone Group.	Well-bedded red medium grained quartz sandstone with intercalated red mudstones (St. Bees Sandstone) (700 m).
PERMIAN (Colter and Barr 1975, Rose and Dunham 1977)	
Sherwood Sandstone Group. (in Furness)	Thin basal breccia (Brockram) overlain by Magnesian Limestone (up to 20 m) and mudstones (St. Bees Shales) (up to 240 m).
CARBONIFEROUS (Ramsbottom et al. 1974, Mitchell et al. 1978)	
Coal Measures. (Ford 1954)	Grey mudstones, siltstones and sandstones with thin workable coals (400 m at Ingleton).
Millstone Grit. (Moseley 1953, Harrison 1970)	Grey mudstones and siltstones with thick, generally felspathic, sandstones (1500 m).
Bowland Shale Group. (Moseley 1953)	Dark shale with calcareous bands and thin sandstones (300 m).
Carboniferous Limestone Series. (Garwood 1912; Garwood and Goodyear 1924; George et al., 1976; Rose and Dunham 1977)	Basal conglomerate overlain by bioclastic and bituminous limestones, with oolitic developments in Furness, and subordinate clay shales. Some dolomitisation in Furness. Upper part of succession alternating limestone, shale and sandstone to east of Bay (Yoredale Formation). In Furness top of succession formed by dark cherty lime-

	stones and thin mudstones (Gleaston Formation).
SILURIAN (Ingham et al. 1978)	
Scout Hill Flags.	Red and grey sandstones and siltstones (200m).
Kirkby Moor Flags.	Greywackes (800 m).
Bannisdale Slates. (Horton Flags at Austwick)	Silty mudstones and siltstones with subordinate greywacke grit (1500 m).
Coniston Grits.	Greywacke grit and thinly bedded siltstones interbedded with mudstones (1800 m).
Coldwell Beds. (Horrace Flags and Harlock Grits in Furness)	Siltstones, calcareous and non-calcareous mudstones, limestones and greywacke (600 m).
Brathay Flags. (Austwick Grits at Austwick)	Cleaved thinly laminated dark grey siltstone and mudstone (300 m).
Stockdale Shales.	Dark grey mudstone and pale green silty mudstones (65 m).
ORDOVICIAN (Ingham et al., 1978, Millward et al., 1978)	
Ashgill Shales.	Strongly cleaved mudstones (300 m).
Coniston Limestone Group.	Calcareous mudstones, impure limestone and rhyolite (150 m).
Borrowdale Volcanic Group.	Lavas, mainly andesitic, tuffs and agglomerates with intercalations of basalt and rhyolite (3000 m).
"Ingletonian".	Sandstones and siltstones, greywackes.

Sea Basin (Figure 2.3) (Moseley 1972, Colter and Barr 1975). The structures in and around the Bay reflect the interplay between the differing structural styles, the ages of the folding, and basement control (Moseley and Ahmed 1967, Moseley 1972, Soper and Moseley 1978).

The north-west corner of the Bay (Figure 2.3) is dissected by NW-SE trending normal faults cutting only slightly folded Carboniferous beds which generally dip to the east and southeast at low angles (Rose and Dunham 1977). In the north east corner and along the east coast the Carboniferous rocks are folded into a series of anticlines and synclines the axial trends of which vary from NNE-SSW in the north, through NE-SW, to N-S at Heysham (Gibb 1970). These beds are cut by several major normal faults trending generally NW-SE. South of a line from Heysham to Barrow the structure of the Permo-Triassic rocks is poorly known except for the presence of tight synclines at Fleetwood and Barrow, which may be portions of a single structure extending across the mouth of the Bay, and the main Boundary Faults. These are major normal faults running NW-SE, with throws to the west of up to 1500 m. They define the boundary of the Permo-Triassic outcrops on the West Cumbria coast and in the Fylde. The former has not been proved to continue south of Walney Island but the latter runs up to Heysham, forming the Permo-Triassic/Carboniferous boundary in that area, and then continues across the Bay into Cartmel.

The structural evidence around and within the Bay indicates that the floor of the Bay is a broad synclinal structure trending NE-SW with a core of Permo-Triassic rocks flanked by outcrops of Millstone Grit. The western limb probably continues the simple dipping and faulted structure of the Furness area. In contrast the eastern limb is probably more complicated being affected by continuations of the folds in the Carboniferous rocks. These will involve the Permo-Triassic rocks to a varying extent. The main syncline is probably cut by an extension of the Cumbrian Coast Boundary Fault, and associated faults in Furness, and the Fylde Boundary Fault, and its continuation into Cartmel.

Mineralisation

The only significant epigenetic minerals in the area are the

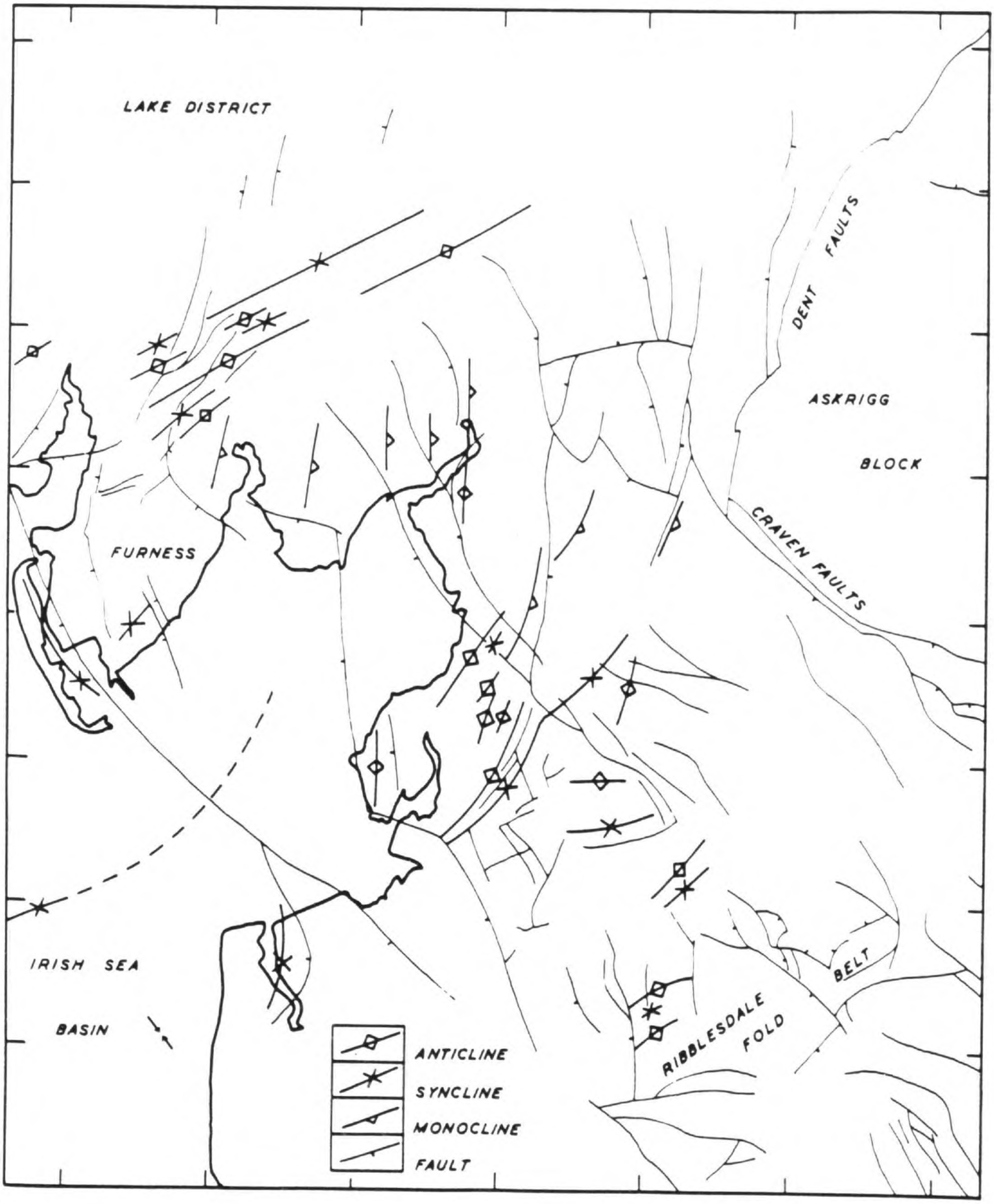


Figure 2.3: Structural setting of Morecambe Bay (Compiled from I.G.S. maps; Gibb, 1970 and Moseley, 1953, 1972).

hematite deposits in Furness (Rose and Dunham 1977). These occur again in very reduced form in the Arnside-Silverdale area (Moseley et al., 1969) where they are associated with malachite. Copper, lead, iron and barium minerals occur within the southern part of the Lake District (Firman 1978), and Harrison (1970) has reported hydrocarbon-bearing nodules in Millstone Grit sandstones at Heysham. Syngenetic minerals are restricted to the Triassic evaporite deposits within the Mercia Mudstone Group which have been proved near Barrow, in the Fylde and in the south-east corner of the Bay, south of Heysham.

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Chapter 3

QUATERNARY HISTORY

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Introduction

The geography of Morecambe Bay (Figure 3.1) is largely the product of events and processes that occurred during the Quaternary Period. Whilst outcrops of solid rock do occur, the coastline of Morecambe Bay is formed largely of unconsolidated sediments of Quaternary age, and in the Bay itself such sediments attain thicknesses of up to 80 metres. The floors of the buried valleys cut in solid rock beneath the Bay and the estuaries and valleys feeding the Bay have altitudes of from -60 to -80m O.D., and indicate that Morecambe Bay probably existed as an embayment of the Irish Sea during each interglacial age, when sea-level attained or exceeded its present level. The rise of sea-level during the present interglacial - the Flandrian Age - and the short period and low amplitude oscillations associated with the rise resulted in the distinctive sedimentary suites in the estuaries and in the low-lying coastal valleys.

Such evidence for the history and evolution of Morecambe Bay during most of the Quaternary Period is fragmentary, and even the record during the Devensian Glacial and Flandrian Interglacial Ages contains gaps, so that the story during the past 70,000 years is incomplete.

Furthermore, Morecambe Bay as a geographical entity has rarely been treated as such, and, whilst some parts of the Bay and its estuaries and river valleys have been described in detail, other parts have not been described at all.

The unconsolidated sediments of Quaternary age have been mapped and described in the Memoirs of the Geological Survey (now the British Geological Survey); De Rance (1875, 1877) and Evans and Wilson (1975) have considered part of the south-west coast of Morecambe Bay, and Aveline (1873) has described part of the north-west coast. Many authors have considered the nature and extent

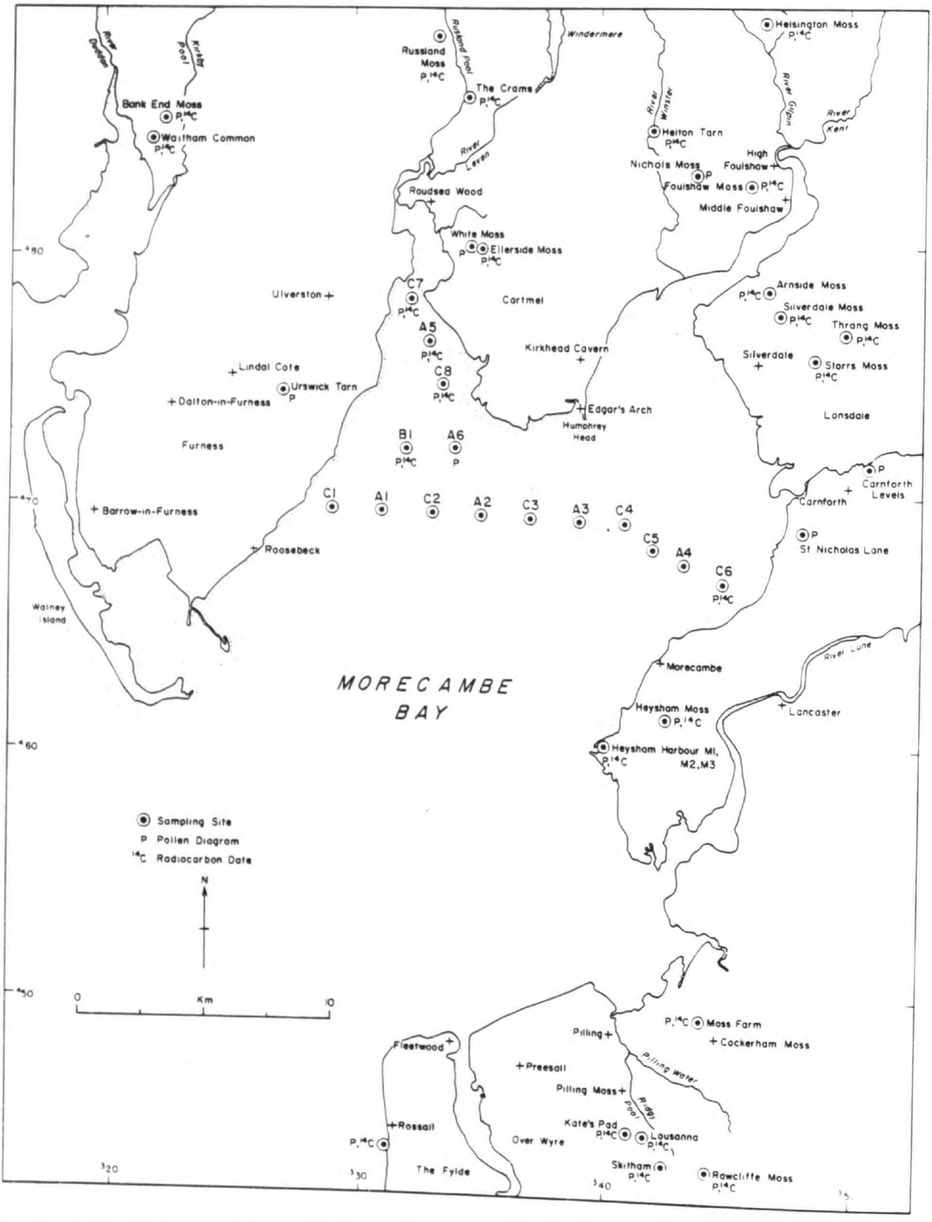

Figure 3.1: A map of Morecambe Bay showing sampling sites and places mentioned in the text.

of glacigenic sediments around the northern shores of Morecambe Bay (e.g. Mackintosh 1869, 1873, 1874; W. G. Kendall 1900; Bolton 1862; Grace and Smith 1922; Gresswell 1951, 1958; Huddart et al. 1977), but few have described these sediments along the eastern and southern shores of the Bay (e.g. Mackintosh 1869; Reade 1902; Gresswell 1967; Vincent 1985).

The geomorphological features around the Bay have been mapped and described by Gresswell (1951, 1958, 1962, 1967) and Ashmead (1974), and the nature and extent of coastal erosion have been considered by W. B. Kendall (1906) and Melville (1948, 1953). Using successive editions of Ordnance Survey maps, Gray (1972) has mapped changes in the extent and location of salt marshes in the Leven and Kent estuaries, and, employing eleven editions of the Admiralty Chart of Morecambe May, Kestner (1970) has been able to show changes in the depth, width and positions of channels within the Bay. (For more detailed discussion see Chapter 4).

The deep organic sediments beneath the Bay have been recorded by W. B. Kendall (1900), Reade (1902), Tooley (1974) and Knight (1977).

The raised mosses, telmatic peats and inorganic sediments adjacent to the estuaries and in the valleys around the Bay have received considerable attention (Munn Rankin 1910a, 1910b, 1911; Pearsall 1918; Erdtman 1928; Osvald 1949; Moseley and Walker 1952; A.G. Smith 1958, 1959; Oldfield 1958, 1960a, 1960b, 1963, 1965, 1967; Oldfield and Statham 1963, 1965; Powell et al. 1971; Barnes 1975; Dickinson 1973, 1975; Shimwell 1985), and have yielded information on post-glacial vegetational history, climate, sea-level changes and prehistoric land-use, to which reference will be made later.

The objectives of this paper are to describe the deposits and landforms of Quaternary age in and adjacent to Morecambe Bay, and to interpret some of these depostits and landforms in terms of sea-level changes and recent tectonic movements. A chronological and stratigraphic framework is provided by Shotton (1973), and different sediment types and landforms are considered under the appropriate stage names: pre-Devensian deposits; Devensian deposits; Flandrian deposits.

Pre-Devensian Deposits and Landforms

There is no unequivocal evidence for any deposits or landforms older than the last glacial age - the Devensian. But the literature contains many references to deposits and landforms that may predate the Devensian Stage (e.g. Bolton 1862; Hodgson 1862; J. D. Kendall 1881; Evans and Arthurton 1973; Huddart et al. 1977; Tooley 1977; Pennington 1978).

Basal till units in Low Furness from 0.9m to 5.4m thick (J.D. Kendall 1881) may be Wolstonian cold stage deposits and are overlaid at Lindal Cotes by a persistent organic stratum. This stratum attained a maximum thickness of 7.3m, attenuating in a north-easterly direction to 1.5m, and was overlaid by a 23m thick upper till. The persistence of the organic layer, its stratigraphic position between two till units and its attenuation to the margins of a depression in the basal till and underlying Carboniferous Limestone gave credence to the autochthonous nature of the layer and its last interglacial or Ipswichian Age. However, a borehole put down by the Institute of Geological Sciences (Anon. 1972) failed to prove the existence of an organic stratum, and the boulder clay recorded was interpreted as the infilling of a solution hollow or swallow hole in the limestone: an explanation proposed by Hodgson (1862) and Ashmead (1974).

Whether or not the organic layer at Lindal Cotes exists and is of Ipswichian Age is still open to question. The borehole was near the south-west margin of the depression and no samples of the upper 26m of the boring were taken (Anon. 1972, p. 119). The boulder clay that was recorded and sampled from 26.12 to 31.30m may therefore be the basal till unit of Wolstonian Age.

Marine erosion features around Morecambe Bay that may be of Ipswichian age include wave-cut notches at altitudes of +4.9 to +5.4m O.D. and an abrasion platform up to 35cm lower, measured by Oldfield (1960) but assigned by him to the time of the maximum post-glacial transgression of the Flandrian Age.

Possible sea caves, benches and water-eroded notches in the Carboniferous Limestone have been described by Ashmead (1974) with altitudes ranging from 12 to 30m. At Whitbarrow, there are notches at 30m: Kirkhead Cavern lies at 30m: and Edgar's Arch or Great Chapel on Humphrey Head also lies at c35m with a blow hole extending from the back of the cave 12m higher on a west-facing slope on the headland. Although Ashmead (1974) assigns a Devensian Age to these presumed marine features, they may be of greater antiquity. It is difficult to reconcile the altitudes of these features with the maximum altitude for eustatic sea-level given by West (1972) for the Ipswichian interglacial as +7.5m O.D., although the Easington raised beach gravel in Shippersea Bay on the Durham coast has been assigned to the Ipswichian (D.B. Smith and Francis 1967), but recently reassigned to the Hoxnian, by D. B. Smith and the erosion surface upon which the marine deposit lies has an altitude of c.27m O.D. (Woolacott 1922). This altitude is closer to the value of +23m O.D. given by West (1972, 1980) for the maximum sea-level altitude in late Hoxnian times and it has been suggested (Tooley 1985) that any marine feature around Morecambe Bay close to this altitude, may be of Hoxnian Age. However, Gale (1981) has criticised Ashmead's (1974) interpretation of the caves and benches as the products of marine erosion, and concluded that the caves have a phreatic origin.

Devensian Deposits and Landforms

The Early, Middle and Late Devensian Ages span a period of time from about 70,000 years B.P. until about 10,000 years B.P., and yet during this long period, glacierization appears to have occurred only during the last 20,000 years. The preceding period was characterised by alternating cold continental conditions during which tundra was characteristic, and temperate conditions during which boreal-type forested or grassland landscapes were characteristic. There is no evidence from Morecambe Bay of the effects that these conditions had on the landforms or deposits.

At some date preceding 30,500±440 B.P. (Birm. 195), which is the date on organic material within gravel overlaid by Irish Sea Till at Four Ashes in the North-West Midlands (see Shotton 1973; Morgan 1973), the Lake District must have nourished a local ice cap and valley glaciers must have pushed south into the valleys now beneath Morecambe Bay, before Lake District ice and Scottish ice became confluent probably at the mouth of what was to become the Bay (Mackintosh 1873). Hence the western part of Morecambe Bay was affected by Irish Sea ice and the rest of the Bay by Lake District ice.

Lancashire is the type area for the tripartite sequence of Upper Boulder Clay or Till, Middle Sands and Gravel and Lower Boulder Clay or Till, first described from the Manchester area by Hull (1864). Mackintosh (1869) mapped the distribution of these deposits around Morecambe Bay, and described the lithology, but in the Furness area Aveline (1873) recognised only a Boulder Drift and a sand and Gravel Drift. Later, in the same area, Grace and Smith (1922) recognised two drifts in Furness: the Irish Sea Drift, covering the southern end of the peninsula and containing erratics from the Cumbrian coast and Eskdale, and Local Drift occurring elsewhere in Furness and containing rocks of local origin. Grace and Smith (1922) subdivided the Irish Sea Drift into a Lower and Upper Boulder Clay, divided by a middle series of sands and gravels, but unlike Mackintosh (1873) they found the two boulder clay beds to be of similar character and content. Huddart et al. (1977) identified two distinct glacial phases in Furness, expressed by an upper and a lower till, separated by fluvio-glacial sands and gravels. Both till units are basal, but they are distinguished by the sand/matrix ratios and by lithology. The sand/matrix ratio of the lower till is 0.792 whereas that of the upper till is 0.513, and the lower till is lithologically distinguished by the higher percentage of rocks from the Borrowdale Volcanic Series, Lower Palaeozoic grits and Carboniferous Limestone. The beds of fluvioglacial sands and gravels were interpreted as sedimentation within a sandur plain.

In Morecambe Bay, Knight (1977) recognised only a single boulder clay unit up to 55m thick and overlaid by clays, silts and sands and varved clays, interpreted as complex sedimentation in a sandur plain (Vincent and Lee 1981) with freshwater pro-glacial lakes.

The complex sequence of tills and fluvio-glacial sands and gravels around and within Morecambe Bay is now attributed to a single glaciation with oscillations of the ice front (Evans and Arthurton, 1973; King, 1976; Johnson et al., 1972; Johnson, 1985). Along the south-west margin of Morecambe Bay, Evans and Wilson (1975) have described and interpreted the till and sand suite in these terms. The basal Boulder Clay here is a purple-grey, heavily compacted till containing comminuted shells and erratics of Cumbrian and Scottish origin. Overlying this till is a Glacial Sand up to 20m in thickness, which is in turn overlain by an upper boulder clay, sandier than the Basal Boulder Clay, less compact and of brown to blue-grey colour. Evans and Wilson (1975) interpret this succession as the product of the melt out of a single ice sheet: the basal Boulder Clay is interpreted as lodgement till, the upper till as flow till and englacial debris.

The landforms associated with glaciation and deglaciation in this area are drumlins, kettleholes, eskers, kame terraces, moraines and meltwater channels, descriptions of which can be found in Mackintosh (1869), Grace and Smith (1922), Gresswell (1951, 1962, 1967), Huddart et al. (1977),Johnson (1975) and Vincent (1985). Huddart et al. (1977) have shown that the drumlin field in Low Furness is formed of basal ice of Lake District origin, and a readvance limit of Irish Sea ice intersects the present coast of Morecambe Bay, south-west of Roosebeck.

During deglaciation in Morecambe Bay, varved sediments (Knight, 1977) bear witness to proglacial lake sedimentation, but, unlike the varved clays with dropstones laid down under brackish water conditions described by Pantin (1977) south-east of the Isle of Man, the sediments in the Bay were probably unaffected by marine conditions. The varved clays, which are up to 16m thick in the Bay, are overlaid by some 2 to 47m of clays, silts and sands that Knight (1977) interprets as deposition in an alluvial fan and slight overconsolidation of these sediments is explained by dessication. Vincent and Lee (1981) have reinterpreted the sedimentation of clays, silts and sands overlying pro-glacial lake sediments as a large complex sandur supplied from wasting ice sheets to the north and the west, and indicated that during a period of dessication, this sandur provided the sediments interpreted as loess on all the limestone outcrops around Morecambe Bay, and mapped as loess by Catt (1977). Vincent (1985) suggests that simultaneously and as the consequence of extensive periglacial activity, talus slopes formed, for example on the flanks of Whitbarrow and Arnside Knott.

The chronology for these changes has not been established, but at least by 14,330±230 B.P. (Q.758) at Blelham Bog and 14,623± 360 B.P. in Low Wray Bay the Windermere Basin was ice free (Pennington, 1975, 1978) and chlorite-containing silts were being discharged from Windermere into Morecambe Bay (Holmes, 1968). The extent of deglaciation is provided by a second date of 14,468±300 B.P. (Birm. 212) from Glanllynnau in North Wales (Coope and Brophy, 1972), and a slightly younger date of 13,490±375 B.P. (Birm. 150) from a basal organic sample in a depression in fluvio-glacial gravels in

Stafford (Morgan 1973) but organic sedimentation in kettleholes elsewhere near Morecambe Bay does not appear to have started until about 12,000 B.P.: for example, High Furlong, Blackpool 12,200±160 B.P. (St. 3832. IGS - C^{14}/135; Hallam et al. 1973), Skitham 11,170±260 B.P. (Gak 2820.; Barnes 1975), Rossall Beach 12,320±155 B.P. (Birm 230.; Tooley 1977) and 11,525±220 B.P. (Hv. 9269.; Tooley unpublished), and St. Bees 12,810±180 B.P. (Q. 71. Godwin and Willis 1959), 12,650±170 B.P. (Birm. 378.; Coope, G. R. in Pennington 1978).

In Low Wray Bay on the west side of Windermere, Pennington (1978) has identified three main lithologic units: the Lower Laminated Clay, Interstadial Sediments and the Upper Laminated Clay. The Lower Laminated Clay marks the end of glaciation in north-west England and is succeeded by sediments assigned to the Windermere Interstadial from c. 14,000 to 11,000 B.P. during which time cool temperate to temperate conditions were interrupted by a climate deterioration at about 12,000 B.P. Interstadial sedimentation ended about 11,000 B.P., and the Upper Laminated Clay comprises c.400 paired varves within 50cm thickness of clay (Pennington 1978). This sedimentation indicates renewed glaciation in the corries of the Windermere Basin, and is equivalent to the Younger Dryas. Under the very cold conditions that occurred cryoturbation phenomena would be formed, and Johnson (1975) has reported involutions, probably of Younger Dryas age, in Furness.

A little further north at Blelham Bog, also within the Windermere basin, Pennington (1975) established a series of chronozone boundaries for the last 4,000 radiocarbon years of the Late Devensian Age. She demonstrated that the chronostratigraphic subdivisions for this period in Scandinavia and Finland (Mangerud et al.,1974) could be compared with subdivisions in western Britain. Hence, from Blelham Bog, the following chronozones were established: pre-Bølling to c.13,000 B.P.: Bølling from c.13,000 to c.12,000 B.P.: Older Dryas from c.12,000 to c.11,800 B.P.: Allerød from c.11,800 to c.11,000 B.P.: Younger Dryas from c.11,000 to c.10,000 B.P.

There is no evidence of the effects of these changing environmental conditions on sedimentation in Morecambe Bay, although the evidence may have existed in the cores, now destroyed, taken for the Morecambe Bay Barrage Feasibility Study (see Tooley 1974 and Knight 1977). The oldest dated record of environmental changes within Morecambe

Bay occurs during the first millenium of the Flandrian Age and is described in the succeeding section.

Flandrian Deposits and Landforms

Buried and intertidal peat beds have been known for many years in Morecambe Bay (Crofton 1876; W. G. Kendall 1900; Reade 1902). Kendall (1900) described a buried peat in Barrow Harbour with altitudes ranging from -14.9 to -17.9m Ordnance Datum, and Reade (1902) recorded a buried peat in Heysham Harbour from -8.2m to -17.6m O.D. These altitudes have been confirmed by more recent work in the Bay (Tooley 1974, 1978, 1980; Huddart et al. 1977). Consolidated peat beds have been recorded persistently at altitudes between -11.1 and -17.6m O.D. (Figures 3.2 and 3.3), and an examination of the pollen assemblages (Huddart et al. 1977; Tooley 1980) shows that the initiation of peat growth was under limnic conditions, probably associated with a rise of sea-level (see Figure 5 in Huddart et al. 1977). Similar changes occurred in the valleys feeding Morecambe Bay, and in many of the basal peats there is a record of changes from fresh to brackish water limnic conditions, succeeded by intertidal sedimentation. Apart from one or two radiocarbon dates from reworked organic material, stratified in the sediments of the Bay, the radiocarbon dates form a series in which age decreases as altitude increases (see Figures 3.1, 3.2 and 3.3):

	Altitude M.O.D.	Radiocarbon dates yr. B.P.	Radiocarbon laboratory	Sites
1.	-17.6	9270±200	Birm. 141	M3
2.	-16.5	8740± 65	Hv. 3361	A5
3.	-16.3	9195±155	Birm. 139	M1
4.	-16.0	8925±200	Birm. 140	M2
5.	-16.0	8330±125	Hv. 3462	C6
6.	-15.8	7725± 95	Hv. 3360	C7
7.	-15.4	8685±175	Hv. 3356	C8
8.	-11.1	7995± 80	Hv. 3362	B1
9.	- 0.3	7750±100	Har. 3709	Rusland Valley
10.	+ 2.9	5734±129	Q. 256	Silverdale Moss.

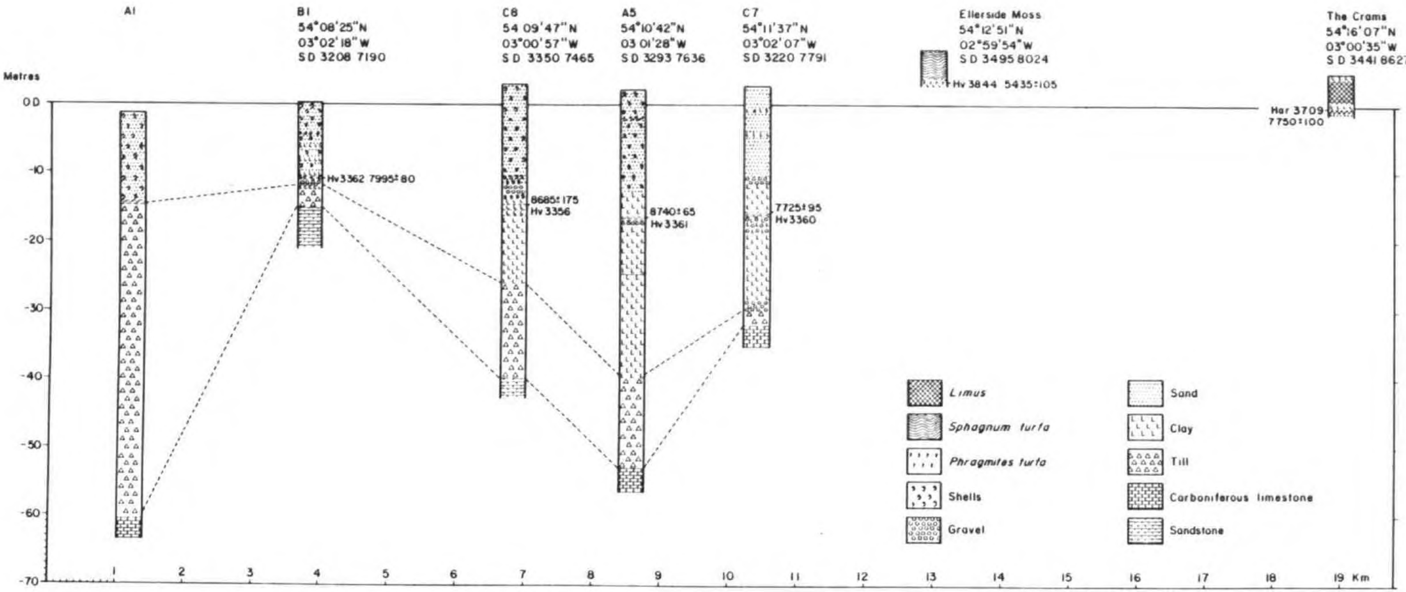

Figure 3.2: The stratigraphy in the estuary and lower valley of the River Leven. The location of the sampling sites is shown on Figure 3.1. The stratigraphic symbols for unconsolidated sediments are according to the scheme proposed by Troels-Smith (1955).

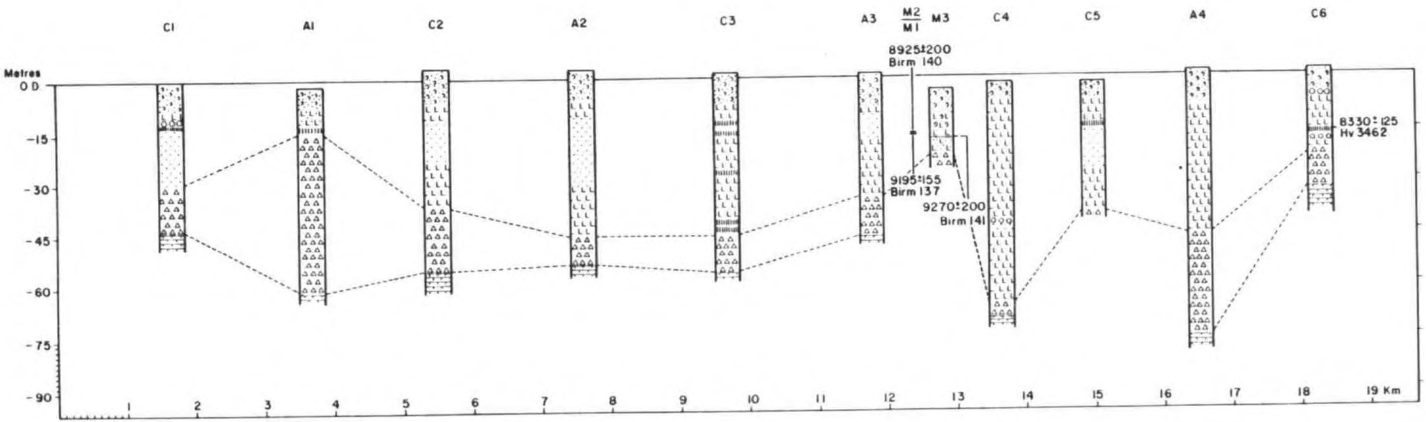

Figure 3.3.: The stratigraphy across Morecambe Bay. The location of the sampling sites is shown on Figure 3.1 and the stratigraphic symbols given on Figure 3.2.

Marine sedimentation ended around Morecambe Bay at about the time of the decline of elm pollen, and this is strongly marked in this area: the change from estuarine clays and silts to Phragmites turfa and succeeded by woody detritus occurred at about 5000 B.P. at altitudes of 3.8 to 4.9 O.D. For example at Ellerside Moss, the end of marine sedimentation is dated at 5435±105 B.P. (Hv.3844) at an altitude of +3.7m O.D.: at Helsington Moss 5277±120 B.P. (Q.85) at +4.8m O.D.: at Arnside Moss 5015±100 B.P. (Hv.3460) at +4.9m O.D.: at Moss Farm, at the north edge of Cockerham Moss, 4830±140 B.P. at +2.9m O.D.: and at Lousanna on Rawcliffe Moss further south, 4900±450 B.P. at +4.8m O.D. Although this is a small sample, it indicates a fundamental change in shape of Morecambe Bay at about the time of the 'elm-decline', when extensive areas of former tidal flat would have been colonised successively by Phragmites, Scirpus and Juncus, and then by alder/oak fen. The extensive contraction in the size of the Bay was the consequence either of a fall of sea-level or massive input of sediment or a combination of both factors. Arguments for a fall in sea-level include the widespread occurrence of the marine regression and independent evidence of a climatic deterioration (see discussion in Tooley 1978). Many pollen diagrams from sites within the catchment of the Bay show marked elm declines and 'Landnam' or 'land-taking' phases, and these may indicate extensive forest clearance by prehistoric folk in early neolithic times. Around the north-east margins of Morecambe Bay, the elm decline has been placed within the range 5435 to 4810 B.P. (Powell et al. 1971; A.G. Smith et al. 1971). The effects of extensive clearances over a 600 year period would be soil erosion and an increased sediment supply to the Bay.

In addition to the marine regression of 'elm-decline' age, there are a few dates recording more recent transgressions at different altitudes. For example, at Arnside Moss a saltmarsh soil overlies woody detrital peat at an altitude of +5.7m O.D. and this has been dated to 1545±35 B.P. (Hv. 3461): further south, at Heysham Moss, a grey-blue, clayey silt is overlaid by peat dated to 4190±150 B.P. (Hv. 2920).

The most complete sequence of post-elm decline marine transgressions has been recorded (Tooley unpublished) from the catchment of the Skelwith Pool, south of White Moss, where 4 periods of transgressive and regressive overlap are registered between c.+2.7 and c.5.9m O.D.

It has been suggested (see Tooley 1978, Huddart et al. 1977) that these dates and altitudes can be grouped together to show periods of transgressive and regressive overlap (Tooley 1982) indicative of secular changes in the sea-level surface. It is possible, however, that some of these changes are more apparent than real, and that local factors such as sediment supply, uplift and subsidence in Morecambe Bay as sea-level continued to rise are the cause of the overlap sequences.

Whatever the explanation, the Flandrian history of Morecambe Bay was characterised by periods of marked dilation when the valleys suffered long period inundation, and periods of marked contraction, when extensive salt-marshes, reedswamps and fens were more characteristic than at present.

One of the most characteristic lowland landforms, upon which de Rance (1877) and Munn Rankin (1919a, 1910b, 1911) remarked were the 'estuarine moors' or raised bogs of the Morecambe Bay coast (Shimwell 1985). They contained a record of the climatic history of the area and of the impact of man on the surrounding vegetation. They also contained prehistoric artifacts - tools and trackways (Rankin's ancient 'corduroy' road) - and bog burials.

A. G. Smith (1959) has described the 'retardation layers' in the stratigraphy of the raised mosses adjacent to the Kent estuary - Nichols Moss and Foulshaw Moss, and in the Gilpin Valley - Helsington Moss, and at the latter site has dated an upper retardation layer to 1514±100 B.P. (Q.83; Godwin and Willis 1960). Dickinson (1973, 1975) has described the raised bog complex near Rusland and identified and dated several recurrence surfaces, indicative of cool and wet periods The recurrence surfaces have been dated AD 1148, AD 605, AD 427, AD 452, 58 BC, 462 BC, 580 BC and 914 BC (see Tooley 1978, p.187).

On the southern shore of Morecambe Bay, Oldfield and Statham (1964-5) have described the raised mosses known as Pilling and Cockerham Moss, and recorded fossil remains of Scheuchzeria palustris. Recurrence surfaces have been noted further south at Rawcliffe Moss (Barnes 1975) and a trackway west of Rawcliffe Moss has been described and dated to 2760±120 B.P. (Q.68) (Godwin and Willis 1960; Edwards 1977; Edwards 1978; Walker 1949). Also from Pilling Moss, is the only record of a bog burial from the coastline mosses of Morecambe Bay (Edwards 1969).

Sea-level Changes

The movement of sea-level in Morecambe Bay and adjacent areas (Tooley 1985) can be summarised in a time-altitude graph (Figure 3.4)

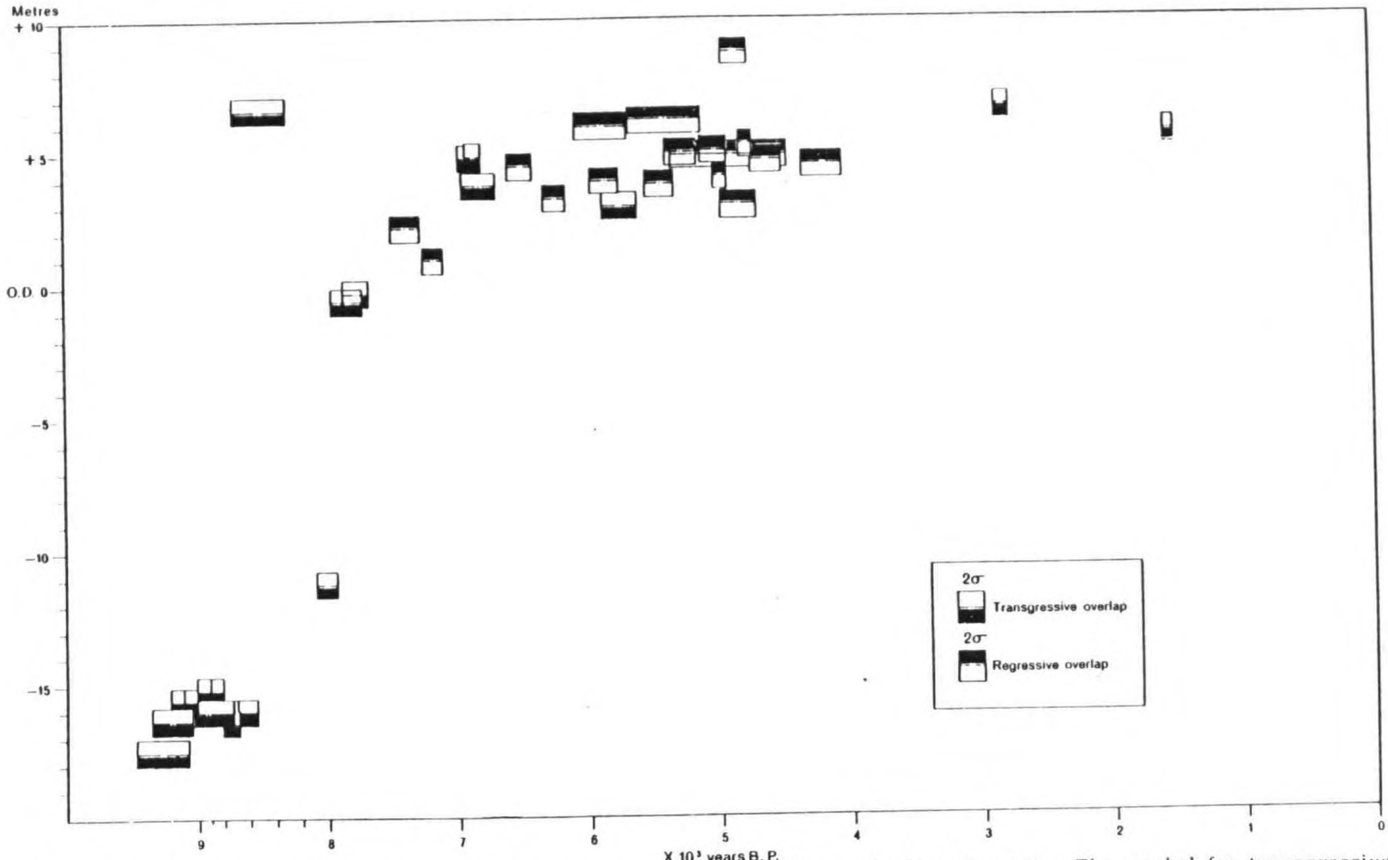

Figure 3.4: A time-altitude graph using variates from Morecambe Bay and adjacent areas. The symbol for transgressive overlap indicates that terrestrial or limnic sediments have been overlapped by brackish-water or marine sediments, and regressive overlap indicates that brackish-water or marine sediments have been overlapped by terrestrial or limnic sediments (see Tooley, 1982). Each radiocarbon date is shown by a dot flanked by a bar giving two standard deviations.

Thirty-five variates have been plotted and each one shows the conditions at the sampling site at the dated level: a transgressive overlap indicates that terrestrial or limnic sediments have been succeeded and overlapped by intertidal sediments; a regressive overlap indicates that marine sediments have been overlapped by terrestrial or limnic sediments. However these successions are interpreted (see Tooley 1978, 1979), the overall trend of sea-level is inescapable: a period of rapid rise of sea-level between about 8000 and 7700 radiocarbon years ago is followed by a period of reduced rise and from the seventh to the fifth millennia a period of nearly static sea-level conditions. There is some evidence for a slight rise and fall of sea-level in the third and second millenia before present. Overlying these general trends are indications from the detailed lithologic characteristics at the sampling sites of a secular pattern in the transgressive and regressive overlaps, and these can be interpreted as oscillations in the eustatic sea-level (Tooley 1982).

Neotectonics

A working hypothesis for the change in altitude of raised beaches in glaciated areas can be derived from Wright (1914, p.407) in which he stated that "Scandinavia, Scotland and Canada all have their systems of warped shore-lines, which rise higher and higher on the land as centres of dispersion are approached". Many investigators (for example, Gresswell 1957, 1958, 1967, in south-west Lancashire, the Fylde and Morecambe Bay) have sought to show this relationship from empirical data. But Sissons (1972) and Mörner (1980) have shown that uplift can be non-uniform, and that raised beach altitudes can change rapidly over short distances.

In 1978, it was pointed out (Tooley 1978) that the gradients on beaches, now buried, were reversed in the Morecambe Bay area during the eighth millennium before present: instead of rising towards the centre of maximum ice loading, the gradient of the buried beaches fell across Morecambe Bay at a rate of 11.9m/100km, only to assume a 'normal' gradient north of Morecambe Bay 11.7m/100km. Flemming (1982) has analysed these data and concluded that while slight relative subsidence in this area appears to characterise the whole of the Flandrian Age, rapid subsidence was characteristic of the eighth millennia before present. Although there are slight gravity anomalies and aeromagnetic anomalies over Morecambe Bay they are not of sufficient magnitude to explain the slight long period and rapid short period subsidence. The aeromagnetic anomalies have a total amplitude of 120 gammas between a low of -70 gammas centred on Blackpool and a high of +50 gammas east of the Leven estuary (The Geological Survey 1965). Morecambe Bay is characterised by relatively high Bouguer gravity anomalies with localised negative closures of 15 mgal and positive closures of 19 mgal. Most of Morecambe Bay lies within the Lower Carboniferous trough, between the East Irish Sea Basin and the Craven Basin (Bott 1978; Institute of Geological Sciences 1977). As fault lines are shown crossing Morecambe Bay (Moseley 1972, 1978), a more reasonable explanation for the short period of rapid subsidence would be that these were reactivated as a consequence of rapid uplift, or sediment or water loading or a combination of all three. The long period subsidence, and its persistence during the interglacial stages of the Quaternary Period, is difficult to explain and singles out Morecambe Bay as an unusual feature on the coast of north-west England.

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Chapter 4

PHYSICAL PROCESSES SHAPING THE INTERTIDAL AND SUBTIDAL ZONES

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The Coastline of Morecambe Bay

The present coastline of Morecambe Bay (Figure 4.1) cuts across many of the elements of the solid geology and unconsolidated Pleistocene and Holocene deposits, which have been considered in more detail in Chapters 2 and 3. Cliffs and shore platforms in Carboniferous and Permo-Triassic rocks occur along relatively limited sections of the coast whereas more commonly glacial and post-glacial deposits form the coastal margin, with drumlin cliffs, scars (or skears) and saltmarshes being the most frequent features.

Cliffs and Shore Platforms in Solid Rock. Coastal outcrops of Carboniferous Limestone near Aldingham and at Sea Wood near Bardsea in south Furness form low cliffs, at maximum only a few metres high, and irregular shore platforms jutting out from the beach shingle, a high proportion of which is derived from erosion of the limestone. The most prominent coastal feature in Carboniferous Limestone is Humphrey Head at the south-east tip of the Cartmel peninsula. The western side is a north-south fault-line scarp with near-vertical cliffs rising to 53m. The eastward dipping strata have led to the formation of a more gently sloping dip-slope on the east side of the headland. Along the eastern margin and at the southern tip the strata form irregular shore platforms which dip eastwards and disappear beneath the sand and mud of Morecambe Bay. Along the coast of the Silverdale-Arnside area there are extensive cliffs of Carboniferous Limestone, which form the promontories of Blackstone Point, Park Point and Jenny Brown's Point and which back areas of rapidly eroding salt marsh. On the promontories the cliffs are actively developing under present marine attack, but those landward of the saltmarsh are protected from such attack except under conditions of high spring tides and storm surges. Shore platforms are found at the cliff foot in many places and in others disappear beneath the saltmarsh. In small bays well-rounded limestone shingle forms beaches, suggesting

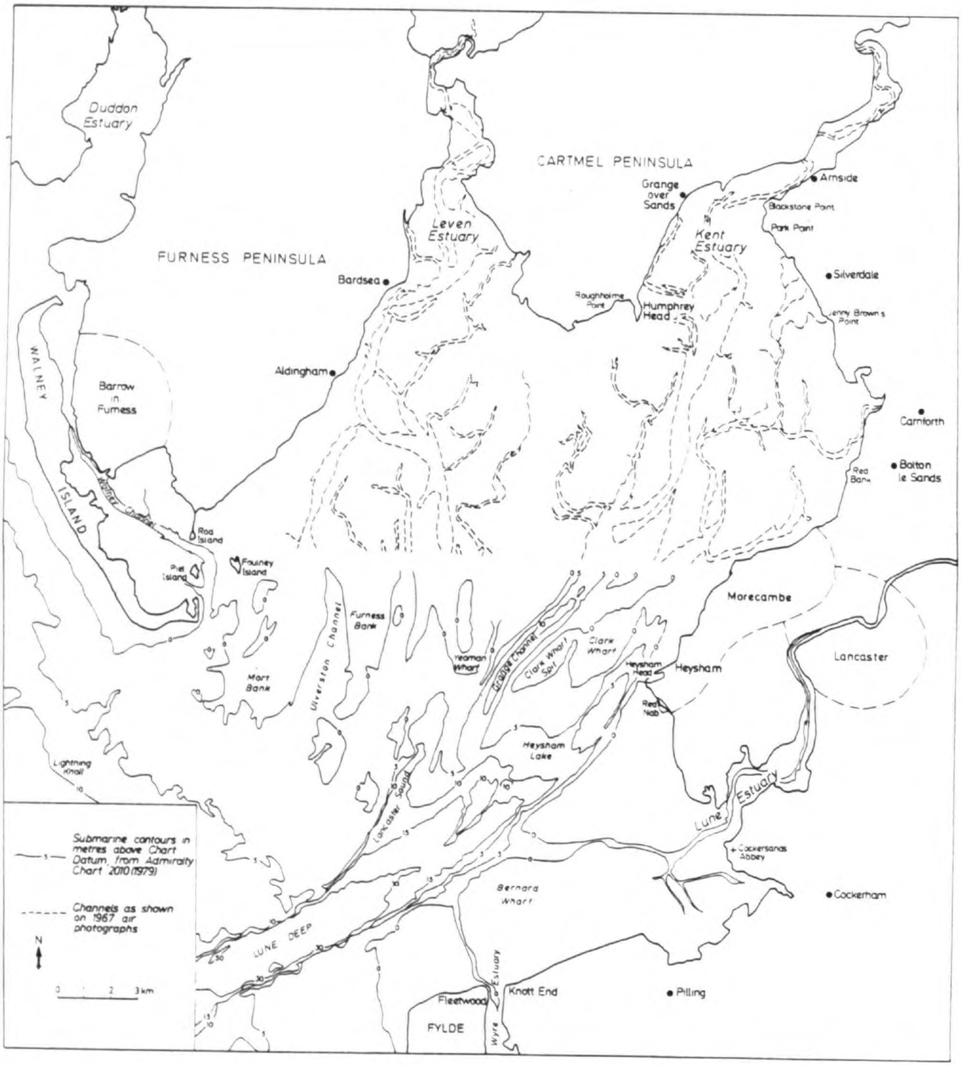


Figure 4.1: Coastline and Bathymetry of Morecambe Bay.

that the saltmarsh has provided protection to this coast for a relatively short time.

The only coastal outcrop of Millstone Grit forms Heysham Head. The lithology varies between a massive, coarse gritstone which produces near-vertical cliffs rising to 15m and interbedded sandstones and shales out-cropping in a shallow anticline and producing a cliff with a stepped profile due to the greater resistance to erosion of the sandstone strata. The pronounced jointing in these interbedded sandstones has led to the out-cropping edges developing a jagged, dog-tooth form.

There are only small coastal outcrops of Permo-Triassic rocks. At Roughholme Point, west of Humphrey Head, a coarse conglomerate composed of limestone particles in a red sandstone matrix forms low cliffs and irregular shore platforms. This weathers to produce a beach of red sand with limestone pebbles. South of Heysham harbour at Red Nab an outcrop on the beach is composed of strata similar to those at Roughholme Point alternating with strata of red sandstone. Near Cockersands Abbey there is an outcrop of thinly bedded red sandstone at the foot of a glacial clay cliff. The sandstone has undergone considerable abrasion by the glacial erratic pebbles and small patches of red sand overlie the pebbles in places.

Coastal Features Associated with Glacial and Post-glacial Deposits. Much of the coastline of Morecambe Bay, especially along the south Furness coast, the western side of the Cartmel peninsula, the east coast south of Carnforth and the south-east coast is backed by low ground underlain by glacial and post-glacial deposits. The most prominent features of these coasts are cliffs cut in drumlins which rise to about 30m. Examples are to be found at Moat Farm, Aldingham, and Bardsea in Furness and at Red Bank, Bolton-le-Sands. The till forming them consists predominantly of clay containing both locally derived limestone and sandstone and more distant erratics from the Lake District and Scotland. In places there are lenses of sand and gravel. At the foot of the cliff and extending for some tens of meters seawards there is commonly a collection of larger erratics, up to about 25cm diameter forming what is locally known as a 'scar' or 'skear'. These represent the coarse fraction from the till which cannot be moved by wave action except under extreme storm conditions and therefore indicate the former extent of the drumlin.

Sand dunes occur at the north-west extremity of Morecambe Bay at the southern end of Walney Island, but extraction of sand and gravel since 1878 (Phillips and Rollinson, 1971) has resulted in considerable disturbance and erosion. Dunes are found also at the south-west extremity in the Knott End and Fleetwood area.

The Bed of Morecambe Bay

The large tidal range experienced in Morecambe Bay, up to 10.5m at spring tides, results in over half the area of the bed of Morecambe Bay being exposed at Low Water Spring Tides. Aerial surveys carried out in 1964 in connection with the Desk Study for a Morecambe Bay Barrage (Water Resources Board, 1966) and in 1967 as part of the subsequent Feasibility Study (Water Resources Board, 1972) reveal clearly the detailed pattern of channels and banks in the inter-tidal zone. The three Admiralty Charts, No. 2010 Morecambe Bay, No. 1552 Plans in Morecambe Bay and No. 3164 Barrow Harbour and Approaches, show the seaward continuation of these channels and banks below Low Water Mark.

The major channel in the entrance to Morecambe Bay is the Lune Deep, with depths down to 82m (see Figure 4.1). It lies towards the southern side and has a south-west to north-east alignment. From its north-eastern end several channels fan out in a northerly and north-easterly direction: Lancaster Sound orientated towards the Leven Estuary, Grange Channel orientated towards the Kent Estuary and Heysham Lake and its associated channels lying parallel and close to the east coast of the Bay. Towards the northern side of the entrance to the Bay lies the channel which at its inner end leads along Walney Channel to Barrow-in-Furness. Between this channel, south of Walney Island and the Lune Deep lie the Ulverston Channel and some other unnamed ones. All the channels so far described are of the flood channel type (Van Veen, 1950), which reach their greatest depth and width at the seaward end and narrow and shoal towards the head of the Bay. There is virtually no development of ebb channels which have the opposite characteristics of being at their deepest and widest at the landward end and narrow and shoal in a seaward direction. Only small ebb barbs are shown on the air photographs leading seawards from the main channels in the inner parts of the Kent and Leven estuaries. It is therefore the tidal currents associated with the flood tide which are dominant in moulding the channel system of the Bay, with its extensive complementary system of sand banks. The channels and banks are highly mobile, capable both of slow, steady lateral movements and of sudden sideways shifts of several kilometers during a few tidal cycles. The rapid movements occur especially in the inner part of the Bay during maximum spring tides and westerly storm conditions.

As Anderson (1972) has demonstrated the predominant type of sediment found both on the banks and in the beds of the channels is very fine and fine sand (60-200μm). Finer silt and clay is found in the most sheltered, low energy environments especially towards the heads of the estuaries and there is a general coarsening of sediment in a seaward direction. Many of the coasts of the Bay are fringed with a narrow steeply sloping beach of coarse sand and shingle, below which lies a broad expanse of medium and fine sand. Scars (or skears) as described above at the foot of drumlin cliffs are also found further seaward of the coast, forming distinct areas of coarse erratics surrounded by sand and finer sediment.

Tides and Tidal Streams

Figure 4.2 shows the form of the monthly tidal curve for Heysham. The semi-diurnal pattern and the large tidal range are clearly evident. Bowden (1955) examined tidal conditions throughout the Irish Sea and more recently Laska (1970) concentrating on the northern half of the Irish Sea has shown that the largest tidal range here is experienced in Morecambe Bay and along the Fylde coast. At maximum spring tides the range at Heysham is about 10.5m and at minimum neap tides it is about 3.4m. Sample curves for two such spring and neap tides are shown in Figure 4.3. These are smooth and slightly asymmetrical curves. Kestner (1972) in a tidal model study forming part of the Feasibility Study for a Morecambe Bay Barrage described the flood tide at Heysham as having a duration of 5h 42 min with the flood currents persisting for 11 min after High Water, and the ebb tide having a duration of 6h 24 min.

The broad pattern of tidal streams is given in the Irish Sea Pocket Tidal Stream Atlas (1962) and is described in the West Coast of England Pilot (1960). Quantitative tidal stream data is given for 6 stations at the entrance to and within Morecambe Bay on Admiralty Chart No. 2010 and Table 4.1 is based on this.

According to the West Coast of England Pilot, in the Irish Sea 19km west of the entrance to the Lune Deep the flood stream runs eastwards at a speed of 1.0 ms^{-1} at spring tides (0.6ms^{-1} at neaps) and the ebb runs westwards at 1.0 ms^{-1} at springs (0.6 ms^{-1} at neaps). In the

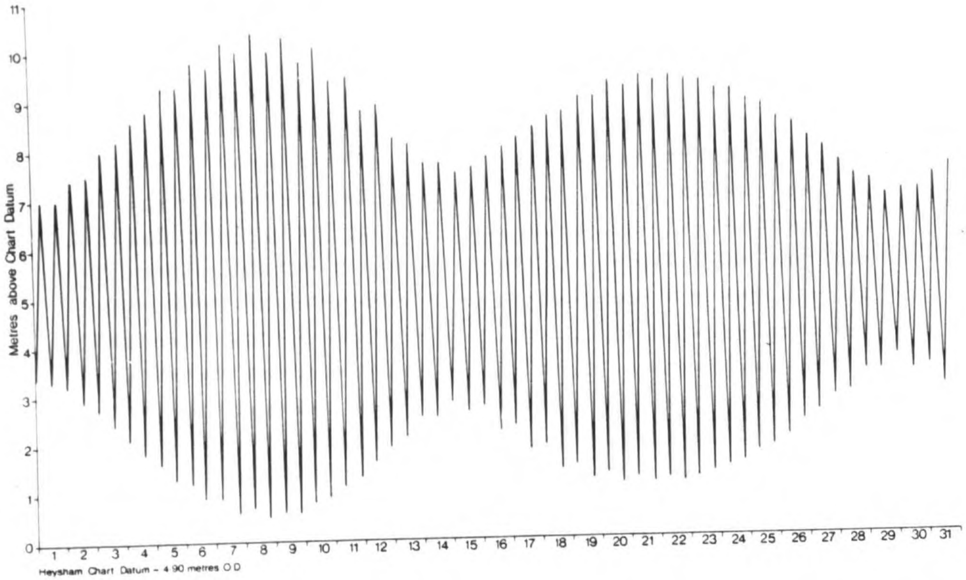


Figure 4.2: Monthly Tidal Curve for Heysham, March 1981.

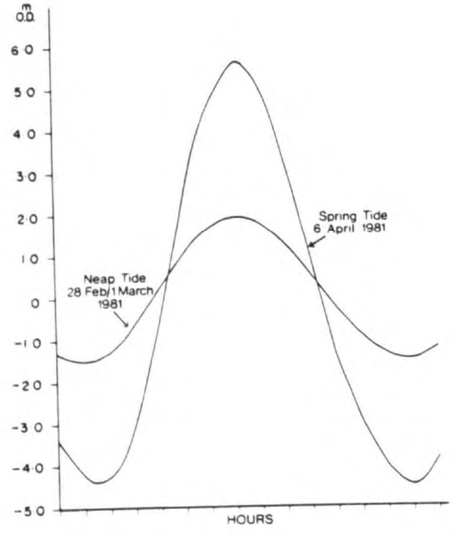


Figure 4.3: Heysham Spring Tidal Curve 6 April 1981 and Neap Tidal Curve 28 February 1981. Data supplied by Institute of Oceanographic Sciences, Bidston.

Table 4.1

TIDAL STREAMS IN MORECAMBE BAY, WITH REFERENCE TO TIME OF H.W. AT LIVERPOOL

		A 53°54'.0N 3 14			B 53°59'.8N 3 13 .1W			C 53°59'.4N 3 09 .7W			D 54°02'.5N 3 10 .2W			E 53°58'.1N 3 01 .6W			F 54°02'.0N 2 55 .9W				
			Rate(ms^{-1})			Rate(ms^{-1})			Rate(ms^{-1})			Rate(ms^{-1})			Rate(ms^{-1})			Rate(ms^{-1})			
	Hours	Dir°	Sp	Np	Dir°	Sp	Np	Dir°	Sp	Np	Dir°	Sp	Np	Dir°	Sp	Np	Dir°	Sp	Np	Hours	
Before HW	6	230	0.3	0.2	140	0.3	0.2	125	0.2	0.1		Slack		249	0.2	0.1	209	0.1	0.0	6	Before HW
	5	109	0.2	0.1	108	0.6	0.4	096	0.4	0.2	057	0.4	0.3	151	0.2	0.1	029	0.1	0.1	5	
	4	085	0.6	0.3	098	0.8	0.5	081	0.6	0.4	052	0.9	0.5	055	0.5	0.3	029	0.3	0.2	4	
	3	080	0.9	0.5	087	1.0	0.6	077	0.9	0.5	053	1.0	0.6	058	1.0	0.6	029	0.8	0.5	3	
	2	070	0.9	0.5	077	0.9	0.5	070	1.0	0.5	055	0.9	0.5	059	1.2	0.7	029	1.3	0.8	2	
	1	057	0.8	0.4	067	0.7	0.4	065	0.8	0.4	055	0.6	0.4	061	0.9	0.5	029	1.1	0.7	1	
	HW	046	0.4	0.2	357	0.3	0.2	025	0.3	0.2	239	0.5	0.3	065	0.3	0.2	029	0.3	0.2	HW	
After HW	1	255	0.2	0.1	285	0.8	0.5	270	0.5	0.3	236	1.1	0.6	245	0.5	0.3	209	0.6	0.4	1	After HW
	2	259	0.5	0.3	275	1.2	0.7	262	1.1	0.6	237	1.0	0.6	236	1.0	0.5	209	1.1	0.7	2	
	3	257	0.8	0.5	265	1.1	0.6	257	1.2	0.7	232	0.7	0.4	241	1.0	0.6	209	1.1	0.7	3	
	4	254	0.9	0.5	252	0.7	0.4	245	0.7	0.4	231	0.5	0.3	234	0.7	0.4	209	0.6	0.4	4	
	5	242	0.7	0.4	227	0.4	0.2	224	0.4	0.2	230	0.3	0.2	249	0.4	0.2	209	0.2	0.2	5	
	6	235	0.4	0.2	165	0.3	0.2	155	0.2	0.1	222	0.1	0.1	254	0.2	0.1	209	0.1	0.1	6	

Sp = Spring Tides

Np = Neap Tides

area 5.5 km south-west of the entrance the flood stream has an anti-clockwise rotary movement which swings from east-south-eastwards to north-eastwards attaining a maximum velocity at springs at 1.0 ms^{-1} (0.6 ms^{-1} at neaps) in an east-north-easterly direction. By contrast the ebb stream is almost rectilinear flowing at 0.9 ms^{-1} at springs (0.5 ms^{-1} at neaps) towards the west-south-west and finally turning to the south-west.

Near Lightning Knoll on the northern side of the entrance to Morecambe Bay a more fully developed anti-clockwise rotary movement occurs. The flood tide begins with a weak south-south-eastward stream which turns eastward to reach a maximum velocity at springs of 0.8 ms^{-1} in a south-eastward to east-south-eastward direction. The rate finally decreases as the stream turns northwards. The ebb begins with a weak north-westward flowing stream which turns west-north-west and westward and there reaches a velocity of 1.0 ms^{-1} at springs. As the rate decreases the tidal stream swings southwards. The tidal stream data on Admiralty Chart No. 2010 shows a slightly different pattern, with the flood reaching a maximum of 1.0 ms^{-1} at springs (0.6 ms^{-1} at neaps) in an easterly direction, and the ebb reaching a maximum of 1.2 ms^{-1} at springs (0.7 ms^{-1} at neaps) in a westerly direction.

In the Lune Deep the tidal streams run approximately in the direction of the channel. The flood stream reaches 1.2 ms^{-1} at spring tides (0.7 ms^{-1} at neaps) and the ebb stream 1.2 ms^{-1} at springs (0.6 ms^{-1} at neaps). In the middle and upper parts of Morecambe Bay the streams generally run in the direction of the channels only when the banks are dry, but when they are submerged the streams flow across the banks. The spring tide rate in each direction in the main channels is about 1.5 ms^{-1}.

Through tidal computations, which allowed for the drying banks, which appear as the water level falls on the ebb and are re-submerged as the level rises on the flood, Flather and Heaps (1975) confirmed the tidal pattern described above. In addition they demonstrated that in Morecambe Bay the flood tide appears first on the north-west side of the entrance around the south tip of Walney Island, when on the south-east side the last of the ebb tide persists. Similarly the ebb tide begins near Walney Island, when the tide is still flooding through the Lune Deep. In the channels of the Lune, Kent and Leven estuaries the ebb tide continues for some time after the tide has turned in the main body of the Bay. This is probably a consequence of distortion of the tidal wave in shallow water. In a tidal chart for all those parts of Morecambe Bay which do not dry at Low Water, Flather and Heaps indicated an increase in tidal amplitude from the entrance to the Bay to the area near Heysham, but with a subsequent decrease into the shallowing channels of the Kent and Leven estuaries.

Stephens (1983) refined this work by producing a higher resolution mathematical model in which the drying banks were reproduced in great detail. Current meter data gathered by the Central Electricity Generating Board in 1978 and by the Ministry of Agriculture Fisheries and Food were used to compare with predicted results from the model. In general Stephens confirmed the tidal patterns described earlier. Eulerian tidal residuals were calculated from the model and show a number of striking features. South of Walney Island there is a south-eastward residual, as the flood tide is stronger than the ebb in this position, but south-west of the Lune Deep there is a south-westward residual as the ebb is stronger than the flood there. Two gyres are produced near Fleetwood, an anticlockwise one to the west, and a clockwise one to the north, on the southern side of the entrance to Morecambe Bay. In the Leven and Kent channels very strong southward residuals result from the ebb tide lasting for 7 to 8 hours.

Storm Surges and Abnormal Water Levels

A comparison between predicted astronomical tides and recorded tide heights for High and Low Water at Barrow-in-Furness from October 1963 to October 1965 (Phillips and Rollinson, 1971) revealed the following. The height of both High and Low Water is raised when a strong wind blows from between south and west. This occurred on 15 occasions lasting from 1 to 4 days during the two-year period and caused the level to be raised between 0.3m and 1.1m above the predicted level; wind velocities of up to 109km/hr were recorded at these times. Conversely strong winds blowing from an easterly quarter tend to lower the height of High and Low Water. On 3 occasions ranging from 1 to 5 days winds of up to 45km/hr depressed the level by between 0.3m and 0.6m.

Lennon (1963a) has shown, on the basis of 14 years of observations at Heysham, that High Water is likely to reach 6.28m O.D. once in 100 years and 6.34m O.D. once in every 200 years. For comparison the highest astronomical tide is about 5.6m O.D. A definite meteorological pattern appears to be associated with large positive surges in the Irish Sea generally (Lennon, 1963b). A deepening and well-developed secondary depression must approach the country at a speed of about 75km/hr from the south-west, so that its right-rear quadrant has latitude to act upon the water surface en route to a specific section of the east coast of the Irish Sea. The depression should be represented by an independent and roughly concentric system of isobars up to a radius of 280 to 370km and it should reach a depth of 50 mb over the country and be associated with a pressure gradient of about 30 mb in 460km in its right-rear quadrant.

Two major storm surges in the Irish Sea occurred on 11-12 November and 14 November 1977 and have been studied by Flather (1981) and Heaps (1983) especially in connection with attempts to produce practical surge predictions using numerical models. The maximum surge height at Heysham on 11 November was computed as 1.85m (although the tide gauge failed slightly below this level), and occurred about 1 hour before predicted High Water on a spring tide. This produced extensive coastal flooding and damage was caused also by the powerful waves which accompanied the surge. An even larger surge occurred on 14 November, but as this arrived near predicted Low Water it did not cause flooding. Large semi-diurnal fluctuations occurred in these surges and probably represent a widespread non-linear interaction between tide and surge over the entire Irish Sea. This may arise from the presence together of an oscillatory tidal current and a non-oscillatory surge current in the main western north-south channel of the Irish Sea.

Another major storm surge affected Morecambe Bay on 31 January-1 February 1983. It reached a peak of 1.5m about 2½ hours before High Water on a spring tide, but was still able to raise High Water to 6.25m O.D. and produce extensive flooding and damage, especially to Morecambe's coastal defences. Because of the flood hazard posed by storm surges the North West Water Authority operates a major flood warning system along the coast of north-west England, including Morecambe Bay (Noonan, 1979).

Waves

Relatively little wave data is available for Morecambe Bay itself. Between 1956 and 1958 records were obtained from a Shipborne Wave Recorder on the Morecambe Bay Light Vessel (53°52'N; 3°30'W) about 31km west of Fleetwood and the data for 1957, first analysed by Darbyshire (1958), has recently been re-analysed by present methods (Draper and Carter, 1982). Parameters of wave height and wave period have been obtained and H_s, the significant wave height; $H_{max(3hr)}$, the most probable height of the highest wave in the recording interval; and ϵ, the spectral width parameter, have been calculated. The results are shown graphically by season. T_z, the mean zero-up-crossing period, was between 3 and 9s with the modal value between 4 and 5s. The most commonly occurring combination of wave period (T_z) and height (H_s) was between 4 and 4.5s and 0.5 and 1.5m. The greatest wave height recorded during the year was H_s 5.9m on 8 December. The estimated 50 year return values are $H_{max\ (3hr)}$ 14.2m and H_s 7.6m.

In September 1974 two Waverider buoys were installed by the Hydraulics Research Station (1975), one in shallow water near Bernard Wharf (53°57'N; 3°1'W) and the other in deep water at 54°52'N; 3°30'W in the former position of the Morecambe Bay Light Vessel west of Fleetwood. The wave data was required in studies being undertaken on behalf of the Central Electricity Generating Board in connection with the Heysham Power Station. The Phase I wave study had only 3 months of records available but these were used for comparison with wave parameters predicted from wind data. Analyses of wave records covering a longer period of time have yet to be published.

The wave pattern within Morecambe Bay is undoubtedly very complex because of refraction produced by the system of channels and banks. Wave refraction diagrams have been constructed for the seaward coast of Walney Island (Phillips and Rollinson, 1971) on the northern side of the entrance to Morecambe Bay, off which the bathymetry is relatively simple, with a gentle slope towards the Irish Sea.

Only to the west-south-west of this coast is the Irish Sea of sufficient depth to allow the development of waves, with a period up to 8s, and waves from this direction are barely refracted before breaking on the coast. Waves up to a maximum period of 6s from the south-west and west are only slightly refracted. The wave energy in these waves will therefore be evenly distributed along this coast. Waves up to 6s from the west-north-west and north-west suffer an increasing degree of refraction with wave energy being concentrated along the north-western section of the island. Conversely waves from the south-south-west, with a maximum possible period of only 4s are so refracted that their energy is concentrated on the southern part of the island.

The method used to construct these wave refraction diagrams is unsuitable for areas with such complex bathymetry as Morecambe Bay itself. It is however clear that the largest and most powerful waves to enter Morecambe Bay are those from between west and south-west. They are generated in the maximum available fetch of about 225km, which is the diagonal width of the Irish Sea. This direction is also that of the prevailing winds and the strongest winds to affect this area. In the depths of water available within this fetch waves of up to 8s period and 102m deep water wave length can form under suitable wind conditions. From observer wave data collected daily at the south-east tip of Walney Island throughout 1966 it was shown that unrefracted waves from this direction had an energy content up to 42.6 joules/m of wave crest/wave length. By contrast winds blowing from the north, east, and south have a maximum fetch limited to the width of the Bay itself and because large areas around the shores of the Bay dry out at Low Water the fetch is limited even further. The size to which waves can form under such wind conditions even when these reach maximum strengths is therefore severely limited.

Table 4.2 shows the number of days in each month of 1966 experiencing waves of deep water wave length (L_o) less than 30m, 30-60m and greater than 60m. Waves will interact with the sea-bed only in water which has a depth less than half the wave length and seaward of this depth they will move independently of the sea-bed. Only waves greater than 60m L_o will interact with the sea-bed in the central part of the Lune Deep, which is over 30m in depth. Waves between 30 and 60m L_o will begin to interact with the sea-bed in the shallower parts of the Lune Deep and the south-west part of Heysham Lake where water depths are 15 to 30m. The third group of waves with a deep water wave length between about 20 and 30m will begin to interact with the sea-bed in water depths between 10 and 15m. The 10m submarine contour is aligned north-west to south-east parallel to the west coast of Walney Island, passes close to Lightning Knoll and swings north-east around the Lune Deep and the south-west part of Heysham Lake. On only 59 days during 1966 were conditions so calm that wave measurements could not be taken from the shore. It can be seen therefore that for the remainder of the year there was a constant inter-relationship between the waves and the whole of the bed of Morecambe Bay except in the Lune Deep and the south-west area of Heysham Lake. Wave action is helping to mould the channels and banks and at the same time they are modifying the wave characteristics.

Table 4.2

DEEP WATER WAVE LENGTHS IN DAYS PER MONTH FOR 1966, CALCULATED FROM OBSERVER WAVE DATA, SOUTH WALNEY ISLAND

1966	Deep Water Wave Length			Calms
	<30m	30-60m	>60m	
January	12	9	6	4
February	10	14	3	1
March	9	13	4	5
April	14	11	1	4
May	14	9	1	7
June	9	15	1	5
July	10	13	0	8
August	14	11	0	6
September	11	10	3	6
October	9	13	1	8
November	10	7	8	5
December	2	23	6	0
Year	124	148	34	59

Deep water wave length calculated according to formula

$$L_o = 1.6T^2$$

where L_o is deep water wave length in metres
T is wave period in seconds.

Sediment Movement

Changes due to sediment movement in the untrained Wyre estuary and the trained Lune estuary were examined by Inglis and Kestner (1958) and in addition to field observations, a mobile-bed model of the Wyre was used to investigate the likely effects of building training walls there. A detailed study of short-term changes in the distribution of fine sediments was carried out subsequently in the Lune estuary by Kestner (1961).

Within Morecambe Bay itself a range of different techniques has been used to study sediment movements and the movement of water close to the sea-bed, including Admiralty Chart analysis, the use of sea-bed drifters and radioactive tracers, and the analysis of current data.

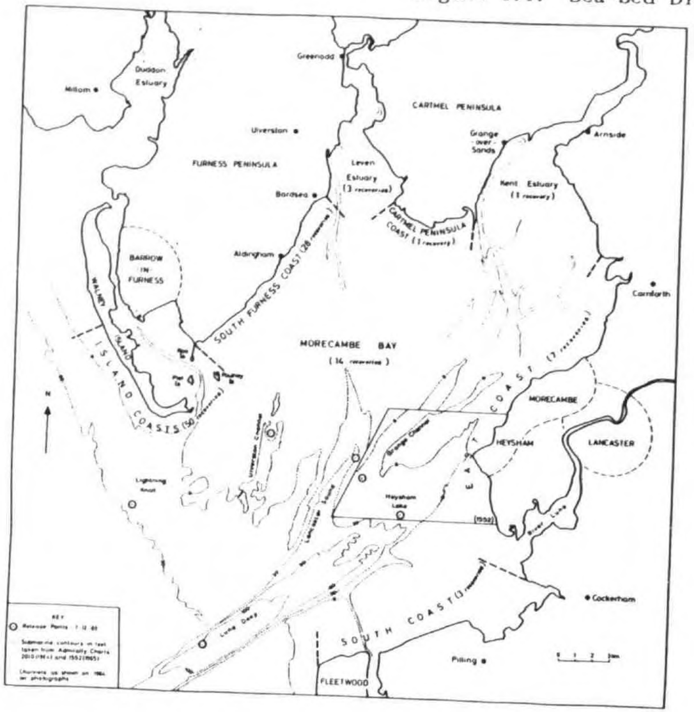
Through the analysis of 11 editions of Admiralty Chart No.2010, Morecambe Bay, Kestner (1970) deduced a series of cyclic changes in the channels and banks between 1845 and 1968. About 1848, Morecambe Harbour was built near the tip of New Grange Channel and during the second half of the 19th century the Midland Railway Company ran regular passenger steamer services from there to Ireland and the Isle of Man. During this period the channel became increasingly difficult to navigate and steamers could only enter the harbour about High Water. Heysham Harbour was opened in 1904, 5km south where a good sea approach existed through Heysham Lake, with a minimum water depth at LWST of 11.3m. The harbour was built on the foreshore with a short channel cut to connect the entrance with the edge of deep water in Heysham Lake and dredging was necessary only in the harbour and short channel. By 1950 Heysham Lake had been so reduced in width and depth that for the first time since before 1884, the 9m contour was not continuous there. By 1968 this trend had so continued that the 5.5m contour was not continuous and Heysham Lake had never been so narrow and shallow since before surveys began in 1845. These changes were produced by the south-eastward movement of a large sandbank into Heysham Lake almost completely blocking the approach channel to the harbour at Low Water.

The 11 editions of the Admiralty Chart show the changes in more detail. Between 1845 and 1884 depths in Heysham Lake increased from 5.5m to 9m as a wide, shallow channel became narrower and deeper.

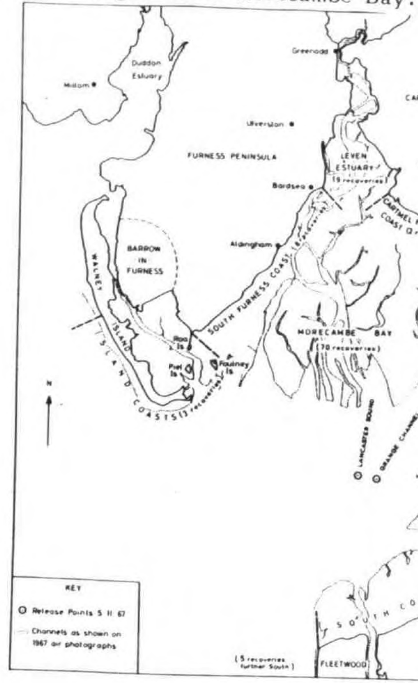
The decrease in width continued throughout the period covered by all these charts, but by 1899 the depths had begun to decrease. The cause of these changes was the steady and continuous sideways travel of the First New Grange Channel and the First Clark Wharf Spit from north-west to south-east into Heysham Lake. (When both had moved markedly south-eastwards a Second Grange Channel and Second Clark Wharf Spit began to develop in the earlier position of the first channel and spit.) As is common in such loose boundary hydraulics, one cause, the steady advance of the sandbank, brought about two opposite effects, first an increase in channel depth and secondly as more sand was brought in, marked shoaling occurred. The rate of movement was variable but between 1845 and 1968 the First New Grange Channel moved 4572m south-eastwards and the First Clark Wharf Spit moved 3292m giving an overall average of about 30.5m per year during the 123 years. The Clark Wharf Spit became smaller as it advanced into Heysham Lake. Kestner postulated that if as seemed likely it completely disappeared in a few years' time, the configuration of banks and channels would be almost identical to that in 1845 when the earlier period of improvement began in Heysham Lake. This prediction is borne out by the 1986 edition of Admiralty Chart No. 1552, Plans in Morecambe Bay.

Two sea-bed drifter investigations were carried out in Morecambe Bay commencing in December 1965 and November 1967 and formed part of the Desk Study and Feasibility Study for the proposed Morecambe Bay Barrage (Phillips, 1968 and 1969). Figure 4.4 shows for each investigation the position of the releases and the pattern of recoveries during the following period of 10 months. Woodhead sea-bed drifters of standard design were used (Phillips, 1970). In the first investigation 300 sea-bed drifters were released on 7 December 1965 in batches of 50 in two localities at the entrance to the Bay and in four of the main flood channels in the central area of the Bay. These releases were made on an ebb tide so that the powerful initial drift would take them into deeper water just beyond the entrance to the Bay and into its outer parts. From the subsequent recovery pattern it appears that the drifters were confined to this area before becoming stranded on the shore. The recovery rate was 36% and the recoveries from all release points were strongly concentrated around the southern end of Walney Island and the adjacent smaller islands, and along the south Furness coast.

Figure 4.4: Sea-bed Drifter Investigations in Morecambe Bay:



A. Release of 6 December 1965.



B. Release of 5 November 1967.

In the second investigation beginning on 5 November 1967, 200 sea-bed drifters were released in batches of 50 in four localities in the main flood channels in the central section of the Bay. The releases were made in the early part of the flood tide so that initially they would be carried towards the head of the Bay and they appear from the recovery pattern to have been mainly confined here. The recovery rate was 76% and the recovery pattern from all release points showed a marked concentration along the eastern coast of the Bay and on the extensive sand banks south of the Cartmel peninsula.

Analysis of wind, wave and tidal conditions suggested that net tidal stream movement was the dominant influence on the movement of water close to the sea-bed which the sea-bed drifters were recording. This movement has a strong influence on the transport of sediment over the sea-bed. The anti-clockwise tidal stream movement in the outer part of the Bay produces a net drift towards the north-west and west and was probably the cause of the concentration of sea-bed drifter recoveries in the first investigation being along the north-west shores of the Bay. The dominance of the flood tide in the flood channels, in the central and inner parts of the Bay, is suggested by the concentration of recoveries in the second investigation being on the northern and eastern shores.

The detailed timing of the sea-bed drifter recoveries showed the importance on a shorter time scale of wind induced surface currents with compensatory reverse currents close to the sea-bed in the shallow water depths of the Bay. During the first investigation prolonged spells of easterly and north-easterly winds coincided with low rates of recoveries on the north-west shores, whereas similar spells of westerly winds coincided with large numbers of recoveries there. In the second investigation periods of westerly winds coincided with low recovery rates on the north-east shores, and periods of north-east and east winds yielded high recovery rates here.

Using the results of a radioactive tracer experiment lasting for 50 tides and velocity measurements Kestner (1972) has shown that during this limited time period Heysham Lake was behaving predominantly as a flood channel, whereas Grange Channel was behaving as an ebb channel. The sand grains were circulating in a loop, north-eastward in Heysham Lake and south-westward in Grange Channel.

Kestner (1970) concluded from his analysis of Admiralty Charts that a decade of migration of channels and banks is required before they are discernible in the Admiralty surveys, so they record relatively long term changes. The sea-bed drifter and radioactive tracer investigations recorded changes on shorter timescales of 10 months and 25 days respectively. It can therefore be difficult to fit together the results obtained using such different research methods. More recent ideas put forward by Kestner (1981) on water circulation and sediment movement in Morecambe Bay are concerned with the effect of slow secondary currents generated by each pair of flood and ebb tides. Drift diagrams for surface-water and sea-bed water movements at 32 stations in Morecambe Bay based on velocity measurements forming part of the Morecambe Bay Barrage Feasibility Study (Hydraulics Research Station, 1970) revealed in addition to the strong primary currents associated with the flood and ebb tides, the existence of important residual drifts produced by variations in the flood and ebb velocities. Those near the sea-bed are most significant for sand movement which is concentrated near the bed. In the central and outer parts of Morecambe Bay these net residual drifts near the sea-bed show a slow anticlockwise circulation, also revealed by the first of the sea-bed drifter investigations (Phillips, 1968) carried out in this same part of the Bay. Kestner believes that the decrease in the tidal stream velocity from a channel towards the south-east side of an adjacent sand bank in the central area of the Bay will cause sand grains, moving in response to the residual drifts to the north-west, to accrete there. On the north-west side of the sand bank as tidal streams increase in velocity into the next channel so erosion will be produced. The net effect will be a slow south-eastward movement of banks and channels as revealed in his Admiralty Chart analysis.

Coastal Effects of Changes in Channels and Banks

Changes in the channels and banks may have important repercussions on neighbouring coasts. In the mid-1960s the beaches at Morecambe and Heysham were composed almost entirely of mud but by the late 1960s the beach material had changed to sand (Phillips, 1976). During this time a flood channel from Heysham Lake moved towards the shore at Morecambe and by the early 1970s the channel lay within 330m of the coast. The source of the sand was probably the rapidly eroding Clark Wharf Spit, and from there it was transported along the flood channel to the Morecambe and Heysham beaches.

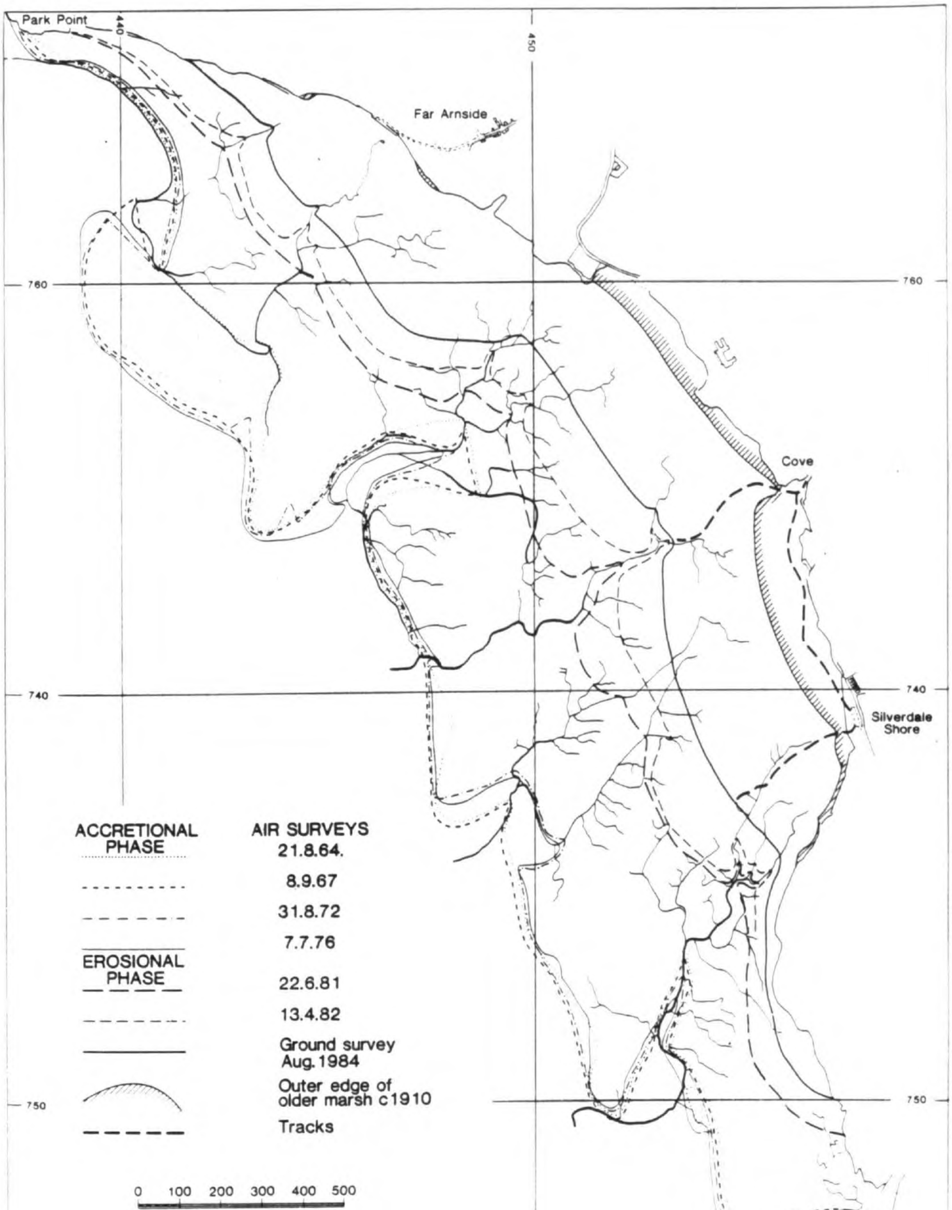


Figure 4.5: Silverdale Saltmarsh Accretion and Erosion 1964-1984.

Further north, along the coast between Park Point and Carnforth, saltmarsh had been extending westwards and accreting since early this century, when the main River Kent channel lay close to the west coast of the estuary. The later stages of this accretion are shown on Figure 4.5 in the positions of the seaward edge of the marsh as plotted from air photography surveys in 1964, 1967, 1972 and 1976. In the late 1970s (most probably in 1977 although the precise date is not known) this accretional phase was sharply reversed. The main River Kent channel and its associated minor ones moved eastwards close to the edge of the Silverdale saltmarsh which suffered such rapid erosion that its width of about 1000m was halved in 5 years, as is shown on air photographs taken in 1981 and 1982. Not only was the seaward edge eroded, but rapid erosion occurred also in the creeks draining the marsh as they cut down to a new lower base level. In 1986, only about 200m remained in the central part of the saltmarsh and the total erosion of the northern and southern ends has exposed the previously protected limestone cliffs and shingle beaches to active marine attack. Similar erosion began to affect the saltmarsh south of Jenny Brown's Point a few years later than it started on the Silverdale saltmarsh.

On the western side of the Kent estuary, conversely, accretion has taken place during this period whilst the main River Kent channel has lain further east. This has probably encouraged the recent colonization and rapid spread of Spartina along the shore at Grange-over-Sands and Kent's Bank, which is further discussed in Chapter 7. 7.

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Chapter 5

WATER QUALITY AND SOURCES OF POLLUTION

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Introduction

The legal responsibility to control effluents discharging to Morecambe Bay rests with the North West Water Authority (NWWA) mainly under the Clean Rivers (Estuaries and Tidal Waters) Act, 1960 and Part 2 of the Control of Pollution Act, 1974. The seaward limits are defined in the 1960 Act as a line stretching from Rossall Point to Hilpsford Point on Walney Island (Figure 5.1).

The area covered by the Lancashire and Western Sea Fisheries Joint Committee (LWSFJC) (in 1986 renamed the North Western and North Wales Sea Fisheries Committee), also includes Morecambe Bay, as the Committee's landward limits follow the line of the old Furness Railway as it crosses the estuaries, somewhat below the tidal limits (Figure 5.1). Virtually all the water quality surveys in recent years on the estuaries draining into the Bay have been carried out by NWWA in conjunction with LWSFJC, and in some cases with Lancaster University and local industry.

LWSFJC conduct their own independent monitoring of the Irish Sea outside the NWWA area, and details of this are discussed in section 2. Section 3 gives details of NWWA monitoring of the inland waters draining to the Bay, and assessments of loadings of inorganic nitrogen and phosphorus passing to Morecambe Bay from each catchment. Section 4 gives brief details of the condition of each estuary draining to the Bay and describes work carried out and local problems.

Coastal Water Quality Sampling

On the seaward side, between 1971 and 1976 Lancashire and Western Sea Fisheries Joint Committee operated a "Surf Zone" coastal water quality sampling programme. Samples were taken at around

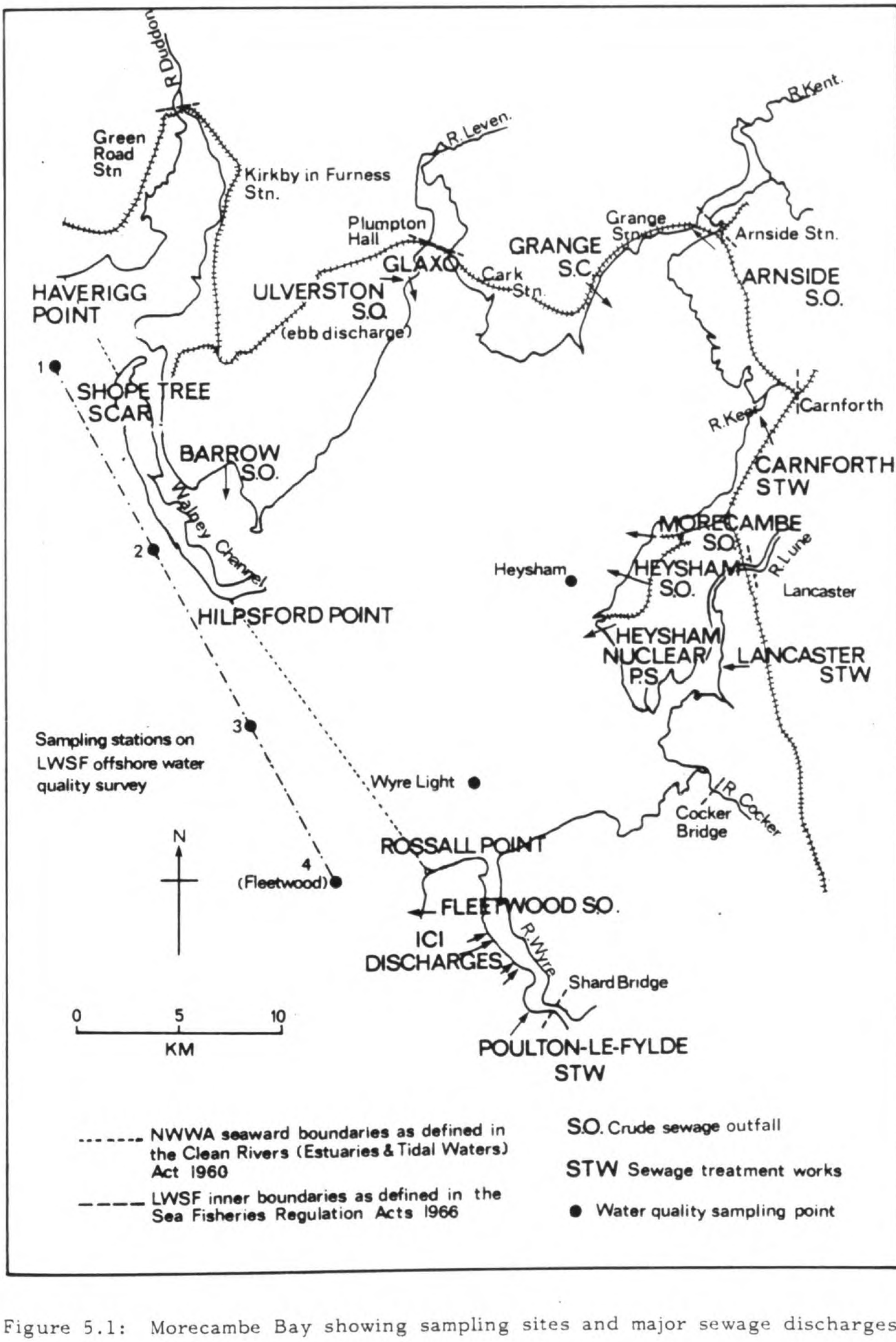

Figure 5.1: Morecambe Bay showing sampling sites and major sewage discharges.

Low Water from just below the Low Water Mark. One of the main findings of the surveys (LWSFJC 1974-1980) was a marked inverse correlation between concentrations of ammoniacal nitrogen and phosphate-P, and distance away from the Mersey Estuary (Figure 5.2). Table 5.1 gives mean PO_4-P and NH_4-N figures for 1971-1976 for the Fleetwood and Heysham stations.

TABLE 5.1

Year	Fleetwood PO_4-P	Fleetwood NH_4-N	Heysham PO_4-P
1971	1.85	-	1.4
1972	1.9	-	1.5
1973	2.1	-	1.6
1974	2.2	6.1	1.8
1975	2.0	9.7	-
1976		12.7	-

concentrations in mg $litre^{-1}$

In 1976 the Surf Zone sampling was superseded by the Offshore Coastal Water Quality Survey which involved sampling from a grid of 25 stations in Liverpool Bay and the Irish Sea, 4 of which stretched in a transect across the mouth of Morecambe Bay from Fleetwood to the Duddon Estuary (Figure 5.1). Means for all samples taken from stations on this transect are given in Table 5.2 for the years for which data are available and some monthly means for the transect are given in Figures 5.3 and 5.4.

Comprehensive data for Heysham are available from a detailed 2½ year study into phytoplankton by Evans (1979). Samples were taken ½ hour before High Water, about ½ mile offshore in the Heysham channel. A summary of mean concentrations is given in Table 5.3 and details of seasonal variation are shown in Figure 5.5.

Sampling of Rivers and Effluents and Flow Measurement

The River Lune provides easily the greatest contribution to the freshwater flow into Morecambe Bay, accounting for nearly 50% of the

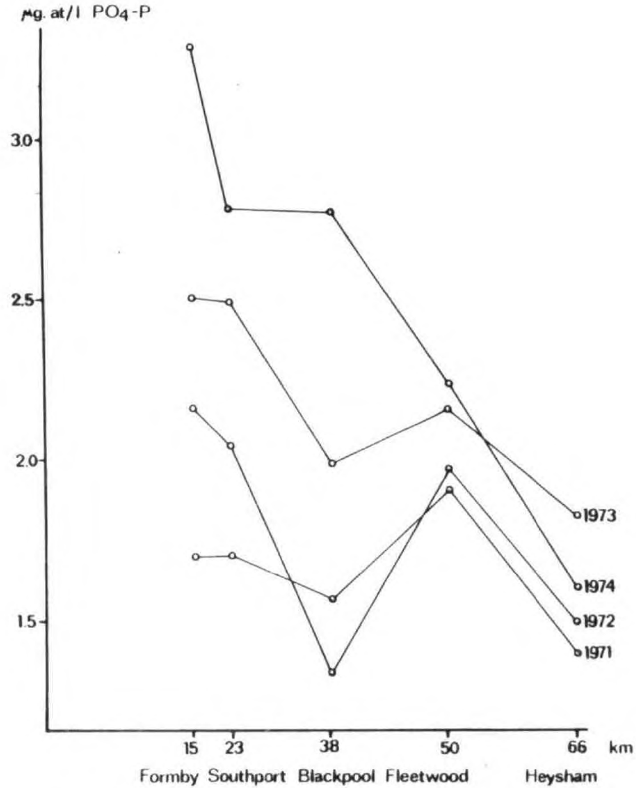

Figure 5.2:

Dissolved reactive orthophosphate phosphorus (average value over each year): distance of station from Mersey estuary.

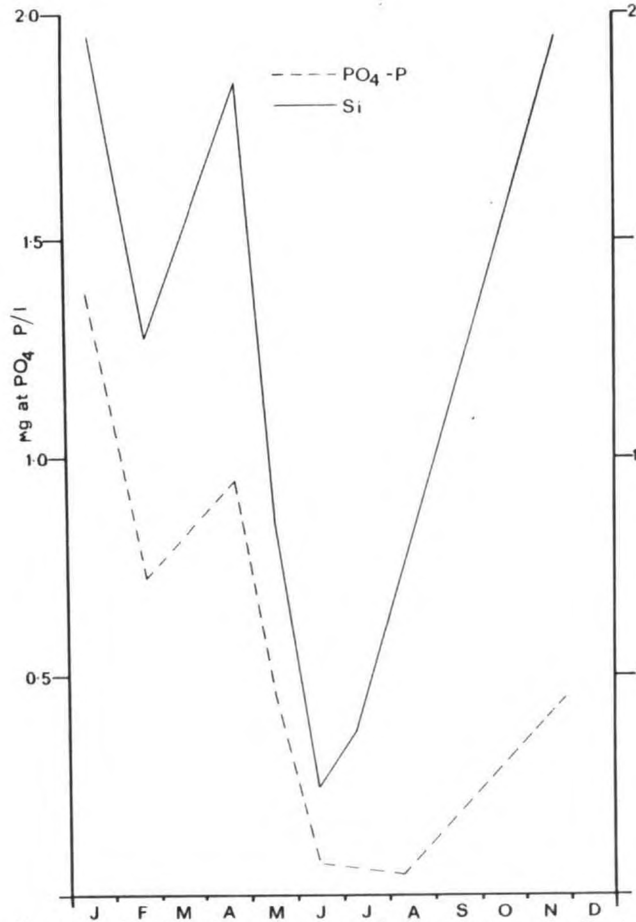

Figure 5.3: Monthly averages of phosphate and silicate on transect across the mouth of Morecambe Bay.

Table 5.2

MORECAMBE BAY WATER QUALITY

Mean values from Offshore Water Quality Stations compared with Wyre Light

Site Description and date	Salinity ‰	pH	Alkalinity m.mol l^{-1}	Suspended Solids mg l^{-1}	PO_4-P	NH_4-N	NO_2-N	NO_3-N	SiO_2-Si	Chlorophyll $\mu g l^{-1}$	Phaeophytin $\mu g l^{-1}$
					← µg atom l^{-1}				→		
Sept. - Dec. 1975 No.4 transect	32-47	7.85	2.29	4	1.59	2.90	0.15	4.52	8.49	1.15	0.64
May-Sept. 1976 No.4 transect	33.1	7.99	2.32	5	0.73	4.6	0.06	1.47	3.8	1.9	1.7
Jan-Nov. 1977 No. 4 transect	32.5	8.05	2.20	20	1.07	1.7	0.24	10.2	5.2	1.1	0.9
Feb. 1980 Fleetwood Stn.	30.6	7.77	2.20	7	1.1	2.2	0.8	17.2	13.7	1.0	0.1
June 1977 and July 1979 Tidal Cycle Survey Wyre Light	32.75	8.01	-	12	0.53	3.34	0.48	1.50	-	4.0	2.9

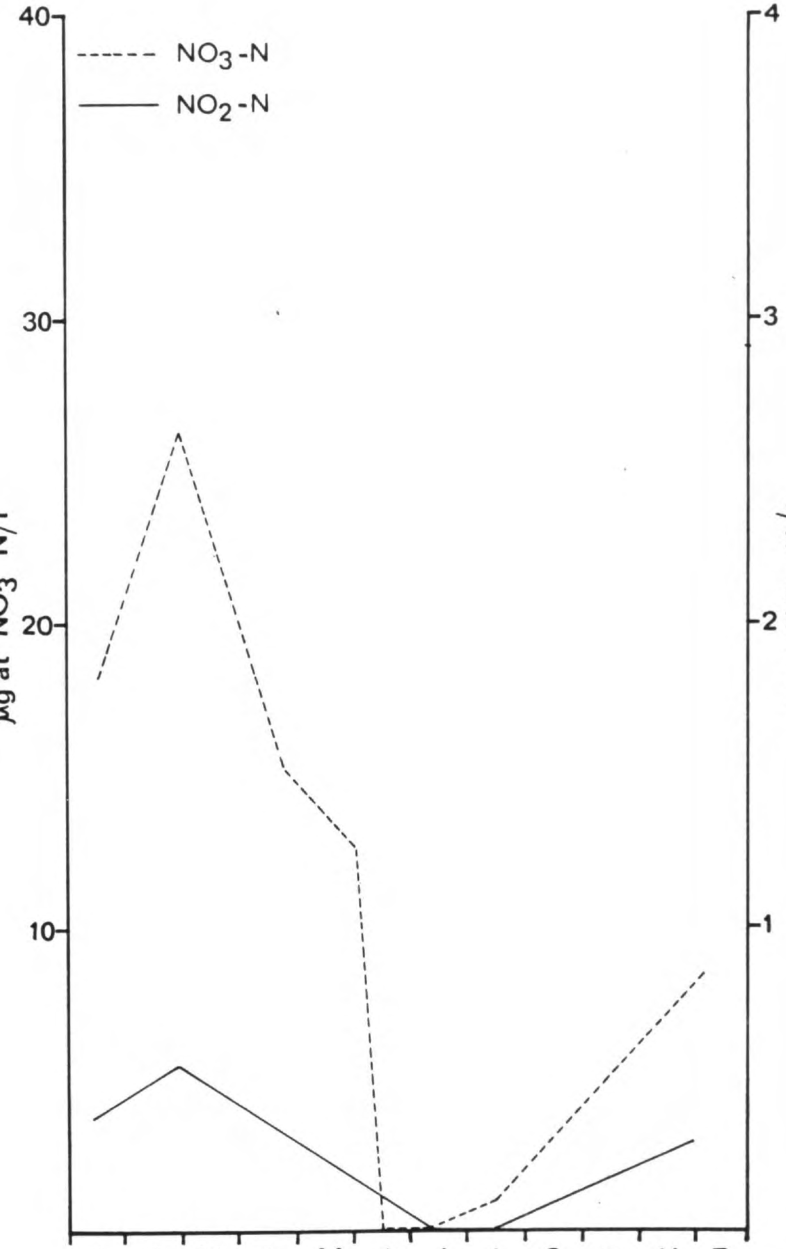

Figure 5.4: Monthly averages of nitrate and nitrite on transect across the mouth of Morecambe Bay.

Table 5.3

MEAN VALUES FOR CERTAIN CHEMICAL AND PHYSICAL PARAMETERS OF SEAWATER, LWSFJC HEYSHAM STATION, 1975-1977

	1975*	1976	1977
Salinity (‰)	31.7	31.7	31.4
Temperature (C)	11.8	11.2	10.1
Dissolved Oxygen			
(mg/l)	9.57	8.96	8.64
(% Sat.)	-	97.1	94.9
pH	7.94	7.92	7.97
Alkalinity (m.equiv./l)	2.217	2.250	2.226
Nutrients			
NH_2-N (μg.at N/l)	-	8.66	9.53
NH_3-N (μg.at N/l)	7.8	5.5	5.8
NO_2-N (μg.at N/l)	0.26	0.54	0.53
NO_3-N (μg.at N/l)	4.59	8.96	12.22
PO_4-P (μg.at P/l)	1.10	1.11	1.13
SiO_2-Si (μg.at Si/l)	-	7.80	7.07
Suspended Solids (mg/l)	22.00	27.00	50.00
Algal Pigments			
chlorophyll a (mg/m^3)	10.91	3.43	2.99
pheo-pigments (mg/m^3)	1.26	2.38	2.04
% degradation	18.00	47.00	47.00
Secchi Depth (m)	-	1.3	1.1

* 1975 - March - December only

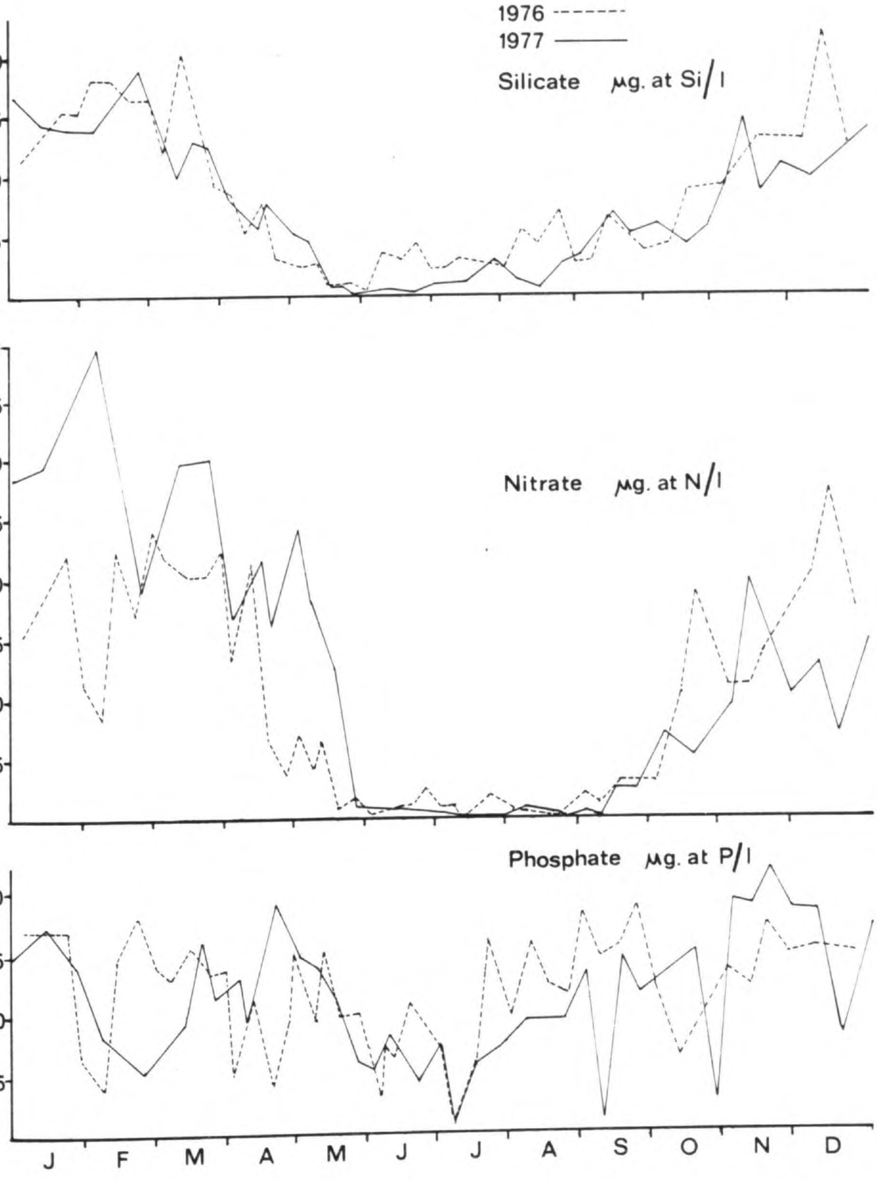

Figure 5.5.: Nutrient concentrations at Heysham sampling station 1976 and 1977.

total. The Rivers Kent and Leven are the next largest, being of similar size and accounting for about 30% of the total between them. The remaining 20% is distributed between the Rivers Wyre, Crake, Beela and Keer in descending size order. River levels on all these rivers with the exception of the Keer are measured continuously and processed to give daily, monthly and annual summaries of river flow data.

The major river inputs to Morecambe Bay are sampled monthly as part of the Department of Environment (DOE) Harmonised Monitoring Programme, or as part of the NWWA internal "key point" monitoring programme, which is effectively an extension to the DOE programme. Detailed water quality and associated flow data are therefore available for the Rivers Kent, Leven, Beela, Wyre and Lune (Tables 5.4 and 5.5). Some information is also available on the Rivers Crake and Keer, but the sampling on these tributaries is less frequent and less detailed, and flows are not available on the Keer.

Metal levels in these rivers are low, but in 1981 the limit of detection for most metals was reduced by a factor of ten, so that the actual levels can now be measured in some cases (Table 5.5) and estimates of the metal loadings passing into Morecambe Bay from inland river sources are now possible. The metals are analysed using concentration by solvent extraction, followed by complexation with carbamate, then atomic absorption spectroscopy. No such attempt has been made to quantify the loadings of toxic metals from sewage and trade effluents as the data are not available.

Flow and quality information, apart from metals, on treated sewage effluents is available, but much of the sewage discharged to Morecambe Bay is untreated, and for estimates of the loadings of nitrogen and phosphorus from these sources, reliance has been placed on flow estimates derived from population served and average crude sewage strengths.

1. Assessment of Inorganic Nitrogen and Phosphorus Loadings

Table 5.6 and Figures 5.6 and 5.7 summarise the position for total inorganic nitrogen (taken as the sum of ammoniacal, nitrite and nitrate nitrogen) and orthophosphate phosphorus.

The figures have been broken down into contributions from river, sewage and trade. The "rivers" contribution includes any sewage and trade effluent discharged above the tidal limit and inputs from significant estuary tributaries. The "sewage" and "trade" contributions

Table 5.4

CHEMICAL ANALYSIS AND FLOWS OF THE MAIN RIVER INPUTS TO MORECAMBE BAY (1975 - 1985 DATA)

Sampling Point Location		Flow Ml/d	pH	BOD_5 mg/l (with ATU)	Suspended Solids mg/l	Dissolved Oxygen % Satn.	SiO_2-Si mg/l	PO_4-P mg/l	NH_4-N mg/l	NO_2-N mg/l	NO_3-N mg/l
River Leven at	mean	1047	-	1.5	5	103	1.1	0.038	0.11	0.01	0.51
Low Wood Bridge		29-5408	5.6-9.0	0.3-3.2	<1-3.2	84-160	<0.1-3.2	<0.005-0.95	0.01-2.6*	0.01-0.2	0.04-7.4
Haverthwaite	range no.	174	172	103	173	164	143	165	172	173	173
River Kent at	mean	655	-	2.1	7	103	2.7	0.20	0.11	0.025	1.7
Sedgwick		49-3343	6.6-9.1	0.6-8.0	<1-65	76-148	0.2-10.0	<0.01-1.1	<0.01-0.95	0.01-0.18	0.1-3.9
	range no.	165	174	101	174	165	143	167	174	174	174
River Keer at	mean	-	-	1.4	13	95		0.06	0,074	0.037	3.1
A6 Road Bridge			7.2-8.0	<0.5-3.2	<3-41	66-196	-	0.03-0.1	0.01-0.18	0.01-0.32	1.7-4.9
	range no.	-	31	23	31	30		30	31	30	31
River Crake at	mean	378	-	1.3	5	97		0.019	0.043	0.009	0.69
Spark Bridge	range	10-1653	6.4-8.0	0.3-2.9	<1-75	88-109	-	0.005-0.12	0.01-0.17	<0.002-0.04	0.1-1.3
	no.	30	36	28	36	35		33	36	36	36
River Beela at	mean	286	-	2.2	9	102	3.2	0.086	0.12	0.033	3.03
Milnthorpe	range	32-1590	6.2-8.9	<0.5-6.9	1-90	51-160	0.2-5.5	<0.01-0.55	<0.01-1.3	<0.01-0.21	0.5-12.2
	no	155	162	99	162	153	143	158	162	162	162

/cont.......

.... Table 5.4 continued.

Sampling Point Location		Flow Ml/d	pH	BOD_5 mg/l (with ATU)	Suspended Solids mg/l	Dissolved Oxygen % Satn.	SiO_2-Si mg/l	PO_4-P mg/l	NH_4-N mg/l	NO_2-N mg/l	NO_3-N mg/l
1981-1985 only	mean	2462	-	1.6	10	106	2.4	0.068	0.10	0.016	1.1
River Lune at	range	194-23915	7.2-9.0	<0.5-4.0	<3-104	90-151	0.4-4.7	<0.01-0.51	0.02-0.55	<0.01-0.15	0.3-2.4
Denny Bridge**	no.	66	66	66	66	61	64	66	66	66	66
River Wyre at	mean	469	-	3.0	16	92	4.1	0.28	0.50	0.076	1.89
St. Michaels	range	10-4527	6.1-9.1	0.9-7.1	2-159	53-160	0.2-10.5	0.02-1.7	0.03-3.1	<0.01-0.8	<0.1-5.1
	no.	176	186	112	186	165	143	176	186	187	187

* results as high as this are extremely isolated events.

** prior to 1981 samples were taken from Forge Bank weir.

Table 5.5

METALS IN RIVERS DRAINING TO MORECAMBE BAY

1981-1985 DATA

Sampling Point Location		Hardness mg/l $CaCO_3$	Alkalinity mg/l $CaCo_3$	Lead µg/l	Mercury µg/l	Cadmium µg/l	Iron µg/l	Copper µg/l	Zinc µg/l	Chromium µg/l	Manganese µg/l	Nickel µg/l
River Leven at Low Wood Bridge Haverthwaite	mean	29	18	3.9	0.08	0.11	82	2.6	5.7	<10	34	1.2
	range	23-104	11-35	3-25.5	0.05-0.45	0.05-0.45	17-945	1.0-7.2	1.5-15	<10	10-154	0.8-5.0
	no.	46	67	57	30	57	59	57	56	59	59	57
River Beela at Milnthorpe	mean	166	117	4.2	0.08	0.12	127	3.5	10.1	<10	31	1.2
	range	96-211	68-167	2.5-37	0.25-0.24	0.05-0.54	20-790	<1-34	<2-135	<10	13-153	0.8-3.0
	no.	46	65	57	21	57	58	57	57	58	58	57
River Kent at Sedgwick	mean	81	68	4.1	0.08	0.13	109	3.3	8.9	<10	31	1.1
	range	55-108	29-137	2.5-14	0.05-0.19	0.05-0.5	20-840	1.5-8.6	<2-24	<10	11.5-212	0.8-2.1
	no.	46	66	58	23	58	59	58	58	59	59	58
River Lune at Denny Bridge	mean	100	79	3.7	0.08	0.10	243	2.8	6.5	<10	33	1.2
	range	59-193	32-131	2.5-10	0.06-0.24	0.06-0.3	40-2040	<1-14	1.5-31	<10	17-100	0.8-2.9
	no.	46	65	58	29	58	58	58	58	58	58	58
River Wyre at St. Michaels	mean	112	79	4.0	0.08	0.17	692	4.4	11.1	<10	98	2.4
	range	47-151	10-126	2.5-12	0.05-0.25	0.05-1.7	165-2600	1.0-9.0	1.5-28	<10	<20-250	1.0-7
	no.	46	79	58	44	58	58	58	58	58	58	58

Note: hardness data taken from 1975-1980

Table 5.6

INORGANIC NITROGEN AND PHOSPHATE PHOSPHORUS LOADINGS**
TO MORECAMBE BAY*

		kgs/day N	kgs/day P
River Lune Estuary	Rivers	4312	162
	Sewage	411	81
	Trade	314	1
	TOTAL	5037	244
River Wyre Estuary	Rivers	1484	60
	Sewage	310	89
	Trade	472	2
	TOTAL	2266	151
River Kent Estuary	Rivers	1969	110
	Sewage *	482	160
	Trade	0	0
	TOTAL	2451	270
River Leven Estuary	Rivers	1353	27
	Sewage	128	43
	Trade	329	129
	TOTAL	1810	199
Walney Channel (South)	Sewage	424	141
Morecambe Bay TOTAL		11988	1005

* "Sewage" includes Morecambe and Heysham Crude outfalls.

** Based on 1975-1981 data.

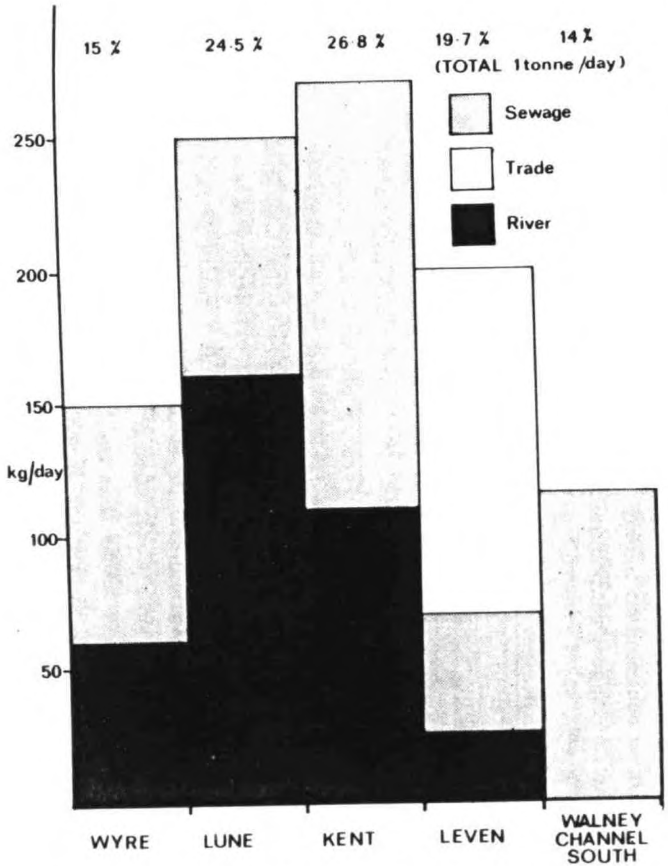

Figure 5.7: Orthophosphate phosphorus loadings into Morecambe Bay.

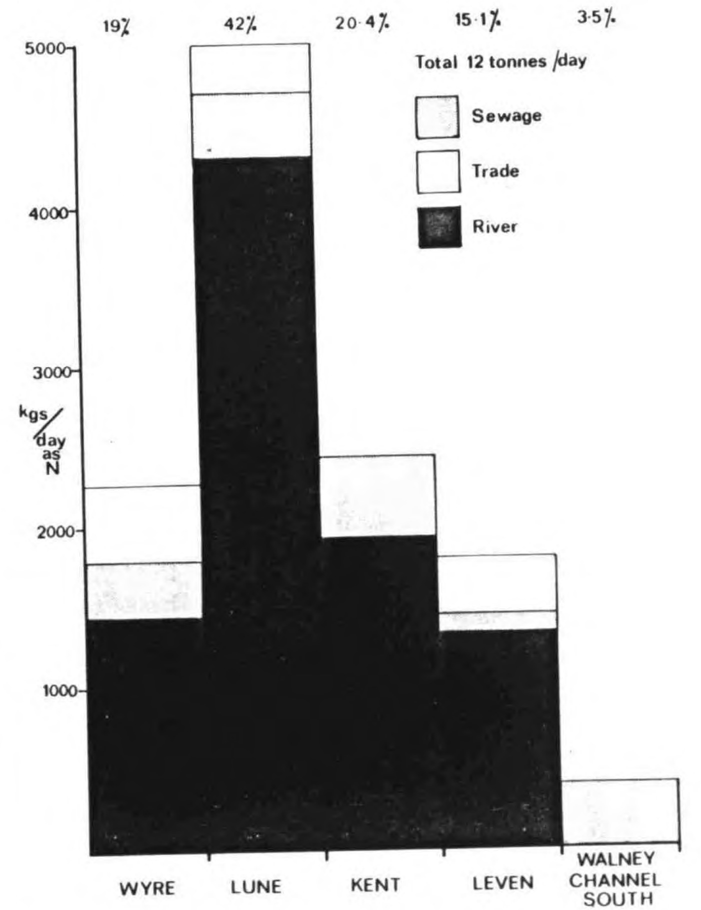

Figure 5.6: Inorganic nitrogen loadings into Morecambe Bay.

refer to any discharges direct to the estuaries (or to small estuarine tributaries).

In no case, except possibly for phosphate-P on the River Kent, is this distinction likely to be at all confusing, as the volumes of sewage or trade effluent discharged into any of the other inland rivers draining into Morecambe Bay are relatively small. The "river" inputs particularly of nitrogen derive almost entirely from diffuse run-off from agricultural activities and leaching of nitrates from agricultural land. It is perhaps somewhat surprising to find that these contributions amount to 76% of the total inorganic nitrogen discharged to the Bay.

The second surprising feature is the large nitrogen contribution from the River Lune. Nearly all of this has come over Skerton Weir as nitrate, rather than as ammonia from the highly polluted Broadfleet system.

As might be expected, there is a marked seasonal fluctuation in nitrate loads about the 12 tonnes/day average figure. A typical winter figure could be of the order of 20-30 tonnes/day for a 3 month period, and only 2-4 tonnes/day for a rather longer period in the summer.

The phospherus loadings show a very different picture, as the river contribution is only 35% of the total, and the sewage at 52% is the biggest contributor.

2. Trends in Nitrogen and Phosphorus loadings

There are no discernable trends in "river" orthophosphate, and it is unlikely that sewage or trade phosphorus loadings will increase dramatically in the next few years. The picture on nitrogen is rather different. Farming practices have changed and are continuing to change quite rapidly, with the emphasis on greater efficiency and productivity. Results of the 1980 DOE River Pollution Survey (National Water Council 1981) demonstrate a substantial increase in the lengths of polluted rivers as a result of farm drainage problems. MAFF Agricultural Development and Advisory Service (1980), in studies on a model farm at Rossendale, noted an 83% increase in nitrate-N losses from the land between 1972 and 1979. Similar increases in nitrate concentrations over the last 10 years have been noted in NWWA rivers, particularly the cleaner ones. Figures for the Lune are presented for the last 15 years (Figure 5.8). Increases on the other Morecambe Bay rivers are not so marked, though still significant.

It is not known to what extent changes in farming practice could influence productivity in Morecambe Bay and this could well be an area worthy of future study.

3. River Wyre Estuary

The estuary is 28 kilometres long from the tidal limit at St. Michaels to Wyre Light. The freshwater flow is relatively small compared with the Ribble, Lune or Kent. In the new estuary classification (National Water Council 1981) it is placed in Class B.

The freshwater input is of dubious quality having recently deteriorated from Class 1B to Class 2 due to illegal discharges of farm drainage. A further deterioration takes place in the upper reaches of the estuary for the same reason, and thereafter discharges of sewage and trade effluent combine to maintain the estuary in a somewhat polluted condition organically, although still allowing the passage of migratory fish.

Major tidal cycle surveys are undertaken every two years, together with LWSFJC and Imperial Chemical Industries who operate chemical plants and a chloralkali plant discharging effluents to the estuary. These major surveys are supplemented by bankside or bridge sampling at approximately fortnightly intervals.

Mercury concentrations have been measured on the surveys. Peak concentrations for total mercury were around 2-4 ug/l but soluble mercury levels measured in 1981 were below the EEC directive limits of 0.5 ug/l for estuarine waters. The maximum value recorded was 0.27 ug/l.

The algal population has been examined in some detail by both LWSFJC and NWWA biologists, who both found a reasonably diverse and well balanced flora.

On most of the surveys a distinct oxygen sag was found in some parts of the estuary, but oxygen levels even at night are not usually low enough to be cause for serious concern. Due to high levels of phytoplankton, the dissolved oxygen levels

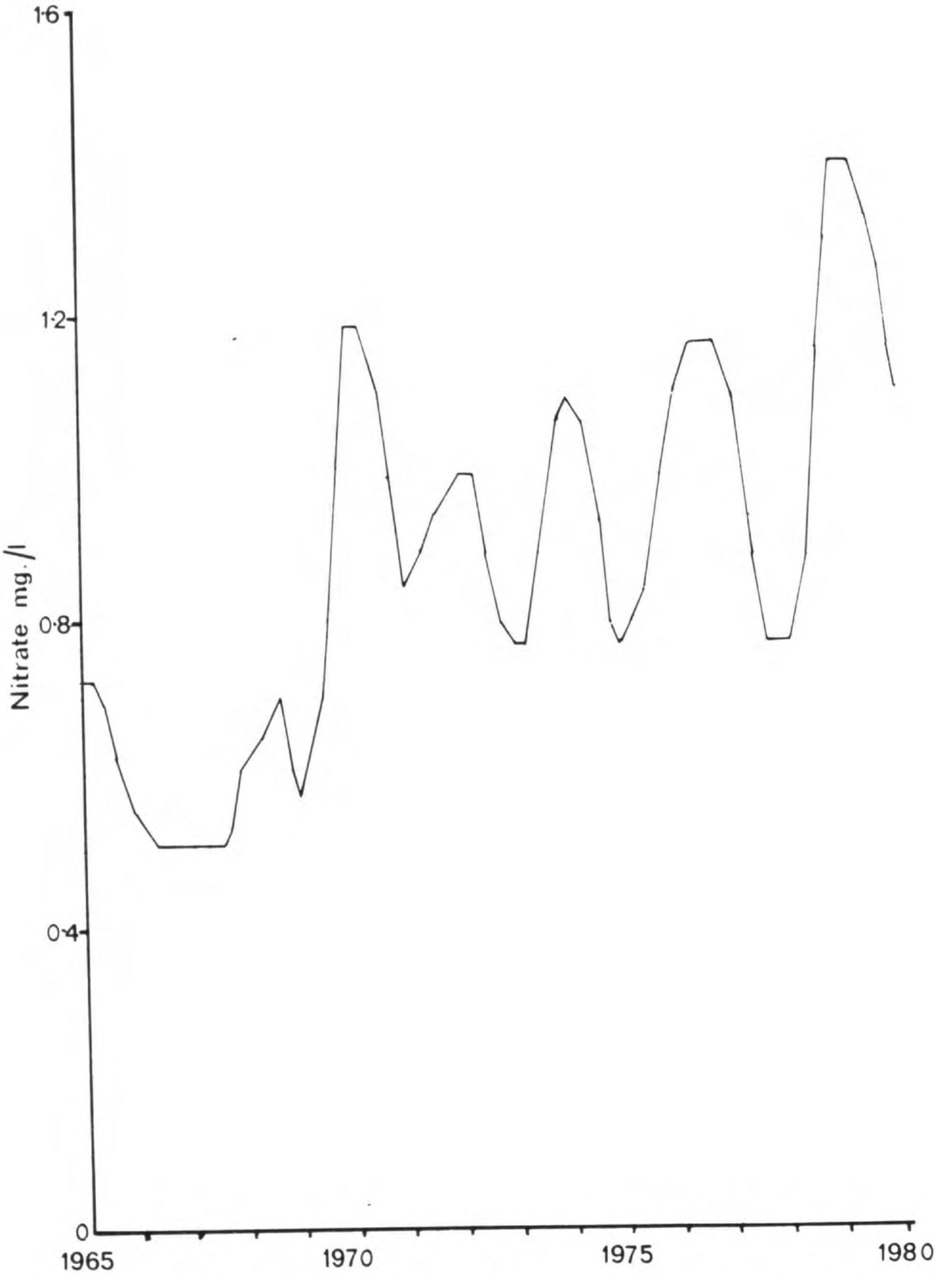

Figure 5.8: River Lune at Forge Weir nitrate trends 1965-1980 (moving average of yearly means).

in some parts of the estuary are frequently supersaturated in summer. This photosynthetic activity is thought to mask to some extent the effects of oxygen uptake due to oxidation of organic pollutants.

4. Lune Estuary

The estuary is 21 kilometres long from Skerton Weir to the Point of Lune with a large clean (Class 1A) fresh water input at its head. Parts of the middle reaches have been trained, an exercise which led to the eventual loss of almost half the tidal volume of the estuary at M.H.W.S. according to Inglis and Kestner (1958). The main discharge to the estuary is an ebb discharge of sewage from Lancaster sewage works. The works has recently been extended to include settlement prior to the ebb discharge, and the estuary is now Class A throughout.

Major tidal cycle surveys, including a 24-hour survey, were carried out in 1975, 1976 and 1977 to provide data to validate a mathematical model developed by the Water Research Centre, (1976 and 1977) prior to construction of the new works. As on the Wyre, photosynthetic activity can be intense with high levels of supersaturation at times. NWWA have found maximum chlorophyll at levels of 150 μg/l and 186% dissolved oxygen saturation. There is considerable input of agricultural drainage to the outer reaches of the estuary via Broadfleet but dilution is fairly high here (unlike the Wyre) and the effect on the Lune Estuary is not great.

5. Kent Estuary

There are no large-scale water quality problems in the estuary but until recently some quite serious local problems existed, particularly in the Grange area, where discharges of crude sewage were made onto the foreshore. Because of this, the west side of the estuary is designated Class B, whilst the rest is in Class A. A sewage treatment works has now been provided, giving full treatment to the Grange sewage and the situation is much improved.

The River Kent is also a good salmon river though not quite in the same class as the Lune. It is one of the most fertile rivers draining to Morecambe Bay mainly as a result of the discharge of treated sewage effluent from Kendal sewage works, about 4.5kms above the tidal limit. Studies for proposed estuarine barrage schemes (Corlett 1972; Counties Public Health Laboratories Ltd., 1969) showed that River Kent water would create a eutrophic storage reservoir.

6. Leven Estuary

The Leven has been a somewhat controversial estuary in recent years with salmon fishermen complaining of declining salmon and sea trout runs (though these have improved considerably in 1980/81) and estuary fishermen complaining of the alleged effect of a large discharge of effluent from a pharmaceutical works on flounders, cockles and other species.

Several surveys have been carried out by NWWA and LWSFJC to determine the dispersion characteristics of sewage and trade effluents, which show in general good dispersion though with some local problems. LWSFJC attribute variations in flounder and cockle catches more to variations in channels and sediments than chemical change. Fish avoidance tests by Water Research Centre on the effluent have proved negative. One of the estuary tributaries (Carter Pool) is in Class C, but the remainder of the Leven Estuary is in Class A. The inland Leven, draining Windermere and Coniston Water (via the Crake) is extremely clean (Class 1A). The only problem is a physical one in summer months, when very low river flows occur on occasions below Windermere.

7. Walney Channel (South)

This is a channel with only a very small freshwater input. At low water it is separated by a bar from the northern half of the channel. It does receive a number of crude or partially treated sewage discharges the largest of which is from Barrow. Some of the discharges include low concentrations of toxic metals derived from trade effluent. Water quality surveys have shown elevated coliform counts in the channel, and slightly elevated ammoniacal nitrogen concentrations but there is no significant oxygen sag. Shellfish examined from near the mouth of the channel did not comply with bacteriological standards laid down in the EEC Shellfish Directive for designated waters. Monitoring of shellfish from within the channel by the Local Authority Environmental Health Department has shown toxic metal levels to be above background levels. Despite these problems the new classification system places the channel within Class A.

8. Heysham Nuclear Power Station

The only major discharge to the Bay itself is that of chlorinated cooling water from Heysham Power Station. Stage 1 has been commissioned, and involves the discharge of 4300 Ml/d of cooling water. Stage 2 will involve an approximately equal amount of cooling water discharged from a second outfall close to the existing outfall. The temperature rise in the surrounding water is predicted to be of the order of 0.5°C (Figure 5.9) and no problems are expected apart from local effects in the immediate vicinity of the outfall.

Joint studies have been undertaken between NWWA, LWSFJC and the Central Electricity Generating Board to determine the effect of the chlorinated discharge on populations of phytoplankton, icthyoplankton and zooplankton. Catches of fish and shrimps on the intake screens will also be studied.

Conclusions

Despite a number of crude sewage discharges and one or two trade effluent discharges, either direct to Morecambe Bay or to the estuaries draining to it, the waters of the Bay generally, though still very productive, have lower nutrient concentrations than Liverpool Bay.

The problem areas tend to be local ones, in the estuaries themselves, and as a result most survey work has been in these areas. With the exception of the Wyre Estuary, however, which is Class B and the Grange side of the Kent Estuary (recently improved), the estuaries are placed in Class A of the new estuary classification.

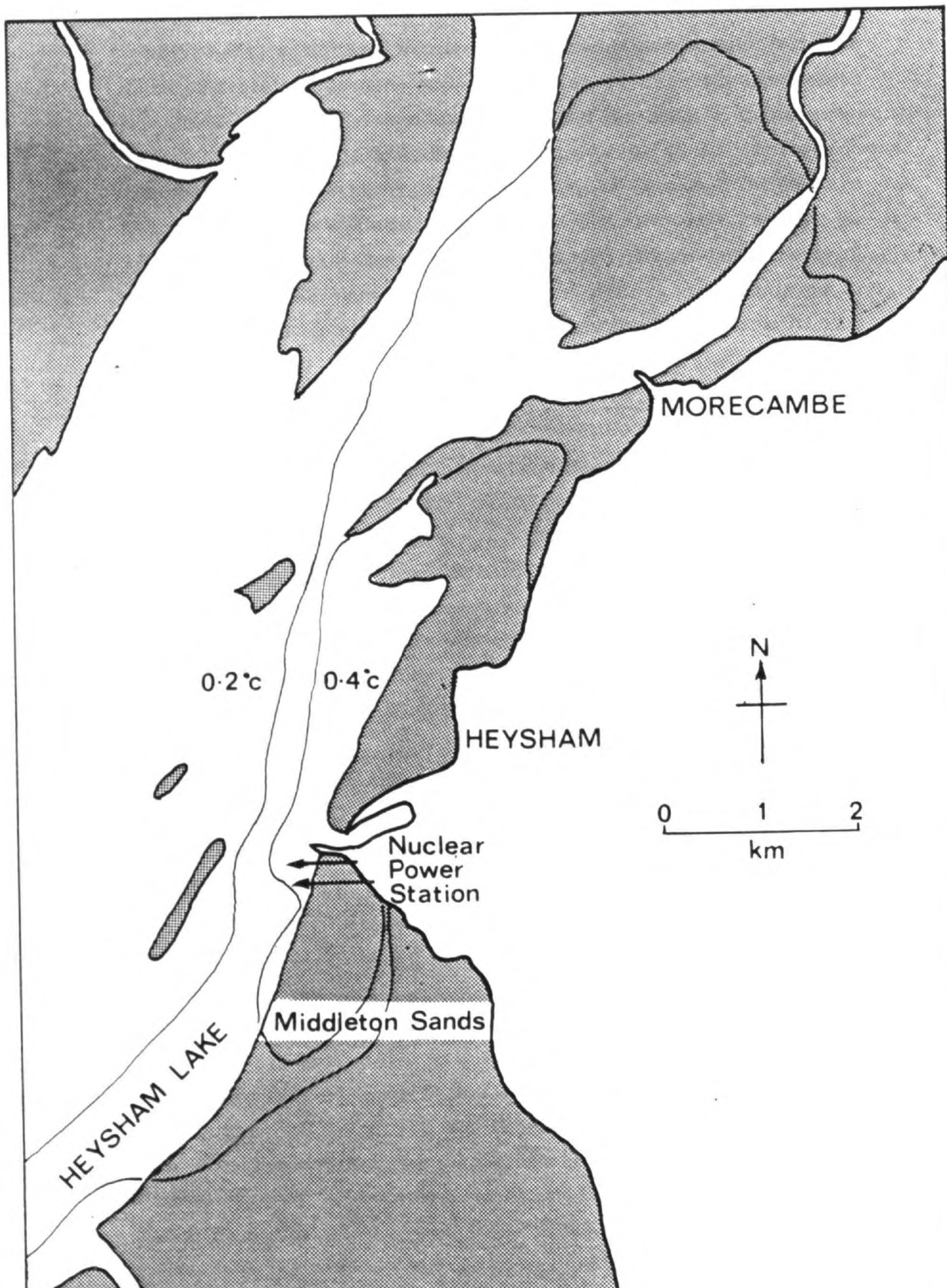

Figure 5.9: Heysham Nuclear Power Station Stages 1 and 2 thermal contours.

Acknowledgements

Thanks are due to Lancashire and Western Sea Fisheries Joint Committee for permission to publish data from their Annual Scientific Reports, and to D. Evans in particular for data from his M.Sc. Thesis. Thanks are also due to the Director of Planning, North West Water Authority, for permission to publish NWWA survey data, and to the Central Electricity Generating Board for permission to publish the data in Figure 5.9.

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Chapter 6

SALT MARSHES

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Introduction

The location of the major areas of salt marsh in the northern part of Morecambe Bay is shown in Figure 6.1. The most recent accurate survey of these areas, in 1970, indicated that there was at that time 1485 ha of marshland subject to periodic tidal submergence (Gray, 1972). This consisted of a number of relatively small marshes bordering the upper estuaries of the rivers Kent and Leven, together with large areas of continuous saltings along the east shore (750 ha at Silverdale and Warton) and the Cartmel peninsula (350 ha). A further 530 ha occur at Pilling and 300 ha in the estuary of the river Lune. In total this area comprises about 5% of the total area of salt marsh around the British coast (estimated at 44,900 ha - Gray 1979, Dijkema et al 1984).

The salt marshes of the Bay are mainly grazed marshes on predominantly sandy substrates and have been classified phytogeographically by Adam (1978) as typically west-coast types (his type B marshes). As he points out it is difficult to separate the effects of a long history of (mainly) sheep grazing from the effects of substrate type in determining the phytosociological relationships of British salt marshes (Adam 1976, 1978) but both of these factors are clearly important in giving the marshes of Morecambe Bay their distinctive character.

History and Development

Reclamation. The postglacial rise in relative sea level in N.W. Britain culminated in the Boreal Atlantic marine transgression (about 6000 years

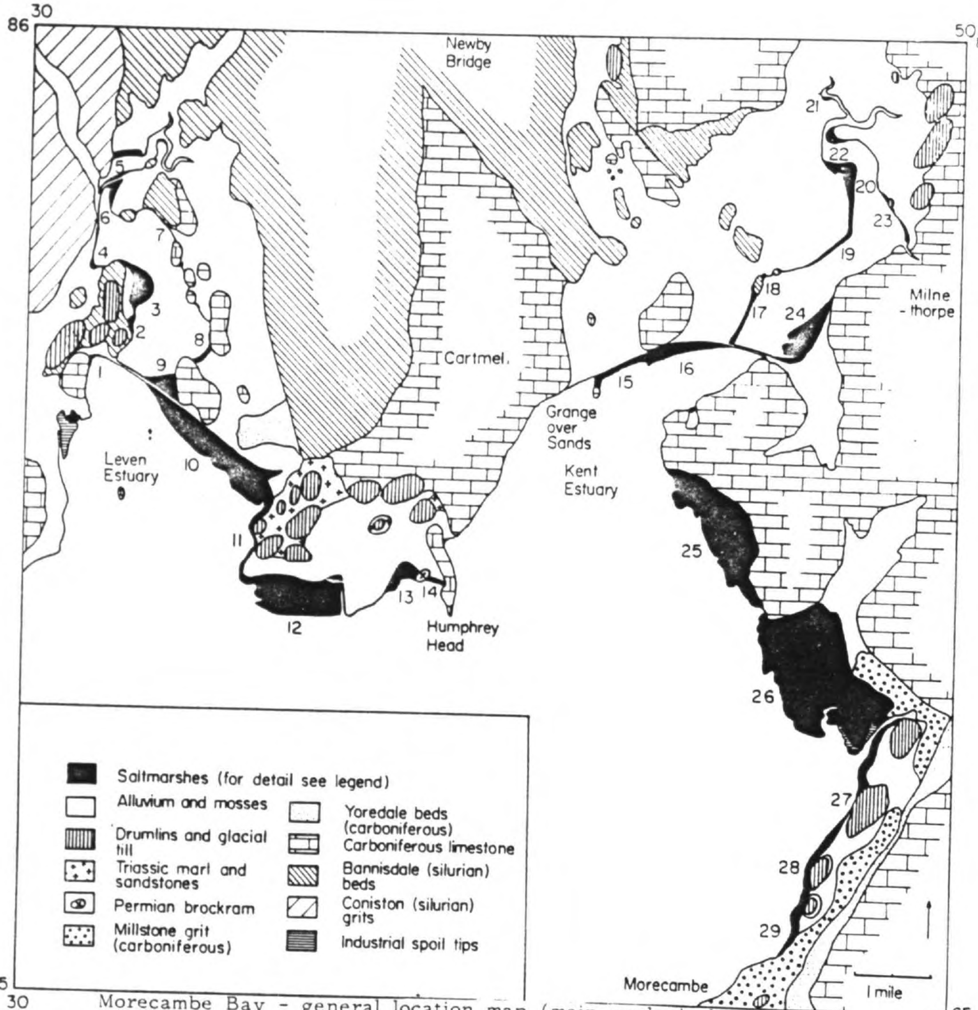

Figure 6.1: Morecambe Bay - general location map (main geological and topographical features based partly on Gresswell 1958). The major salt marsh areas are as follows.

1. Plumpton Hall
2. Ashes Point
3. Plumpton
4. Arrad
5. Colton Beck
6. Greenodd
7. Roudsea Wood
8. Low Frith
9. Capes Head
10. Holker
11. Canon Winder
12. West Plain
13. East Plain
14. Humphrey Head
15. Holme
16. Meathop
17. Brogden Bank
18. Crag Wood
19. Low Foulshaw
20. High Foulshaw
21. R. Gilpin
22. Halforth
23. Fishcarling
24. Storth
25. Silverdale
26. Warton
27. Bolton
28. Red Bank
29. Hest Bank

B.P.) which was responsible for the deposition of the raised beach fringing the Bay and its present river valleys (Oldfield, 1960, 1963, 1965; Greswell, 1958). (This is examined in more detail in Chapter 3). This low-lying land (below 6.1 m above O.D.) with its characteristic 'mosses' and reclaimed marsh is protected from tidal inundation by almost 60 km of artificial embankments linking the natural geomorphological features (Figure 6.1).

Since the earliest sea walls were built by the monks of Furness Abbey during the 13th century (West, 1774) about 1300 ha of marshland has been reclaimed in the area. The construction of the Ulverston-Lancaster railway in 1857 allowed the reclamation of almost 400 ha alone. Piecemeal reclamation of the margins of the Bay has yielded agricultural land of generally low value, a golf course (at Meathop), and ornamental gardens (at Ulverston and Carnforth). At Leighton Moss land reclaimed in 1840 was farmed until abandoned to freshwater marshland in 1918 and on the Cartmel peninsula 120 ha of West Plain enclosed in 1807 was later abandoned, reverting to intertidal marshland following the destruction of the sea bank in 1828. A full account of the reclamation history of the Bay is given by Gray and Adam (1974).

Recent History. Seaward of these embankments there has been progressive silting and salt marsh development similar to that occurring in the Solway estuary to the north (Marshall, 1962) and the Ribble and Dee estuaries to the south (Stopford, 1951; Marker, 1967). Although a total of almost 400 ha of salt marsh were added between 1845 and 1967 it can be seen from the data in Table 6.1 and the maps in Figure 6.2 that there have been considerable local fluctuations in the pattern of marsh growth. This has largely resulted from the changes in position of the low-water channels of the principal rivers flowing into the Bay.

The changes in low-water channels, which may fluctuate in a cyclic manner (Kestner and Inglis, 1956; Gray, 1979), are influenced by the building of reclamation banks and training walls in the upper reaches of the estuary. Attempts to stabilise the main channel of the Leven by building a breakwater in 1860 due south of the railway bridge are likely to have encouraged the development of salt marsh along the western edge of the Cartmel Peninsula. Similarly the growth of salt marsh at Silverdale has been influenced by the lateral migrations of the main Kent channel producing alternating periods of sandy beaches suitable

Table 6.1

SALT MARSH AREA (ha) AT VARIOUS DATES (1845-1967)

Locality	1845	1888	1910	1946	1967
River Kent (above viaduct)	84	109	273	142	142
Meathop and Holme	55	25	25	33	69
Silverdale	7	128	40	109	244
Warton	7	197	*255	485	506
South of River Keer	15	22	*16	87	80
Cartmel peninsula	360	116	219	208	353
River Leven (above viaduct)	36	55	*44	*19	84
Other	7	11	?	4	7
Total	557	663	872	1087	1485
Gain		106	209	215	398

* Approximate figure.

Table 6.2

SUMMARY OF SOIL DATA (0-4 cm samples) FOR 168 SITES

Variable	Min.	Mean	Max.	Standard deviation
1. % loss on ignition	1.0	8.4	56.6	9.1
2. Na (mg/100 g)	2.5	201.3	1550.0	279.0
3. K (mg/100 g)	1.3	34.9	120.0	24.7
4. Ca (mg/100 g)	127.0	1919.3	4130.0	1057.0
5. Mg (mg/100 g)	46.0	150.5	347.0	63.6
6. P (mg/100 g)	0.5	2.7	8.2	1.3
7. Total N%	0.01	0.25	1.55	0.31
8. % silt	0.3	12.1	45.0	8.6
9. % clay	1.7	8.3	27.0	5.5
10. Elevation (m)	3.5	4.9	6.2	0.7

(for methods of analysis and further details see Gray and Bunce (1972))

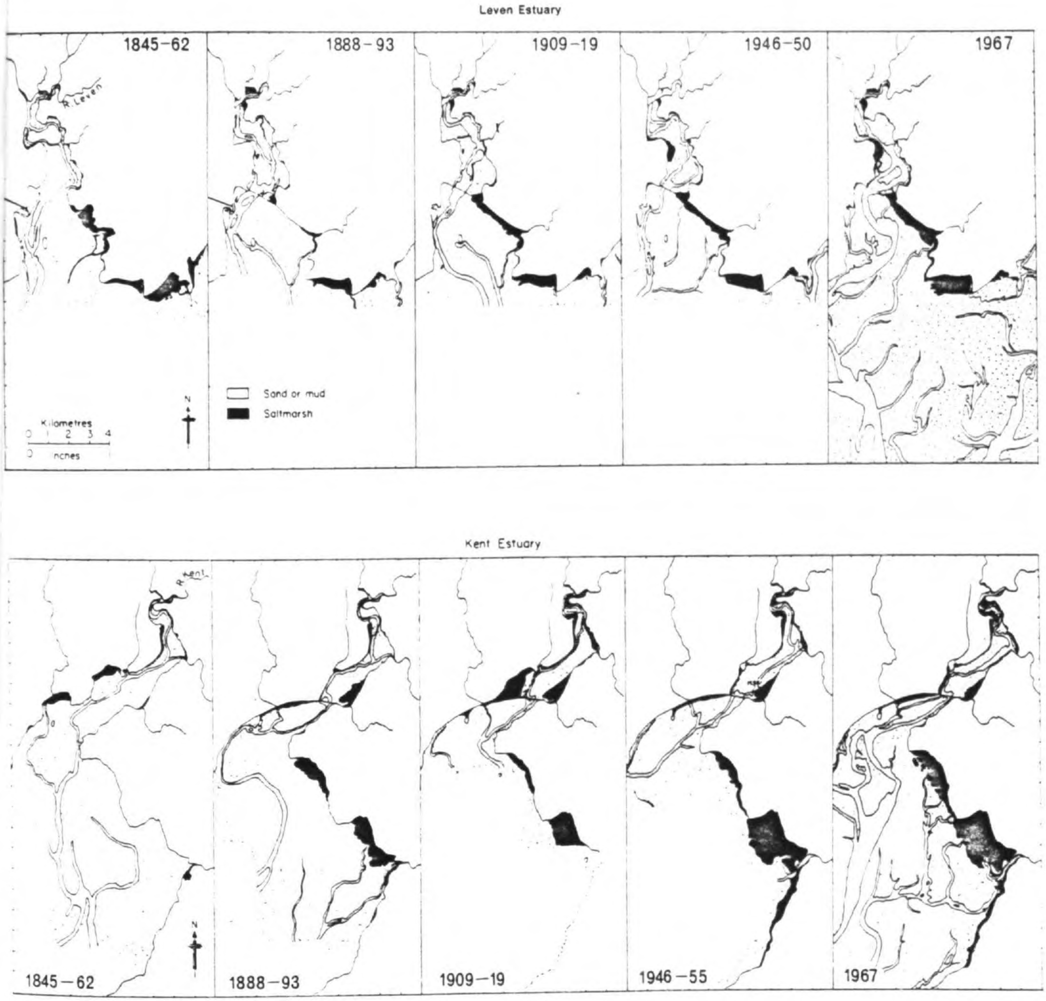

Figure 6.2: Salt marsh distribution and area at various dates (based on O.S. 6 in. and 25 in. series, estate and local maps).

for bathing (the 1840s - Harris 1963 - and the early 1900s) and extensive salt marsh (from 1850 to the end of the century and from 1915 to the mid 1960s). Since 1977 the Silverdale marshes have undergone extensive frontal erosion, as discussed in Chapter 4.

In recent years the major changes in salt marsh area have involved extensive erosion at Silverdale, Holker and Storth (with some recovery at Storth), the loss of marsh at Greenodd following the road construction in 1983, and, on the plus side, the development of new marshes in the Crake outfall, to the east of the Leven channel south of the foot-bridge, and the forward extension of several other areas. A feature of recent changes is the spread of Spartina anglica, especially on the muddier substrates south of the river Keer, and in the north around Holme Island and Plumpton (c. 2.3 ha) and at Kents Bank (invasion well under way, without continuous swards in 1986). Overall there is now less Festuca/Puccinellia marsh but more (at least 5.5 ha) of new S. anglica marsh in the Bay (Whiteside 1982). (For further discussion of Spartina see Chapter 7).

Physical Features

Topography. A characteristic feature of the salt marshes is the presence of cliffs, which may be up to 1 metre in height, often separating large terraces of uniform altitude. Similar cliffs and terraces are present in the Solway, the Ribble, and a number of other west-coast estuaries. Terraces are most evident in the profiles of the marshes in the northern part of Morecambe Bay, some of which have several terraces at different elevations. For example, on the north bank of the river Kent a terrace at 6.1 m O.D. extends from Crag Wood to High Foulshaw (being present on all the marshes even where they are not contiguous) and has below it a terrace at 5.3m, and another at 4.9m (Gray, 1972). There are no distinct terraces in the marshes in the south of the Bay where the general level of the main marsh slopes gradually down towards Morecambe from 5.1m at Bolton-le-Sands to 4.2m at Hest Bank.

The major cause of terracing is believed to be the fluctuation of low-water channels (see above), which, as they migrate towards the bank produce a cliff where blocks of material are sheared off the eroding edge. Later, when the channel moves abruptly to occupy a position at some distance away, salt marsh gradually develops on the terrace below the cliff. (This has occurred at Storth marsh over the period 1980-1986). The terraces are generally saucer-shaped, a central depression resulting either from natural settlement and compaction under sheep grazing or the preferential accretion of silt on the tops of the cliffs, or both. Depressions close to a cliff may result from the digging out of sediment to form sea banks or may be the remnants of the former channel. The creeks draining the terraces have a relatively simple 'herring-bone' pattern, characteristic of salt marsh creeks on sandy soils (Chapman, 1960).

Tidal relations. Salt marshes are confined to the upper 2.5m of the very large tidal range in Morecambe Bay. This range (9.5m from Mean High Water Spring tide level to Mean Low Water Spring tide level) results in a highly unstable intertidal system, generating a heavy suspended sediment load and carrying it over considerable distances. The deposition of these sediments is partly balanced by the eroding force of the rapidly falling ebb tide and by fluvial erosion. High-water levels, which are generally affected by meteorological conditions, are very susceptible in the Bay to the effects of winds blowing from the south-west where there is a considerable fetch. Strong S.W. winds may raise the actual high tide level well above the predicted height, the highest recorded storm tide reaching 7.6m a.O.D. on 8 October 1896. (Tidal conditions and storm surges are examined in more detail in Chapter 4.)

This highly dynamic tidal regime is an important factor in limiting the salt marsh to the upper levels. Most of the vegetation has its lowest level at about 3.9m O.D. although pioneer individuals (of Spartina anglica or Salicornia species) may be found down to 3.5m, some 80cms above Mean High Water Neap Tide level. The marshes have a somewhat truncated vertical range compared to those in some other parts of Britain, a lower zone of vegetation often present elsewhere being very restricted within the Bay. The low silt content and poor organic status of the sandflats may be a further factor limiting the seaward development of marsh, as has been suggested for the Solway (Perkins, 1967).

The extremely sandy nature of large areas of the intertidal sediments also produces a characteristic feature of the Morecambe Bay marshes - the unusual, dune-like, accretion of wind-blown sand in the pioneer vegetation zone during periods of continuous low tides.

This was a particularly noticeable feature of the marshes on the northern part of the east shore (Silverdale-Warton).

At high tide the marshes are flooded by the overspilling of drainage creeks and of the lower terraces. The presence of these latter features creates discontinuities in the tidal submergence pattern. For example, a terrace at 4.0m will be flooded by 200 more tides a year than one at 4.75m (see Gray 1972).

Soils. Table 6.2 summarises the data from physical and chemical analyses of 168 soil samples taken from the salt marsh and sandflat zones in 1969 (Gray and Bunce 1972). Further analysis of the data from that survey reveals a pattern of soil types ranging from coarse-grained, structureless, nutrient-poor sands at low elevations and with generally high calcium content to fine-textured organic silt with a low calcium content occurring at higher elevations. Sedimentary laminae, alternating bands of light and dark (generally finer) sediments, are found locally and may persist below the thin humorose soils of the higher marshes. As might be expected the major trend of variation reflects the gradual maturing of the soils under the influence of salt marsh development. However there is local variation in soil type at all elevations, both in the sediment type (% silt and clay) and in sodium content, and this point-to-point variation becomes more pronounced with increasing elevation (Gray and Bunce, 1972).

Vegetation

Zonation and Marsh Types. Arguably the single most important factor controlling the distribution of flowering plant species on salt marshes is the degree of tidal submergence. The gradual decrease in the frequency of tidal submergence, together with accretion, produces overall gradients up the marsh in habitat factors such as the height of the water table, and the drainage characteristics, aeration, and salinity of the soils. Whilst these gradients are considerably disturbed by local variation in topography and sediment type and by the interaction of these with cyclical and seasonal variation (e.g. Brereton, 1971; Jefferies, 1972; Gray, Parsell and Scott, 1979) the overriding influence of the tides is reflected in the contrasting vertical ranges of the individual plant species. The vertical ranges of some common species of the

Morecambe Bay marshes are given in Figure 6.3 which also shows the submergence curve and the major salt marsh types (see below).

Although the factors controlling the lower limit of most species are likely to be those associated with increased tidal submergence (e.g. salinity, physical disturbance), those controlling their upper limits are more probably related to competitive interaction with other species (able to survive in the increasingly tide-free conditions). The existence of plant communities can therefore be seen to be a function of the overlapping vertical ranges of the individual species. Since many of these are persistent perennial grasses the same species may occur, at different levels of abundance, in several recognisably different communities.

Despite this blurring of the zonation it is possible to recognise at least 4 major marsh types. These types, distinguished on the basis of a combination of soil and vegetation data (Gray and Bunce, 1972) are defined in Table 6.3 and their species composition is briefly described below. More complete species lists are given in Appendix 6.1.

1. Pioneer zones

This type consists of scattered individuals of pioneer species, notably Puccinellia maritima, and occasionally, Spartina anglica and/or Salicornia species. Possibly because of the mainly sandy sediments in the pioneer zones dense stands of Spartina were (until recently, see above and Chapter 7) largely restricted to the southern Bay where it is well established on Walney Island, from Hest Bank southwards, and in the Lune estuary. Agrostis stolonifera descends into the pioneer zones in the upper reaches of the Kent and Leven where soil salinities are very much reduced, and occasionally Suaeda maritima or Aster tripolium may be found in the few areas where there is no grazing.

2. Low-level Saltings

Above the pioneer zone, a zone with an extremely narrow vertical range (from 4.5 to 4.7 m) may be recognised. Consisting of Puccinellia maritima-dominated swards these areas may represent a critical threshold elevation at which salt marsh formation occurs. The tidal submergence rate increases sharply at this point over a correspondingly small increase in height, the difference in submergence rates above and below this level being about 100 tides per annum (Figure 6.3).

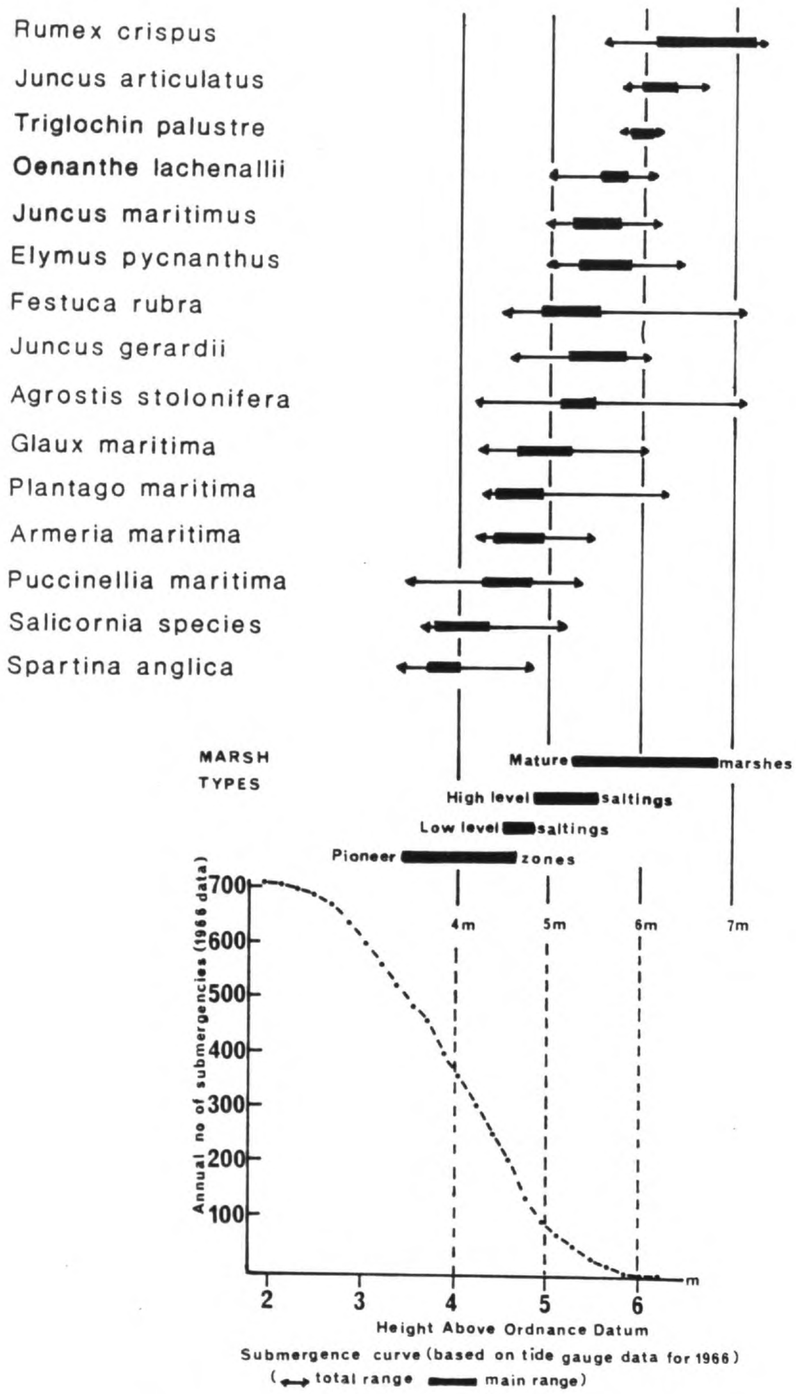

Figure 6.3: Submergence curve and vertical range of the major salt marsh types and some of the common species.

Table 6.3

DEFINITION OF THE MAJOR VEGETATION/ENVIRONMENT GROUPS WITHIN MORECAMBE BAY SALT MARSHES

Marsh type	Soil	Vegetation	Elevation (m O.D.)	Approx. vt.range (m)	Approx. no. of tidal submergence per annum
Mature marshes	Well-developed organic soils with silt and low calcium. Sodium may be high	High marsh types with glycophtic element. Generally diverse in species often obtained from eutrophic marginal habitats.	Mean 5.6 Range 5.3-6.6	1.3	Mean 6 Range 0-40
High-level saltings	At intermediate stage of development. Relatively high organic, high silt, medium calcium and relatively high sodium. Locally low elevation	*Festuca* swards sometimes with *Juncus gerardii*	Mean 5.4 Range 4.9-5.8	0.9	Mean c.50 Range 10-100
	Locally high-level sites with less organic material, sodium, and silt than II	*Festuca* swards communities with *Armeria* and hummock species such as *Plantago coronopus*			
Low-level saltings	Low-level immature soils with high salinity, relatively high silt	*Puccinellia* swards and open communities with colonizing species	Mean 4.6 Range 4.5-4.7	0.2	Mean c.200 Range 150-220
Pioneer zones and bare sites	Low-level immature soils of mobile flats with high calcium and low silt.	Pioneer phase with either bare sand or *Spartina*, *Salicornia*, or *Puccinellia* present at low densities.	Mean 4.1 Range 3.5-4.6	1.1	Mean c.350 Range 200-520+

Other species present, generally on the tops of hummocks, include Festuca rubra, Armeria maritima, Cochlearia officinalis, Spergularia media and Glaux maritima.

3. High-level Saltings

The major changes in the communities above the low-level saltings are the replacement of Puccinellia by Festuca rubra as the most dominant grass species and their increasing species richness and point-to-point heterogeneity. The distribution of the 3 most frequently found grasses, Puccinellia maritima, Festuca rubra and Agrostis stolonifera, often shows a clear pattern at this level with Puccinellia in the hollows, Festuca on the humps and Agrostis on the edges of humps. The results of competition experiments suggest that this pattern may be explained by the contrasting competitive abilities of the 3 species under different levels of water-logging and salinity (Gray and Scott, 1977).

Other typical species of the high-level saltings include Armeria maritima, Plantago maritima, Glaux maritima and, in higher and more brackish areas, Plantago coronopus and Juncus gerardii. The presence of Juncus maritimus and *Elymus pycnanthus in some areas indicates the transition to mature marsh types.

4. Mature marshes

At the highest elevations in the Bay and, particularly, in the brackish areas of the upper estuary two basic types of mature marsh community may be found. The first are highly diverse species-rich communities generally occurring on rarely-flooded sites and the second are communities largely dominated by a single species.

Several Juncus and Carex species are found in the first community type, whilst species such as Festuca arundinacea and Holcus lanatus represent the invasion of glycophytic species and Parapholis strigosa reflects high soil fertilities at lower elevations. There is variation within these communities based on local gradients in topography and drainage. Thus distinct 'brackish water meadow' associations can be found in low-lying areas such as borrow pits, old creeks and pans and in more freely drained areas a grass-dominated community can be found (see Appendix 6.1). Characteristic species of the second type of mature marsh, that largely dominated by one species, are

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* This taxon is highly variable in the Bay. There is possibly a hybrid complex with E. larctus.

Phragmites australis and Scirpus maritimus.

Mature marshes are the least common of the 4 marsh types, by far the largest area being covered by the saltings (types 2 and 3 above). They contain, however, many of the species of restricted distribution, some of which are alleged to be at or near their geographical limits (e.g. Blysmus rufus).

Management

Grazing. The salt marshes, like those of the neighbouring estuaries of the Solway, Duddon, Lune and Ribble, have a long history of grazing, mainly by sheep. Unlike other salt marshes in Britain, particularly in the south and east, there has been no major decline in this practice and less than 1% of the total salt marsh area in the Bay had remained ungrazed up to 1974 (this area, 10.8 ha at Holme Island, has been grazed since then).

Sheep-grazing is a major enterprise for many of the farms fringing the Bay and farmers point out the advantages of a fluke-free, worm-free, self-fertilizing grazing system with low husbandry, fencing, and ditching costs. The half-bred Masham type ewe (Swaledale X Teeswater) is the favoured breed although some Herdwicks occur (generally hoggs). Two main practices occur; either the production of fat lambs and wool, or the buying in of spring lambs in September to be wool-cropped once and sold out the following September as breeding ewes (shearlings).

Stocking rates are high, averaging 4.75 sheep/ha (1 lamb = 0.5 ewe units) and rising as high as 6.45 sheep/ha. On average 80-100 days are lost each year because of high tides and winter grazing is uncommon. Fattening in the spring generally starts later than inland (late April or early May). Live weight gains are high and crops average 1.25 lambs/ewe. A fuller account of sheep grazing in the Bay is given in Gray (1970). Some beef cattle graze the marshes, notably at Warton and, in the 1970s, at West Plain.

Heavy grazing is clearly a major factor in producing the characteristic low swards dominated by persistent grass species (especially Puccinellia maritima, Festuca rubra and Agrostis stolonifera) and leads to the selection of prostrate biotypes within these species (Gray, Parsell and Scott, 1979; Gray and Scott, 1980; Gray, 1985). The restriction of large populations of Limonium vulgare, Limonium humile, Halimione portulacoides, Suaeda maritima and Aster tripolium to ungrazed areas and those, such as Chapel Island, largely inaccessible to sheep, suggests that these species are largely eliminated by grazing (a fact confirmed by the grazing of Holme Island marsh) and also discussed by Bakker (1985).

Turf-cutting. The removal for sale of 'sea-washed' turf is practised on the saltings, cutting being mainly done by machine in October and November. The turves are cut to a depth of c.3.5 cm and generally 30 cm x 45 cm (although longer turves may be cut and rolled). A strip of turf about 5 cm wide is generally left between cuts, to give a straight edge to each turf and to aid recolonisation of the bare grass. This recolonisation however is rarely by Festuca rubra but usually by species from lower down the marsh (Gray and Scott, 1977). Thus poorer quality turves are produced, a factor which, together with the availability of cheaper lawn seed mixtures, may have hastened the decline of turf cutting in the Bay. Turves may be recut after 5 years but a period of 10 years between cuts is more common.

The building of hard-core tracks and bridges across creeks to gain access to the turf-cutting areas on the saltings has created habitats in which bare-ground species may survive e.g. Centaurium pulchellum (see also Gray, 1972).

Further Research Needs

This account has largely been confined to the flowering plants of the salt marshes in the northern part of Morecambe Bay (from Morecambe to Aldingham) and the factors affecting their distribution and abundance. It is based mainly on studies carried out between 1968 and 1970 which did not include surveys of the algae of the salt marshes, of their fauna, or of the flora and fauna of other coastal habitat types around the Bay such as cliffs and rocky outcrops. There is clearly a need to bring this work up to date and to extend it both geographically and to other organisms and habitat types. Within the salt marsh ecosystem, for example, the microalgae are likely to have an important role as primary producers, stabilisers of mobile sediments, and fixers of atmospheric nitrogen - all activities which are known from other areas (e.g. The Wash - Coles, 1979) to be important precursors to the development of higher plants on salt marshes. Salt marshes too are known to be important roosting areas for wading birds and feeding areas for wildfowl. The RSPB now controls large areas of salt marsh in the Bay and is managing them to maintain bird populations.

The salt marshes of Morecambe Bay are probably the most-studied examples of heavily grazed west coast marshes in Britain. They still contain small areas of species-rich brackish marsh (including, at Roudsea, an extremely rare example of the transition to tidal woodland), and are relatively less remote than other large salt marsh areas to the north and south (being both accessible and within relatively easy reach from several large centres of population). These facts make them ideal research targets for biologists. They also, particularly through easy accessibility and the discharge of relatively unpolluted water into the Bay, make them the target of people with a quite different set of objectives (e.g. Taylor, 1979).

Appendix 6.1

List of flowering plant species recorded from 168 2 x 2m quadrats in the northern part of the Morecambe Bay salt marshes (listed by marsh type - see Table 3).

status: r = rare, o = occasional, c = common, d = often locally dominant
names: according to Clapham, Tutin and Warburg (1962)

Pioneer zones

Agrostis stolonifera (r)
Aster tripolium (r)
Puccinellia maritima (d)
Salicornia species (mainly S. dolichostachya) (o)
Spartina anglica (d)
Spergularia media (o)
Suaeda maritima (o)

Low-level saltings

Agrostis stolonifera (r)
Armeria maritima (o)
Aster tripolium (r)
Cochlearia officinalis (o)
Festuca rubra (o)
Glaux maritima (c)
Plantago coronopus (r)
Plantago maritima (r)
Puccinellia maritima (d)
Salicornia species (o)
Spartina anglica (o)
Spergularia media (c)
Spergularia media (c)
Suaeda maritima (o)

High-level saltings

Agropyron pungens (o)
(renamed *Elymus pycnanthus*)
Agrostis stolonifera (d)
Armeria maritima (c)
Aster tripolium (r)
Centaurium littorale (r)
Centaurium pulchellum (r)
Cochlearia officinalis (o)
Festuca rubra (d)
Glaux maritima (c)
Halimione portulacoides (r)
Juncus gerardii (c)
Juncus maritimus (o)
Limonium vulgae (r)
Limonium humile (r)
Parapholis strigosa (r)
Plantago coronopus (c)
Plantago maritima (c)
Potentilla anserina (r)
Puccinellia maritima (c)
Rumex crispus (r)
Salicornia species (o)
Spergularia media (c)
Suaeda maritima (o)

Mature Marshes

Achillea ptarmica (r)
Agropyron pungens (o)
(renamed *Elymus pycnanthus)*
Agropyron repens (o)
(renamed *E. farctus)*
Agrostis stolonifera (d)
Alopecurus geniculatus (r)
Anthoxanthum odoratum (r)
Armeria maritima (r)
Aster tripolium (r)
Atriplex hastata (o)
Blysmus rufus (r)
Carex demissa (r)
C. distans (o)
C. disticha (r)
C. extensa (o)
C. flacca (r)
C. nigra (r)
C. otrubae (o)
C. ovalis (r)
C. panicea (r)
Centaurium pulchellum (r)
Cerastium holosteoides (c)
Cirsium arvense (o)
C. palustre (r)
C. vulgare (r)
Cochlearia officinalis (r)
Cynosorus cristatus (o)
Dactylis glomerata (o)
Deschampsia caespitosa (o)
Eleocharis palustris (o)
E. uniglumis (r)
E. quinqueflora (r)
Festuca arundinacea (d)
F. rubra (d)
Filipendula ulmaria (r)
Glaux maritima (r)
Hieracium sp. (o)
Holcus lanatus (o)
Hydrocotyle vulgaris (r)
Iris pseudacorus (r)
Juncus acutiflorus (r)
J. articulatus (o)
J. bufonius (o)
J. conglomeratus (o)
J. effusus (o)
J. gerardii (c)
J. inflexus (r)
J. maritimus (c)
J. tenuis (r)
Leontodon autumnalis (c)
L. taraxacoides (c)
Limonium humile (r)
Lotus pedunculatus (c)
Oenanthe lachenalii (c)
Parapholis strigosa (o)
Phalaris arundinacea (r)
Phragmites australis (d)
Plantago coronopus (o)
P. lanceolata (r)
P. maritima (r)
Poa annua (o)
Potamogeton filiformis (r)
Potentilla anserina (c)
Puccinellia maritima (r)
Ranunculus repens (r)
R. sceleratus (r)
Rorippa islandica (r)
Rumex crispus (o)
Sagina maritima (o)
S. procumbens (o)
Samolus valerandi (o)
Scirpus maritimus (d)
Scirpus tabernaemontani (r)

Mature Marshes cont.

Silene maritima (r)
Spergularia marina (o)
S. media (r)
Stellaria media (r)
Suaeda maritima (r)
Trifolium repens (c)
Triglochin maritima (o)
Triglochin palustre (r)
Tripleurospermum maritimum (o)

(N.B. This is not a comprehensive list of species of the Bay salt marshes. Status refers to the general abundance in the sample quadrats).

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Chapter 7

SPARTINA COLONIZATION

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Introduction

The history of the spread of Spartina around coasts in Britain is thoroughly documented. Dates of first "sightings" in different places have been noted for many years; many of these first appearances have been as a result of planting; others have been the result of natural spread.

Spartina maritima is a native in Britain and is unevenly distributed around the south and east coasts in tidal salt marshes. In Southampton Water in 1829 Bronfield noted the appearance of a North American grass - Spartina alterniflora, which spread within that estuary. Its arrival from North America has usually been attributed to the shipping involved in the trade between Britain and the Atlantic littoral of the U.S.A. where it is a common pioneer species of salt marshes. The presence of the two grasses in Southampton Water resulted at first in a hybrid Spartina X townsendii N and J Groves, a male sterile grass which spread slowly over the tidal flats there. The first collection of this grass was at Hythe in 1870, but approximately ten years later an increasingly vigorous spread of Spartina was noted. This more rapid spread has been attributed to the development of a fertile amphidiploid derived from the sterile Spartina X townsendii by a doubling of the chromosomes. The fertile grass was collected at Lymington, Hampshire in 1892, the Isle of Wight in 1893 and Poole harbour in 1900. By 1913 it had colonised in every estuary between Chichester and Poole, spreading outwards from Southampton Water. This fertile grass was named Spartina anglica by C.E. Hubbard in 1968.

Since the initial colonisation, Spartina anglica has been extensively planted around the British coasts, north to about southern Scotland, and from these plantings it has spread locally by establishment of seedlings and by fragments of rhizome carried by the tide. Rhizome growths spread to form a concentric ring formation around the original growth resulting in a characteristic tussock form (Goodman, 1969). Roots and rhizome stabilise the substrate and as leaves and culms grow upward it reduces greatly the erosion of deposited mud, silt and sand thus raising the level of coastal marshes where it establishes.

Annual Cycle of Spartina

Spartina in west coast marshes of England normally follows the annual cycle observed in the Dee estuary by Taylor and Burrows (1968) and summarised below:

March and April:	New shoot production.
May and June:	Appearance of seedlings.
July:	Peak of shoot production. First flowers near end of month.
August and September:	Maximum flowering period.
October:	Increase in number of living shoots. Ripening and fall of fruits.
November and December:	New rhizome bud development. Death of flowering shoots.
January and February:	Dying down of shoots. Colour change from green to straw-like thatch.

In Morecambe Bay the flowering period is frequently extended when autumn weather is mild. This is especially true where the grass has developed into a sward.

Morphology of Spartina

To distinguish between Spartina X townsendii and Spartina anglica it is thought that a chromosome count is necessary. This may be the only reliable method but Hubbard (1968) states that:

> "It (Spartina anglica) may be distinguished from the latter (Spartina X townsendii) by its mostly broader and more widely spreading upper leaf-blades, longer ligular hairs and mostly longer wider and more hairy spikelets, and its longer perfect anthers."

Table 7.1 shows the morphology of Spartina spp. in Britain. Although the two plants are very similar in appearance Spartina anglica has fewer but more hardy rhizomes and fewer tillers per unit area. This gives a less dense sward but it is difficult to distinguish as such because of the longer and broader leaves of the amphidiploid. Measurements were made to attempt to establish which type is to be found in Morecambe Bay. Averages calculated gave the results shown in Table 7.2.

It will be seen that these measurements do not give conclusive results - the grass may be Spartina X townsendii or Spartina anglica in a number of cases. These and other measurements made, do, however, suggest that the well-established grass growing in the inner marsh areas can be safely assumed to be Spartina anglica, particularly since fertile seed is often set. Where measurements are less conclusive and the height of the culm is lower and the length and width of the blade markedly less, the substrate is shingle or the location is at the edge of the marsh. These environments are less favourable than those of the inner marsh and usually more exposed. They are the areas of growth of the pioneer plants and variations in the stability of the substrate or its nutrient status may account for the differences.

Wave beating of the grass at the edge of the marshes has been suggested as a possible reason for this dwarf growth. In Morecambe Bay low energy wave conditions usually obtain but when wave beating occurs it is likely to be most vigorous in coastal areas facing west-south-west. This exposure may also result in a slow growth at the front of marshes facing this direction. Some dwarf growth can be observed in sheltered estuarine marshes e.g. in the Lune estuary and at Plumpton Hall marsh so the relationship between grass height and wave beating are inconclusive for Morecambe Bay.

Detailed studies are needed to establish whether or not there are different types of Spartina in Morecambe Bay.

Table 7.1

THE MORPHOLOGY OF *SPARTINA* SPP. IN BRITAIN

	Height of culm	Blades		Ligule	Panicles		Spikes	Spikelets		Anther	Blade Angle	Chromo-Some Number
	(cms)	Length (cms)	Width (mm)	Length (cms)	Length (cms)	Number of Spikes	Length (cms)	Length (cms)	Width (mm)	Length (mm)	(deg)	
Spartina maritima	15-50	2-18	6	0.2 to 0.6	4-10	1-5 mostly 2-3	3-8	11-15	-	4-6	-	2n=60
Spartina alterniflora	40-100	10-40	5-12	1.0 to 1.8	10-25	3-13	-	10-18	-	5-7	-	2n=62
Spartina X townsendii	30-130	6-30	4-12	1.0 to 2.0	up to 25	2-9	4-15	12-18	2.0 to 2.5	5-8	30-40	62
Spartina anglica	30-130	10-45	6-15	2.0 to 3.0	12-40	2-12	up to 25	14-21	2.5 to 3.0	8-13	30-60	2n=122

After Hubbard (1968) and Marchant (1967)

Table 7.2

MORPHOLOGICAL FEATURES OF SPARTINA IN MORECAMBE BAY

Marsh Area	Height of culm (cm)	Length of blade (cm)	Width of blade (mm)	Anther length (mm)
1. Hest Bank				
Main marsh	68.0	20.3	10.0	11.2
Outer clumps	35.0	14.0	9.0	11.3
2. Rampside				
Inner marsh	130.00	25.0	11.2	11.5
Central marsh	75.00	20.5	10.6	11.5
Outer marsh	40.00	12.0	9.3	11.5
3. Plumpton Hall				
Inner marsh	78.0	17.5	10.0	10.0
Outer marsh	40.0	14.0	9.0	10.0
4. Humphrey Head				
Channels of middle marsh	100.00	25.0	11.2	11.5
Outer marsh	50.00	16.0	9.4	11.5

The Spread of Spartina in Morecambe Bay

The first record of Spartina near the Morecambe Bay area was the plantings made in the Ribble estuary in 1932 (Hubbard and Stebbings, 1967); by subsequent natural spread it colonised the Wyre estuary by 1942. It is likely that the Wyre estuary population is the source from which Spartina spread into the Bay itself.

A few dates of early 'sightings' can be noted and summarised as follows:

Marsh	Date	Notes
Rampside	1949	Recorded by A. L. Evans, R.S.P.B. Warden for Foulney.
Hest Bank	earlier than 1959	Shown on map (Goodman et al) as having successful establishment possibly from plantings: no date given for plantings.
Plumpton Hall	1960	First clumps noticed by local farmer - near sewage outfall and railway embankment.
Humphrey Head	1967	Photograph of the marsh published in local paper.
Red Bank Farm	1970	Two clumps noted by author.
Newbarns embayment (North of Arnside Knott)	1974	Small clumps noted by author.

Spartina to the south of the Lune estuary had undergone a considerable spread by 1970. On the edge of Morecambe Bay it has spread most rapidly in the channel between Walney Island and the Furness peninsula. A photograph taken in 1965 shows a few clumps with extensive area of mud between in the sheltered area to the east of the spit at the southern end of the island. Now there is a continuous sward and an extensive area to the north has also been colonised.

The Present Distribution of Spartina (December 1986)

The distribution of Spartina was mapped in April 1982 and is shown in Figure 7.1. The mapping was undertaken using 1 : 50,000 Ordnance Survey maps as a base and its presence/absence recorded for each kilometre grid square. There were few squares where it was not to be found.

The spread of the grass within salt marshes was, however, far from continuous. The pattern of distribution could be categorised as continuous sward or in patches.

Continuous Swards of Spartina

There are a number of marshes just outside the immediate Bay environment where Spartina growth has extended to form continuous swards. These include:

(i) the area west of Walney Channel in the shelter to the east of the island;

(ii) the Lune estuary east of Sunderland Point on both the north and south sides of the river channel;

(iii) within the Wyre estuary.

In each case the grass is growing on silt - known to be Spartina's preferred substrate. Each area is sheltered from the most vigorous wind and wave action from the west. Within Morecambe Bay continuous swards are found at Rampside, Plumpton Hall and to the south of the Lune near Cockersands Abbey.

Near Rampside an embankment was built to connect Roa Island with the Furness peninsula in 1848-49. This left a bridge at Conck Hole which allowed drainage and movement of tidal currents. The bridge was later closed and the Foulney embankment constructed. Within the sheltered zone between the two embankments small areas of salt marsh developed. The extent of this original marsh can still be observed as the vegetation on it includes a variety of salt marsh plants e.g. Cochlearia officinalis, Armeria maritima, Suaeda maritima, Puccinellia maritima and a zone dominated by Halimione portulacoides. Beyond this in a seaward direction extends the Spartina sward, with some development of Halimione near channels and Salicornia europaea in open areas between clumps near the seaward edge.

Figure 7.1: Distribution of Spartina in Morecambe Bay, April 1982.

Spartina occurs across the complete range of vegetation and marsh heights. In 1972 clumps occurred along the seaward of the Spartinetum approximately 400 metres from the back of the marsh. By 1980 the edge of the sward had advanced by a further 100 metres. The seaward spread has now (1986) slowed down but clumps have consolidated and Spartina remains well established in the outer marsh. Spartina debris frequently covers plants in the landward section. In this part of the marsh it seems possible that there may be some "die-back" of the grass and an increase in the spread of more varied salt marsh plants. The substrate at the back of the marsh is mainly of fine sand with an 8% clay component. The seaward sections show a marked decrease of fine material and an increase in medium/coarse sand.

Plumpton Hall marsh lies in a sheltered part of the Leven estuary in an embankment between Tridley Point and the Old Pier at Plumpton Quarries. The viaduct carrying the railway betwen the Cartmel and Furness peninsulas crosses the Leven here. The substrate has a very high proportion of fine material (clay/silt and fine sand). In 1972 the Spartina growth was in clumps growing vigorously but still separated by considerable areas of mud. By 1974 many of these clumps had coalesced to form a continuous sward. The Spartina has now (1986) spread across the entire embayment and is limited on its seaward side by the Leven channel.

Rampside and Plumpton Hall are both sheltered and eastward facing marshes. Another area of continuous sward is narrow but occurs along the coast from Cockersands Point to Bank End Farm and faces west. The gentle off-shore gradient of Cockerham Sands has clearly afforded sufficient protection from vigorous wave action to allow this spread. Detailed surveys are needed in this area to assess the potential spread and the effects of the construction of the dyke across the Cockerham Marsh to the south.

A small area of sward has now developed in the Kent estuary to the west of the causeway across to Holme island. The marsh was a narrow zone and Spartina was in isolated clumps until 1982. (This patch is not shown on the map as revision of this has not been possible).

Discontinuous patches of Spartina

All other marsh areas shown on Figure 7.1 have Spartina growth which is not at present continuous. In most cases the grass is growing in association with salt marshes. The clumps are generally increasing in size and spreading mainly in the lower zones of the marshes - at the seaward edge and in the channels and pans. There is, however, a noteworthy spread, across some established marshes - for example at Humphrey Head, Hest Bank near Red Bank Farm and along the south coast between Fluke Hall and Knott End jetty. At present, however, this spread is slow as much of the marsh areas have a continuous cover of other plants.

Other clumps also occur in isolated patches - sparse and scattered, not associated with the salt marshes and often a considerable distance from them. The grass in these is usually dwarfed and the growth of clumps even slower than those associated with marshes. Off the coast between Bank End Farm and Fluke Hall and on the seaward side of Hatlex Beck near the southern end of the Hest Bank marsh, these clumps are established on medium/coarse sand. Other discontinuous growth can be found on shingle in areas scattered around the Bay. The Spartina in these is usually sparse with considerable distance between clumps; it is characterised by a particularly slow spread. Examples occur along the Furness coast at Bardsea (near a sewage outfall - a nutrient enrichment factor?) and the Newbarns embayment in the Kent estuary below Arnside Knott.

Near Kent's Bank station and along the shore from there towards Humphry Head are scattered clumps up to 1.5 metres in diameter. Spartina here is the pioneer plant and is growing vigorously. It has made its appearance since 1982 and its potential spread is of concern to residents. (See Chapter 4 for discussion of channel changes in the Kent Estuary, which have led to accretion here.)

Conclusions

Spartina growth in Morecambe Bay has undoubtedly become increase-ingly significant during the last twenty years. It has filled an ecological niche in the lower zones of salt marsh areas and has become a major pioneer species in their development. It effectively holds sediment and is building up marshes in a number of areas. Spartina-colonised sections of the south Hest Bank marsh withstood erosion during the winter of 1981-82 when other sections were lost. The potential range for further spread is considerable on inter-tidal flats.

The changes which might result from this have been and are the object of some concern. Encroachment of the inter-tidal flats could perhaps affect the feeding grounds of the over-wintering wading birds which annually visit the Bay. Spread along the coast to resorts such as Morecambe, Arnside or Grange-over-Sands could change coastal environments of beaches at present used for recreation by holiday-makers and residents. In the summer of 1982 clumps of the grass on shingle along the shore at Morecambe were sprayed with a herbicide and this appears to have been effective in killing them. This is, however, expensive and may not be an appropriate solution to the restriction of development in other areas. Farmers in the Glasson area are concerned about the spread of Spartina into existing marshes as it reduces the area of palatable grasses available for sheep grazing.

It seems essential, therefore, to monitor the growth and spread of Spartina in as many sites around the Bay as possible. Research undertaken into the relationship between the grass and nitrogen in the soils in the Cockerham Sands area could yield valuable evidence as to its potential spread. If this monitoring could be linked with studies of the movement of channels in the Bay it might be possible to make some assessment as to which areas might be colonised - and perhaps which marshes might be eroded.

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Chapter 8

INVERTEBRATES OF THE INTERTIDAL ZONE

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Introduction

In 1902, the Honorary Director of the Scientific Work at the Lancashire Sea Fisheries Laboratory, Professor W. A. Herdman, wrote in his annual report, "I assume that what we stand most in need of at present is full and accurate statistics in regard to our fisheries, and much more detailed information than we have as to the distribution round the coast both of fishes in all stages of growth, and also of the lower animals with which they are associated". Professor Herdman was making then a case for a scientific research vessel which would carry out a routine sampling programme to assess the distribution of fish, plankton and benthic food invertebrates. At that time a research vessel would have cost £6,000 -£8,000 with an annual recurrent cost of £2,000. Over eighty years later, quantitative studies on sub-littoral benthic invertebrates remain virtually non-existent in the Bay, and the capital and recurrent costs of such survey work have become prohibitive for those scientific institutions suitably placed to undertake it.

Since Professor Herdman's time there has been some improvement in the monitoring of fish stocks but, despite the proximity of the Universities of Lancaster, Liverpool, Manchester and Salford, information on the invertebrate population of the intertidal zone of Morecambe Bay is still extremely limited. The close association between the marine laboratory at Port Erin and the Lancashire and Western Sea Fisheries (LWSF, in 1986 renamed the North Western and North Wales Sea Fisheries Committee) has led to a concern largely with work on commercial fisheries and water quality investigations.

No comprehensive species list exists although there are some reliable but unpublished observations and collections available which would contribute to one (see Appendix 8.1). Although the immediate pressures for the use of the Bay in water supply and storage have passed, these schemes and the advent of the nuclear power station and its associated warm water discharges, growing concern with radionuclide contamination and proposals for developments of a recreational nature which may be encouraged to come to the area, underline the need for such a list and also for a baseline of invertebrate population data against which the environmental impact of these activities may be assessed. The commercial importance of flatfish and the growing importance of the wading bird populations in academic study of bird migration patterns emphasise the need to have as full a knowledge as possible of all levels in the food chain.

The intertidal zone, like the sub-littoral, has also become expensive to study because of the time and labour required for continuing surveys. Further deterrents to research into invertebrate population dynamics in Morecambe Bay are the exhausting physical conditions and the extreme instability of any area chosen for investigation. Over 310 km^2 of sand banks and mud flats are constantly changing and extremes of erosion and deposition are common. The presence in the January strandline of both Macoma and Mytilus in viable condition is testimony to the extent of storm disturbance. The impact of winter storms might be predicted from the alignment of the mouth of the Bay facing west and south-west with prevailing winds blowing over a fetch of 225 km. Waves with a breaker height of 2m and a period of 8.6 seconds are recorded at the southern end of Walney and ebb and flood tidal currents as high as 5 ms^{-1} on springs are noted. It has been calculated that the 12,000 tonnes of seed mussels which may be present in late summer on 100 ha of the skear known as 'South America' is usually totally destroyed by autumn and winter storms.

The introduction, or proposed introduction, of new environmental pressures have been stimuli, and a source of funds for more recent work. Until 1968 there existed only the studies of Drinnan (1957) on the distribution and numbers of cockles, Fincham (1969) on shallow water amphipods, and Dare (1970) on cockle distribution. In 1968, Corlett, Anderson, Jeffers and Prater (Corlett, 1970) began a major systematic survey of the invertebrate fauna as part of the feasibility studies associated with the Morecambe Bay Barrage schemes. Clare (1983) examined seasonal variation in population density, settlement patterns and growth rates in the area of heated water discharge from the Heysham Nuclear Power station. The material of this review draws heavily on these more recent studies.

Environmental Factors

The environmental factor which exerts the major influence on the number and type of benthic invertebrate species is the substrate particle size. This in turn influences other factors which affect benthic invertebrates. The most important of these are the water content, which alters the thixotropic or dilatant properties of the substrate and its ease of penetration by burrowing species; the organic carbon and nitrogen content which indicate nutrient availability; and oxygen. Locally, salinity variations are considerable with large freshwater inflows from the Leven, Kent, Wyre and Lune estuaries. On Knott End skear at just before low tide salinity is reduced to around $23^o/_{oo}$ on spring tides.

The studies of Anderson (1972) sampling a 1km x 0.5km grid on 287 sites record a mean particle diameter of the bay sediments ranging from 20µm - 210µm with the finer sediments found in coastal inlets, in sheltered shallow water areas and at the tops of shores. Deposits become increasingly coarse lower down the shore with areas of vigorous currents disrupting these patterns locally and associated with coarser sediments. The predominant sediment types are very fine with silt contents (<62.5µm) of up to 66% at Rampside, Bardsea and the Leven estuary. In the upper Bay generally up to 30% of the sediment is <62.5µm.

In addition to these vast areas of mud and sand there are 400 hectares of 'skear', mainly found off Heysham and S.E. Walney Island. These consist of low lying cobble stones formed by coastal erosion of glacially formed drumlins which provide firmer anchorage and cover for species characteristic of rocky shores. Across the entrance to the Bay is a large deposit of gravel and sand which provides a suitable substratum for numerous colonies of hydroids, particularly Sertulariidae, which play an important role in the early settlement of Mytilus edulis.

The Fauna of Particulate Substrates

Generally the invertebrate fauna is characterised by a low variety of regularly occurring species although a considerable variety is recorded in exceptional years.

Neresis diversicolor

This species is present widely but at relatively low densities. The pattern of distribution is of disappearance at the seaward end of estuaries, increasing in middle regions and at upper levels where the salinity is lowered and the proportion of mud increases. The high salinity of the intertidal areas may partly explain its low numbers but the absence of mud is probably a more important factor. Anderson quotes a range of 25 - 300/m² over most of her surveyed areas but biomass would give a better indication of the level of biological production than numbers alone. The maximum densities were found in the Kent estuary, the Grange flats and a small area off Humphrey Head with the highest recorded density of 750/m². This can be compared with 3000/m² found in the Tamar Estuary (Spooner and Moore, 1940), 1212/m² in the Towy (Howells, 1964), and 5674/m² in the Humber (Jones and Ratcliffe, 1979). Each of these estuaries is considerably muddier than the Bay. In a survey of the feeding of flatfish within the bay, Hayward (1970) found that although nereids were in the gut of fish taken from most areas they were most abundant in fish taken from deeper waters.

Nephthys species

The species N.hombergi, N. longosetosa, N.caeca and N.cirrosa, are all rcorded but only the first two reach any considerable density. Anderson found N.hombergi not to be widely distributed with numbers ranging from 25-100/m². More recent work in the area around the outfall from the nuclear power station south of Heysham Harbour shows densities as high as 300/m² with peak numbers occurring in July; north of the harbour peak numbers are reached in September. N.longosetosa has been recorded in densities up to 450/m² with peaks in July (Clare, 1981).

Arenicola marina

This species occurs from 0.9m - 3.7m O.D. The highest densities recorded by Anderson were 20-100/m² between 1.8 - 3.7m O.D. Below 1.8m, and correlating with the disappearance of siltier substrate fractions, densities dropped to 1-20/m². Longbottom (1970) records the absence of this species in mud $<$80μm and Arenicola is scarce in the Bay where the mean particle diameter is less than 75μm and scarce on the lower shore when particle size is greater than 120μm. It is likely, as with Nephthys, that where local conditions are more favourable, these numbers will be exceeded. Clare (1983) has found that maximum cast numbers (2-12/m²) appear in June on his site south of Heysham harbour, with minimum numbers in December; here the mean particle diameter is 120μm. These are however large specimens and the maximum biomass recorded in 1979 was approximately 70 g/m².

During September 1971 a significant number of dead lugworms were reported on Flookborough Sands, and in areas between Hest Bank and Liverpool associated with a bloom of the dinoflagellate Gyrodinium aureolum (Helm et al., 1974). Lugworm deaths were also reported in October 1975 at Heysham, Walney Island and along the Lancashire coast, by Lancashire and Western Sea Fisheries.

Corophium volutator

This amphipod is of spasmodic occurrence below MHWNT but is one of the dominant invertebrates from MHWNT to above MHWST. Anderson found a zone of maximum density at 3.7 m O.D. and the association with silty substrates which characterises its distribution was confirmed with highest densities occurring on the high level flats where the silt content ranged from 30-66%. The maximum density recorded by Anderson was $8700/m^2$, relatively low compared with figures of $24000/m^2$ in the Dee estuary (Longbottom, 1970), $11000/m^2$ in the Tamar (Spooner and Moore, 1940), $17136/m^2$ in the Towy (Howells, 1964), and $2077/m^2$ in the Humber (Jones and Ratcliffe, 1979). However, in true muds, such as are found at high level on Roosecote sands, numbers as high as $12000/m^2$ have been found (Adams, 1980). Prater (1970), records the size distribution of Corophium in late winter as large, from 2.5-8.5 mm with 68.2% of the individuals between 5-6 mm length. Of these over 56% were to be found in the top 4 cm, 31.2% between 4 and 6 cm and 12.4% between 6 and 10 cm.

Crangon crangon

A thriving shrimp fishing industry has existed in the Bay for centuries. Peak landings of 610-660 tonnes p.a. have been recorded since 1945 in the Lancashire and Western Sea Fisheries District, and 85% of these landings have been taken from the shrimping grounds of Morecambe Bay and the Fylde Coast (Driver, 1976). In the period from 1967 landings fell to 300 tonnes p.a. and as a result a study of the fishery was made in 1973 and 1974 jointly by LWSF Joint Committee and Ministry of Agriculture Fisheries and Food. It was found that the decline paralleled that experienced in the same period in other European fisheries. Landings of shrimps were compared with variations in temperature, salinity and predators and an expression of use in forecasting of catches was obtained relating landings in one year to the total rainfall, average air temperature and landings of shrimps and flatfish in the previous year. In 1979 the equation

$$S_2 = 14206 - 1270t + 3.165r + 0.479\ S_1$$

where

S_1 = shrimp catch in year 1 (cwt)

S_2 = shrimp catch in year 2 (cwt)
t = average air temperature in year 1(°c) } at Morecambe
r = total rainfall in year 1 (mm) }

predicted a landing of 8711 cwt (443 tonnes). In actual fact landings were 8184 cwt (416 tonnes) (LWSF Joint Committee 1979). It has been claimed that the action of predators, (cod, plaice, dab, flounder and sole) is of little or no importance in controlling shrimp landings, but in 1981 the error of the formula was 26% and this was associated with a good year class of cod in 1979. It was suggested by Driver that the primary control is the level of the previous years' stock and in the period 1967-74 the downward trend in landings was preceded by a rise in average temperature and a fall in average rainfall. However since 1979 the formula has proved increasingly inaccurate and is clearly over-simplified. Factors such as wind, which reduces the amount of fishing done, and on-land economic factors such as the availability of shrimp pickers, often influence landings significantly.

In the summer of 1973 the LWSFJC began a study of the migration behaviour of shrimps and also of their predation. Their report indicated the need for long term sampling to elucidate breeding and migratory behaviour but the work has not been completed. During September 1971 a decline in brown shrimp catches was attributed to a bloom of the dinoflagellate Gyrodinium.

Hydrobia ulvae

The distribution of Hydrobia follows that of Corphium fairly closely, although its seaward limit and zone of maximum abundance occur at slightly lower shore levels. Anderson recorded a maximum density of $5525/m^2$ which is normal for the species although densities of $30000-60000/m^2$ have been recorded (Thamdrup 1935). The sampling method of Anderson was not designed to assess accurately this small species and Prater (1970) records that in November and in February 79% and 88% respectively were under 1 mm, and none of these would have been retained by the sieves used in the Anderson surveys. Waders probably take very few Hydrobia of this small size.

Cerastoderma edule

The most favourable situations for the settlement of cockle spat in Britain are the large sandy estuaries such as those of the Thames, Burry Inlet, Wash and Morecambe Bay. Sea temperature, salinity, tidal level, exposure to wave action, food supply, density and time of settlement are all of influence in the growth of cockles. Characteristically, where winter temperatures are relatively low, the growth rings of Morecambe Bay cockles are usually very clear but disturbance of the animals, even if only of short duration, produces disturbance rings which are a reflection of checks to growth. Morecambe Bay cockles are intermediate in size between the large specimens found from Barra (>50mm) and those from the Burry Inlet (<30mm). When densities are high (and the Bay populations have never recovered from the severe winter of 1962-3 when most were eliminated), cockles are washed out into heaps as drainage channels change course. The exposure of the beds will certainly affect growth adversely. From a survey by Cole (1955) in January 1954 the sizes at the formation of the first, second and third winter rings were 8.0mm, 21.0mm and 24.4mm. The comparable measurements for Barra specimens were 15.1mm, 24.5mm, and 29.0mm. Specimens showing more than four rings are very scarce and none has been found with more than six rings. Since continued growth is likely to be related to competition for food it would be of interest to see whether the newly establishing stocks on Cartmel Wharf have the same life expectancy. Over-fishing and oyster catcher predation (average number on the bay 38000, with as many as 140 cockles found in the crop of one shot bird) were also implicated in the decline of cockle populations (Crisp 1964).

In 1933-37, Orton (1933 and 1937) recorded cockle spat below 5mm in length at a density exceeding 100000/m^2 on Cark Sands in July. Spawning began in April and young spat was usually plentiful in the beds towards the end of June. Orton also referred to the very high mortality of spat on the Dee and Cark beds which he suggested might be due to parasites, overcrowding or pollution. The heaviest spatfalls were where tidal streams met and where banks provided shelter at about mid-tide level. The spatfalls were contemporaneous with considerable deposits of fine sand and some detritus and the larvae of Polydora, Macoma and other bivalves and worms. Cole suggested that spatfalls in the Burry Inlet were frequently high but experience in the Bay since 1962-3 suggests that they are spasmodic. In 1968 spatfall was recorded by Anderson in densities not greater than 100/m^2 between 0.9m and 2.7m O.D. but mention is made of much larger numbers of 'very small' individuals in the Kent Estuary south of Grange and the sampling methods used would not have given accurate counts of small spat.

Macoma balthica

This was found by Anderson to be the most widespread species in the bay occurring at 95% of her sampling sites. It occurs from just below O.D. up to MHWST with maximum density between 1.8m and 2.7m O.D. Over 56000/m^2, mainly spat, were found in the Kent Estuary south of Grange but a figure of 2000-4000/m^2 was more typical. Maximum abundance was found in sediments of median particle diameter of around 80μm, with a silt content of approximately 30%. These figures compare with less than 1000/m^2 normally found in the Solway by Perkins and Williams (1966). An analysis of the size distribution of the Cartmel Wharf and Kent Estuary populations showed that 48.6% were under 6mm and only three exceeded 19mm. There was a steady increase in size from 0.0m O.D. to 4.6m O.D. Spawning and settlement periods were not clarified by Anderson but recently Clare has observed settlement in July on a site adjacent to the power station outfall as high as 3200/m^2. Within 2 months numbers had fallen to 1200/m^2 and in 4 months to less than 400/m^2. Previously settlement has been recorded in April in the Thames estuary (Caddy, 1966) and in June in Scotland (Stephen 1931). About 90% of Macoma are within a depth (4cm) accessible to knot, dunlin and redshank.

Scrobicularia plana

This species was known in the northern part of the Bay in fairly large numbers before 1963 but it has not recovered from the extremely severe winter of 1962-3. Hughes (1970) has shown that its presence is characterised by the dominance of a particular year class and depends on spasmodic good spat years. At this latitude it will not compete well with Macoma.

Tellina tenuis

This species is restricted to lower levels in the shore with a preference for sediments with a median particle diameter greater than 90μm. It occurs at low densities with a mean of 50/m^2.

The distribution of the twelve most abundant invertebrate species in relation to a shore level is shown in Figure 8.1 which is taken from Anderson (1972).

The Fauna of the Skears

Mytilus edulis

A paradoxical feature of the ecology of this species in Great Britain is that the conditions which are favourable for both settlement and growth

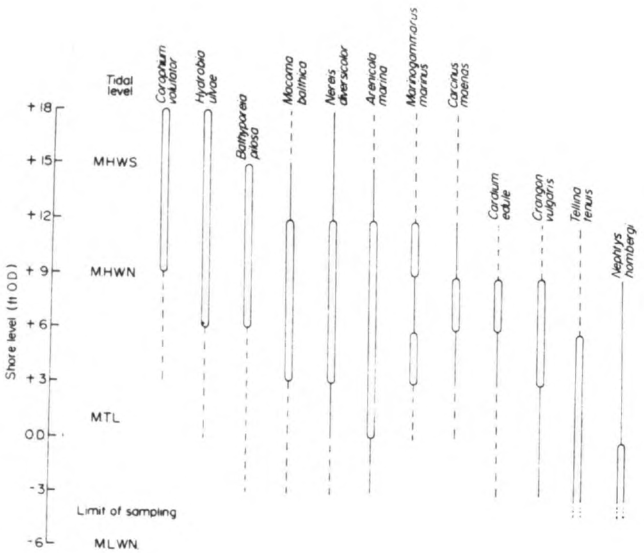

Figure 8.1: Distribution of the twelve most abundant invertebrate species surveyed in Morecambe Bay in relation to shore level. Open bars indicate densities greater than the mean; ___, densities greater than half the mean; ----, present.

and survival rarely coincide. Morecambe Bay is exceptional for the size and regularity of its intertidal settlements of Mytilus with spat occurring in abundance throughout the year. In part because of the very heavy spatfalls and also because of a natural cycle of physical events on the mussel beds, growth and survival after spatfall is restricted. It has been calculated by Dare (1976) that if only one-third of the annual seed production on the largest mussel ground in the Bay could be utilised by cropping and transplanting in late summer to areas where growth potential is good, then the production of the British mussel industry could be doubled. It is as a reliable source of seed for restocking heavily-fished natural beds and for transplanting to good growing grounds which are rarely areas of adequate spatfall that Morecambe Bay is of commercial importance.

From the studies of Dare, Daniel (1921), Scott and Baxter (1905) and Johnstone (1898) it is clear that spawning takes place throughout the year with settlement on the main mussel beds of 'South America' at Roosebeck and Knott End skear at Heysham occurring from December through to April. But the main spawning is from April to July and it is unlikely that late autumn or winter spawning contributes significantly to the high settlements on the intertidal skears from December to April. The anomaly is explained by evidence that there is an over-wintering of the early plantigrades on filamentous algae and hydroid colonies in deeper waters. Hydroids are plentiful on gravels across the entrance to the Bay (Fraser, 1935) whilst Heysham Lake has dense beds of Sertularia just 5km from the Heysham Skears (Haddock et al., 1956). The hydrography of the Bay influences the timing of settlement of these overwintering plantigrades which is completed at Roosebeck before large numbers reach Knott End Skear which is more subject to lower temperatures and reduced salinities.

The major spring spawnings are presumed to settle elsewhere than Roosebeck or Knott End skears in deeper waters or to suffer mortality when attempting to attach on older intertidally settlements.

Winter and spring settlements of 1-2mm spat at densities as high as 100000-200000/m^2 develop by June into crowded beds of fast growing but loosely attached mussels. Up to 12000 tonnes of seed mussels may be present on 100 ha of South America Skear. At MLWST lifespan is usually less than 3 years, a very low survival when compared with the potential of Mytilus at high shore levels on the Yorkshire coast where they may live for 17-20 years. The causes of mortality are a combination of biological and physical factors with predators such as Carcinus maenas, Platichthys flesus, Platichthys platessa and Limanda limanda taking a regular toll. Swarms of Asterias can have catastrophic effects; in 1969 at Roosebeck a massive 1.5km x 15m swarm (over 2.25 ha) at a density of $340/m^2$ cleared 35 acres in the 3 months of summer (Driver 1977). Other predators include knot which feeds extensively on plantigrades, the herring gull, oystercatcher and eider duck. The maximum biomass estimate (kg dry flesh/m^2) for Knott End was found by Dare to be 1.15-1.37, and for 'South America' to be 0.10-1.06. These figures are far greater than anything so far recorded for other lamellibranchs.

By early September the mussels may be raised up off the stones by up to 0.75m of mud and faeces and are very unstable. The density has fallen to about $15000/m^2$. At this stage the beds are susceptible to tidal scour which effects a considerable thinning out of the population. Winter storms then complete the process and in 1968 an estimated 3000 tonnes of inch long seed mussels were lost from one mussel bed during autumn storms. This destruction by storms of the beds in autumn is almost an annual event.

Mytilicola intestinalis

It is possible that the annual storm destruction of the mussel stock prevents the build up of infestation by its parasite Mytilicola. The control of the spread of this parasite becomes of major economic importance if the Morecambe Bay mussels are to be extensively used in transplanting to restock commercial fisheries. A centre of infestation has been known since 1951 to be centred on Barrow-in-Furness. Surveys by LWSFJC (1979) have shown that since then its range has extended and it is now present in small numbers on the beds at Roosebeck. No trace was found at Heysham. The parasite which is not fully host specific and can develop in the digestive tract of Ostrea, Cerastoderma and Crepidula, causes loss of condition and a fall in growth rate. For its spread it needs an uninterrupted bed of mussels but it is possible that the spread into the Bay from Barrow could be assisted by transport on ship's hulls launched there and by bait mussels used in fishing. The male and female need to infect the same host for reproduction to occur and because the individual life span is only 9-10 months with a small number of eggs produced, spread of infection is normally very slow.

Appendix 8.1 indicates the variety of species which occurs on the skears. Systematic observations of populations on these areas are unpublished, but those made on the Heysham area show a variability of occurrence and of abundance of species. In particular the severe winter of 1962-3 resulted in reductions of fauna similar to those recorded elsewhere around the British coasts at that time. The sponges Halichondria panacea and Cliona celata which were common prior to 1962-3 have shown different recovery rates with Cliona returning in 1968 whilst Halichondria has since exhibited only small and patchy colonies. Actinia equina has been rare since 1963 and Tealia felina has also decreased in numbers. Heavy mussel settlement will reduce the habitats available for other species and the odd incidence of an exceptional number of normally occasional species, such as the swarms of Asterias rubens in 1957 and 1978, will have their explanation in factors away from the skears themselves.

Both the skears and the sand and mud flats present difficult environments for long term studies of invertebrate population dynamics. The physical factors in the Bay result in both habitats being extremely unstable in the long-term and makes field study of the impact of pollutants or changing use difficult as the essential instability of the substratum is the dominant environmental factor in the vast area of Morecambe Bay.

Appendix 8.1

INVERTEBRATE SPECIES LIST

The following data are based on surveys conducted from the dates indicated under the supervision of J. Clare and D. Jones.

Key to sites

A	Roa Island 1968	Skears
B	Heysham flat and Knott End Skears 1954	Skears
C	Bare Ayre Skear 1968	Skears
D	Skears adjacent to Knott End 1975	Skears
E	Heysham Lake: Wyre Light to Heysham No.2 1975	Trawls
F	Wyre channel 1975	Trawls
G	Bare sands 1968	Sand and Mud
H	Heysham sands 1978	Sand and Mud
J	Middleton sands 1978	Sand and Mud
K	Wyre Estuary 1975	Sand and Mud
L	Stone Jetty, Morecambe 1968	Rock
M	Throbshaw Point and Near Naze 1970	Rock
N	Red Nab 1974	Rock

	A	B	C	D	E	F	G	H	J	K	L	M	N
PORIFERA													
Sycon coronatum	X	X											
Grantia compressa	X												
Suberites domuncula	X												
Cliona celata	X	X											
Hymeniacidon perleve	X	X											
Haliclona oculata	X				X								
Ophlitaspongia seriata	X												
Halichondria panicea	X	X			X								
COELENTERATA													
Corymorpha nutans		X											
Tubularia indivisia	X	X			X								
Tubularia larynx		X			X								
Sarsia tubulosa		X	X										
Clava multicornis		X											
Clava squamata	X	X											
Hydractinia echinata	X	X			X								
Bougainvillia ramosa		X											
Garveia nutans		X											
Dicoryne conferta	X	X											
Endendrium ramosum	X				X								
Campanularia flexuosa	X	X		X							X		
Campanularia gelatinosa		X	X	X		X					X	X	
Clytia johnstoni		X											
Obelia dichotoma	X	X	X	X								X	X
Obelia geniculata	X												
Gonothyraea loveni		X											
Opercularella lacerata		X											
Halecium halecinum		X			X								
Dynamena pumila	X	X									X		
Hydrallmania falcata	X			X									
Sertularia argentea		X			X								
Sertularia operculata		X			X								
Steenstrupia nutans		X											
Lizzia blondina		X											
Chrysaora isoesceles		X											
Aureleia aurita		X											
Rhizostoma octopus	X				X								

COELENTERATA (cont.)	A	B	C	D	E	F	G	H	J	K	L	M	N
Alcyonium digitatum	X	X			X								
Telia felina	X	X			X	X							
Diadumene cincta		X											
Metridium senile var. dianthus	X	X	X			X					X		
var. pallidum		X	X										
Sagartia elegans var. nivea		X											
var. rosea	X	X											
var. minitia	X	X	X										
var. aurantiaca		X											
Sagartia troglodytes													
var. ornata	X	X	X										
var. decorata		X											
Cerus pedunculatus	X												
Actinothoë sphyrodeta		X											
CTENOPHORA													
Pleurobrachia pileus	X	X	X	X	X	X						X	X
PLATYHELMINTHES													
Leptoplana tremellaris	X	X	X	X	X							X	
NEMERTINI													
Cephalothrix linearis		X											
Lineus longissimus	X												
Lineus ruber	X	X	X										
Emplectonema gracile		X											
Emplectonema neesi		X											
Amphiporus lactifloreus		X	X										
ANNELIDA													
Aphrodite aculeata					X								
Lepidonotus squamatus	X	X			X								
Lagisea extenuata	X	X											
Phyllodoce maculata	X	X	X	X				X	X				
Nereis pelagica		X											
Nereis irrorata								X					
Nereis diversicolor	X	X	X	X			X	X	X	X			
Nereis longissima		X	X						X				
Nereis virens		X	X										
Nephthys caeca								X	X				
Nephthys hombergi							X	X	X	X			

ANNELIDA (cont.)	A	B	C	D	E	F	G	H	J	K	L	M	N
Nephthys longosetosa								X	X				
Nephthys cirrosa								X	X				
Glycera convoluta							X	X	X	X			
Scolecolepius fuliginosa		X											
Nerine cirratulus							X	X		X			
Spiophanes bombyx		X											
Pygospio elegans	X	X	X	X			X	X	X	X		X	
Polydora caeca	X	X	X	X								X	X
Notomastus latericius		X											
Capitella capitata		X											
Arenicola marina	X	X	X	X			X	X	X	X			
Sabellaria spinulosa	X	X											
Pectinaria koreni	X				X			X					
Amphitrite gracilis	X	X											
Lanice conchilega	X	X	X	X								X	X
Sabella pavonina	X	X			X								
Dasychone bombyx	X	X											
Hydroides norvegica	X												
Pomatoceros triqueter	X	X	X	X	X	X						X	X
Filograna implexa	X												
Spirorbis pagenstecheri	X												
Spirorbis borealis	X												
CRUSTACEA													
Verruca stroemia	X												
Chthamalus stellatus	X												
Balanus balanus	X	X			X								
Balanus crenatus	X	X	X	X	X	X					X	X	X
Balanus balanoides	X	X	X	X		X					X	X	X
Balanus hameri		X											
Elminius modestus	X	X	X	X		X					X	X	X
Sacculina carcini		X			X		X	X	X	X			
Depranorchis neglecta					X								
Eurydice pulchra								X				X	
Sphaeroma serratum		X								X			
Idotea baltica	X	X											
Idotea neglecta	X												
Idotea linearis		X				X							
Janira maculosa	X												
Jaera albifrons	X	X	X	X								X	X

CRUSTACEA (cont.)	A	B	C	D	E	F	G	H	J	K	L	M	N
Ligia oceania	X	X	X	X							X	X	X
Bathyporeia pelagica								X	X				
Calliopus laeviusculus		X											
Melita palmata	X	X											
Melita obtusata	X	X	X	X								X	X
Gammarus locusta	X	X	X	X							X	X	X
Talitrus saltator	X											X	X
Orchestia gammarella	X												
Amphithoe littorina	X	X											
Caprella linearis	X	X			X								
Praunus flexuosus	X	X			X								
Pandalus montagui	X	X			X								
Hippolyte varians	X	X			X								
Hippolyte inermis	X	X											
Spirontocaris cranchii		X											
Athanas nitescens		X			X								
Leander serratus	X	X			X								
Leander elegans	X	X		X	X	X						X	X
Crangon vulgaris	X	X	X	X	X	X	X	X	X	X		X	X
Homarus vulgaris	X												
Galathea dispersa	X												
Galathea squamifera	X												
Porcellana platycheles	X												
Porcellana longicornis	X	X			X								
Eupagurus bernhardus	X	X			X								
Eupagurus prideauxi	X												
Eupagurus cuanensis	X												
Macropipus puber	X				X								
Macropipus holsatus					X								
Macropipus depurator	X	X			X	X							
Carcinus maenas	X	X	X	X	X	X					X	X	X
Cancer pagurus	X	X			X								
Pilumnus hirtellus	X	X											
Pinnotheres pisum	X	X											
Hyas araneus	X	X			X								
Inachus dorsettensis	X	X			X								
Macropodia longirostris	X	X			X								
Macropodia rostrata	X	X											

CRUSTACEA (cont.)	A	B	C	D	E	F	G	H	J	K	L	M	N
Nymphon brevirostre		X			X								
Phoxoclidium tubulariae		X											
Pycnogonum littorale	X	X									X		
Lipura maritima			X										
MOLLUSCA													
Lepidopleurus asellus	X	X	X	X								X	
Acanthochitona crinitus	X												
Patella vulgata	X	X										X	X
Gibbula cineraria	X												
Gibbula umbilicalis	X												
Littorina littorea	X	X	X	X							X	X	X
Littorina saxatilis	X	X	X	X							X	X	X
Littorina neritoides	X		X									X	
Littorina littoralis	X											X	X
Hydrobia ulvae	X	X	X	X								X	X
Lammelaria perspicua	X												
Nucella lapillus	X	X										X	
Buccinum undatum	X	X			X	X							
Haminoea hydatis	X												
Berthella plumula	X												
Tritonia hombergi					X								
Dendronotus frondosus	X	X			X								
Doto coronata		X											
Goniodoris custanea	X												
Ancula cristata		X											
Acanthodoris pilosa		X			X								
Onchidoris bilamellata	X	X	X			X					X		
Onchidoris muricata	X	X				X							
Onchidoris depressa	X												
Palio dubia		X											
Cadlina laevis	X												
Archidoris pseudoargus	X												
Coryphella verrucosa	X	X			X								
Facelina auriculata													
var. coronata	X	X											
var. curta	X	X			X								
Aeolida papillosa	X	X											
Eubranchus pallidus		X											

	A	B	C	D	E	F	G	H	J	K	L	M	N
MOLLUSCA (cont.)													
Cuthona nana		X											
Tergipes tergipes		X	X	X									
Modiolus modiolus	X												
Mytilus edulis	X	X	X	X		X					X	X	X
Ostrea edulis	X												
Anomia ephippium	X												
Chlamys varia					X								
Chlamys opercularis		X											
Cerastoderma edule							X	X	X	X			
Scrobicularia plana			X	X			X		X	X			
Macoma balthica		X	X	X			X	X	X	X			
Tellina fabula								X	X				
Tellina tenuis								X	X				
Mya truncata	X												
Mya arenaria		X					X		X				
Pholas dactylus	X	X	X										
Sepiola atlantica					X								
Alloteuthis subulata					X								
Moschites cirrosa		X											
BRYOZOA													
Membranipora membranacea	X	X	X	X	X	X						X	
Flustra foliacea					X								
ECHINODERMATA													
Stichastrella rosea					X								
Asterias rubens	X	X			X	X						X	
Ophiothrix fragalis	X	X			X								
Amphipholis squamata	X												
Psammechinus miliaris	X												
Echinus esculentus	X												

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Chapter 9

BIRDS

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This account of the birds of Morecambe Bay is divided into the following sections:

- Waders
- Wildfowl
- Gulls and terns
- Seabirds other than gulls and terns
- Passerines and other groups

Records of rare species and occasional visitors not mentioned in the text are to be found in the Lancashire and Cumbria Bird Reports. The sectors of the Bay referred to in the sections on Waders and Wildfowl are shown in Figure 9.3.

WADERS

Introduction

Morecambe Bay is the most important estuary for wading birds in Britain and the third most important estuary in Europe (Prater, 1976). It is important as a wintering area, as a passage area during spring and autumn for arctic breeding species which winter further south, and as a moulting area in late summer (Wilson, 1973). Peak counts for all species using the Bay totalled an average of c. 244,000 birds in the period 1969-75 (Prater, 1977). Four species breed in relatively small numbers and the Bay also serves as a summering area for small numbers of immature birds. The species for which Morecambe Bay is of international importance are given in Table 9.1.

Systematic work on the wader populations started in July 1967 and continued until May 1975 during which period monthly counts were made of the whole Bay and fortnightly counts of the east side from the Kent to the Lune. After May 1975 only mid-winter counts have been undertaken for the whole Bay but counts every month have continued on the R.S.P.B. reserve and also at South Walney. Studies of the food and feeding ecology of the most important species have been carried out by Prater (1970) and Davidson and Mercer (1971) while the relationship between the roosting and feeding areas has been studied by Prater and Wilson (1970). Ringing of waders has been carried out regularly since 1967 by the Morecambe Bay Wader Ringing Group.

Roosting and Feeding Areas (Figure 9.1)

Counts of the total wader populations can only be made successfully when the birds are roosting on spring tides. The low water feeding areas of each roost can be located by plotting flight lines to and from the roost and also by locating sub-roosts. Maps for each species and area of the Bay have been produced by Prater and Wilson, and these show the relationship between the spring tide roosts and the low water feeding areas. Although some overlap between roosts does occur along with seasonal variations the feeding area of each roost has been found to be remarkably constant and thus the number of birds counted at high water springs is a relatively accurate estimation of the numbers feeding in any area.

Under nearly all circumstances waders roost as near as possible to their feeding grounds. This results in a succession of roosts being used related to the tidal height. Sand banks used as roosts on neap tides are also used as sub-roosts on higher tides and so waders quickly change their roost site with the tidal cycle so assisting in maximum exploitation of each area and also conserving energy in a period when little or no feeding occurs. This roosting cycle results in a succession of habitats being used over a tidal cycle. Sand banks are used on neap and low spring tides, shingle beaches and salt marsh on moderate spring tides, and fields on the extreme spring tides.

Human disturbance is the one major factor which drives waders to roost some distance from the feeding grounds. Disturbance in the Bay is mainly caused by human leisure activities ranging from dog walkers

Table 9.1

WILDFOWL AND WADERS FOR WHICH MORECAMBE BAY IS OF INTERNATIONAL IMPORTANCE 1969-1975

Species	Highest Average monthly count	% West European Population	Months above 1% of W. European Pop. *	Rank of importance in British Estuaries
Pinkfeet	3,000 +	4.0	2 3	9
Shelduck	5,600	4.3	10 11 12 1 2 3	2
Wigeon	4,125	1.0	1	9
Pintail	555	1.1	11	10
Oystercatcher	44,710	8.0	7 8 9 10 11 12 1 2 3 4 5	1
Ringed Plover	7,280	14.5	7 8 9 10 3 4 5	1
Knot	80,206	16.0	8 9 10 11 12 1 2 3 4	1
Sanderling	11,857	23.7	7 8 9 4 5	1
Dunlin	48,722	4.1	7 8 9 10 11 12 1 2 3 4 5	1
Bar Tail	8,076	9.1	7 8 9 10 11 12 1 2 3	1
Curlew	16,065	8.0	7 8 9 10 11 12 1 2 3 4	1
Redshank	12,420	9.9	7 8 9 10 11 12 1 2 3 4	1

* Underlined: month with highest counts.

After Prater, A.J., 1981.

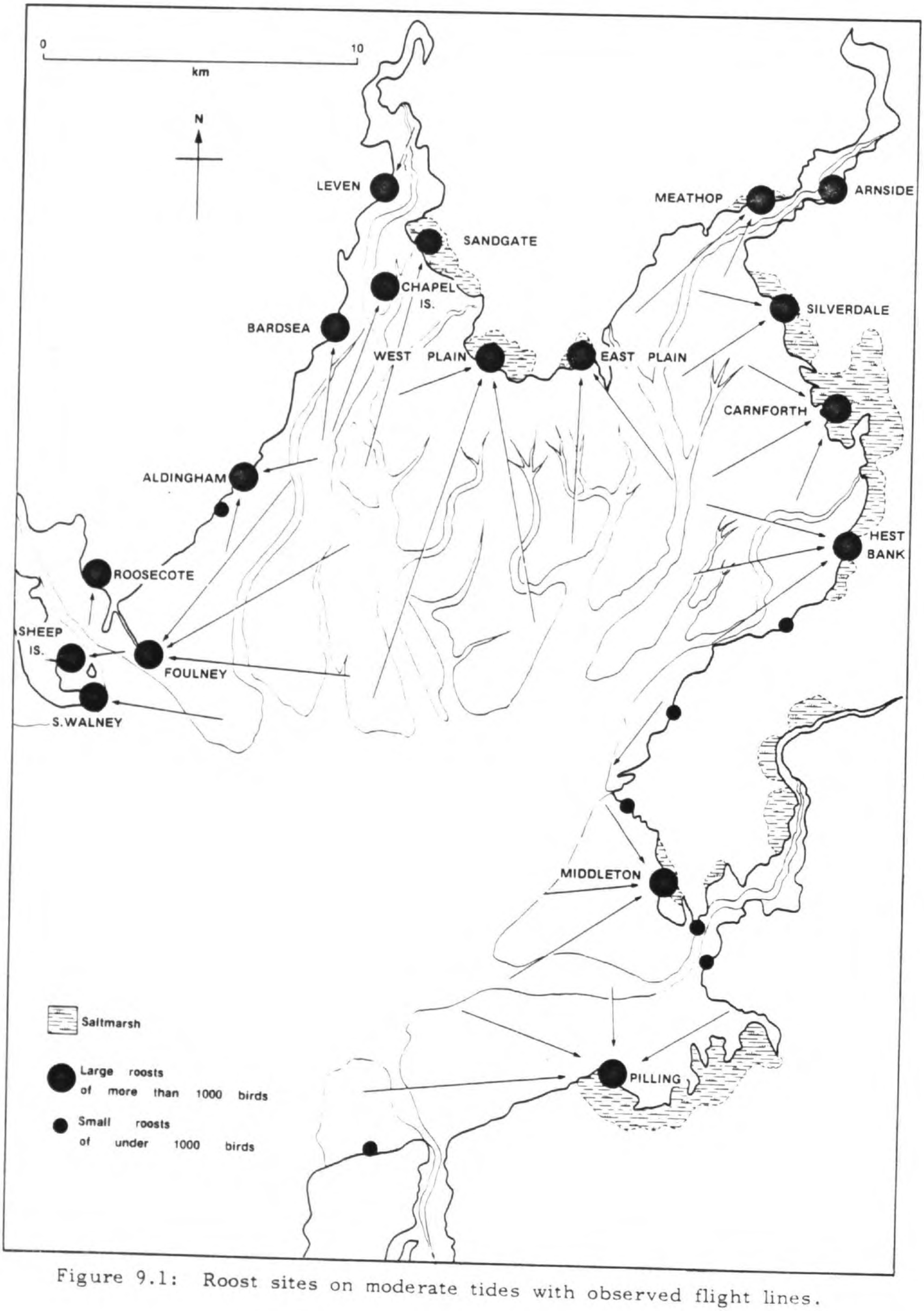

Figure 9.1: Roost sites on moderate tides with observed flight lines.

to wildfowling. Disturbance pressures are low on neap tides or low water feeding areas as these are usually remote from the shore, but increase as the spring tides bring the birds closer to the shore. Disturbance is also seasonal being at its greatest intensity on fine weekends in late summer, early autumn and spring. Birds do however quickly take advantage of a relaxation of disturbance pressures. This is well illustrated on the east side of the Bay from Sunderland Point to Jenny Brown's Point: during periods of high disturbance only two roosts are used on spring tides, on the salt marshes of Middleton and Carnforth Marsh, but with no disturbance five other sites are used on this stretch of coast. There are also marked differences between species in their reaction to disturbance with curlew being the most timid, possibly because they are still shot in many parts of the Bay. Indeed since shooting has stopped on the R.S.P.B. reserve curlew have become much more approachable; at one time anyone appearing on the edge of the narrow salt marsh at the Hest Bank roost would have put off the roosting curlew, but after two seasons of no shooting they would tolerate large numbers of people there. Turnstone represent the other extreme, a flock of up to 300 can often be seen roosting on a small shingle spit below Morecambe promenade only about 25 metres from people walking on the promenade. The position of the roosts used at times of severe disturbance pressures are shown in Figure 9.1. At the time of writing these roosts appear secure and are located in all relevant areas of the Bay. Their importance to roosting waders cannot be over-emphasised and although in some areas alternative sites may be available any loss of such sites would result in severe pressures on the wader populations at times of disturbance.

The roosting pattern shown in Figure 9.1 has remained constant over the past 13 years. Only one spring tide roost has been lost, which was on the sea wall at Red Rocks, Heysham which as been destroyed by the building work connected with the second stage of the Heysham Nuclear Power Station. This may well be only a temporary feature as once the Station is built there should be undisturbed areas which the waders can use again. The displaced birds have moved to the Middleton roost. Roosting patterns at night on spring tides are somewhat different from the daytime pattern. Almost all the small roosts shown in Figure 9.1 are not used at night, the birds concentrating instead on the larger roosts on the salt marshes and shingle beaches. This is rather surprising as no significant disturbance occurs on spring tides at night.

Food Preferences

The results of gizzard analysis of birds shot in winter by Prater are given in Table 9.2. The importance of molluscs especially Macoma, Hydrobia and Mytilus is striking and shows the dependance, at least in winter, of the most abundant waders on these food supplies. Further research is needed, especially on curlew and bar-tailed godwit in winter and most species at other seasons, perhaps above all in spring when the Bay holds very large populations of knot, ringed plover, sanderling and dunlin bound for the Icelandic/Greenland breeding grounds.

Feeding behaviour and food preferences are discussed under each species along with distribution within the Bay. The mid-winter distribution of the major species between the various sectors of the Bay is shown in Figure 9.2.

Oystercatcher (Haematopus ostralegus) (Figure 9.4)

Breeding population A census in 1978 gave a total of 202 pairs breeding on the shingle beaches and salt marshes of the Bay (K. Briggs, personal communication) with concentrations of 59 on the south half of Walney and 60 on Foulney Island, 37 on Carnforth Marsh and 21 around the Lune estuary. There is a population of c. 140 pairs inland on the shingle beds of the River Lune.

Passage and Wintering Populations. This species showed a marked decline after the severe winter of 1962/63 but has since made a slow recovery starting in the late 1960s and through the 1970s although the population appears to have stabilized recently (Wilson, 1973). The decrease was associated by Dare (1966) with a parallel decline of the previously vast cockle stocks which all but disappeared after the 1962/63 winter. Dare also linked the build up of a large field feeding population with the cockle decline. This habit has continued even as the intertidal feeding has improved, an estimate of c. 8000 birds feeding inland mainly on earthworms was made in January 1969. Numbers vary from year to year and especially with weather and tidal conditions, with highest numbers during wet weather and high tides and lowest during periods of hard frost.

Table 9.2

FOOD TAKEN BY WADER SPECIES IN MORECAMBE BAY IN WINTER BASED ON GIZZARD ANALYSIS

	Turnstone	Curlew	Redshank	Knot	Dunlin
No. of gizzards	16.0	6	49.0	80.0	120
Macoma	0.3	44.5	10.8	65.6	34.2
Tellina		17.6	0.3	1.9	0.6
Cardium		4.2	0.3	2.0	4.2
Mytilus	10.2	13.4	1.6	8.9	0.6
Hydrobia	0.3		49.0	17.4	38.6
Nereis	3.4	4.2	8.3	0.1	3.9
Gammarus	3.8		0.6		
Corophium			18.9	2.2	9.5
Bathyporeia					1.0
Crangon			0.3		0.6
Carcinus	32.2	12.6	4.6	0.4	0.4
Balanus	41.8	1.7	2.3	0.4	0.1
Littorina	6.4	1.7	0.1	0.3	
Salicornia					5.0
Others	1.5		2.8	0.8	1.3

Note. Prey given as % volume of food items.

After Prater, A.J., 1970.

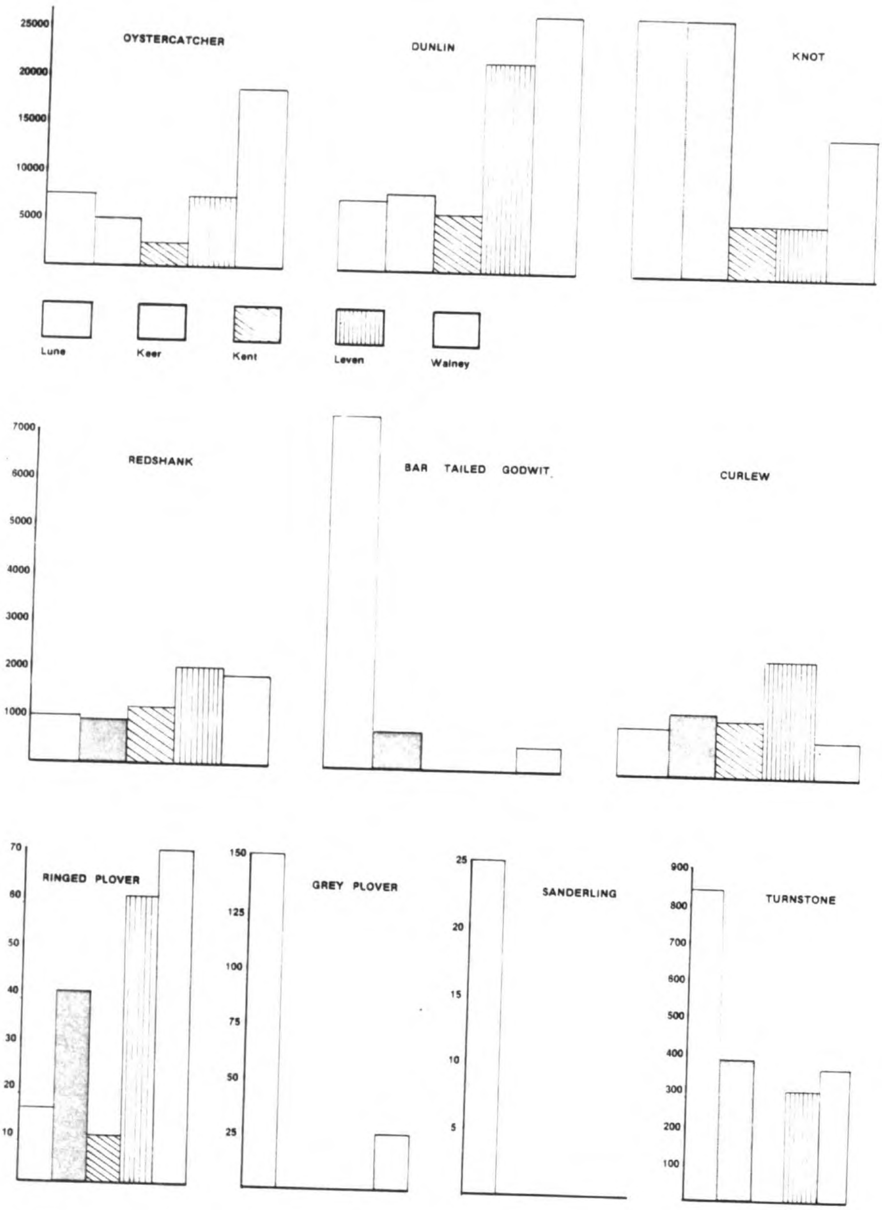

Figure 9.2: Mid-winter distribution of waders in Morecambe Bay 1969-1975 (for location of sectors see Figure 3).

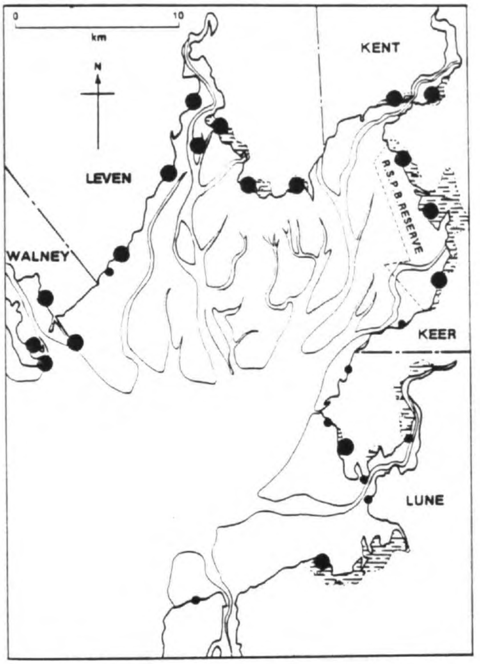

Figure 9.3: Sectors of the Bay and main wader roosts.

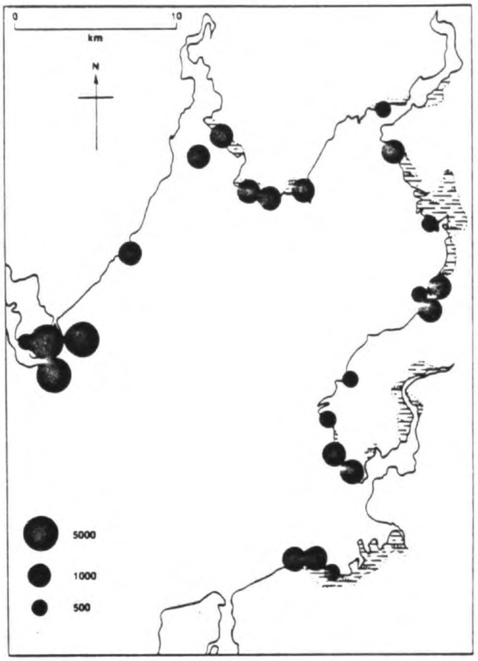

Figure 9.4: Oystercatcher.

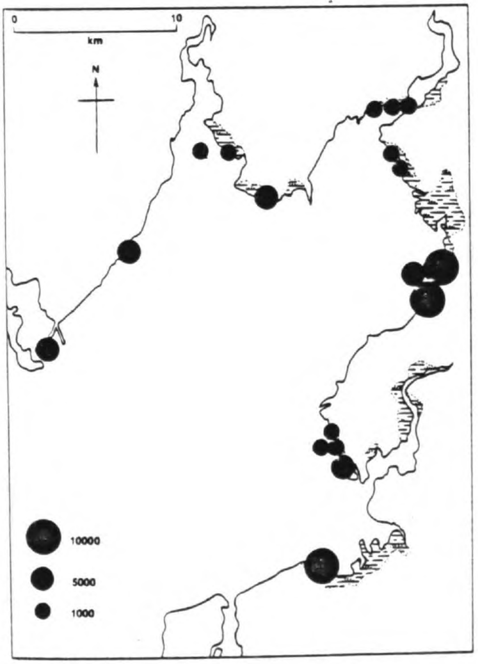

Figure 9.5: Knot.

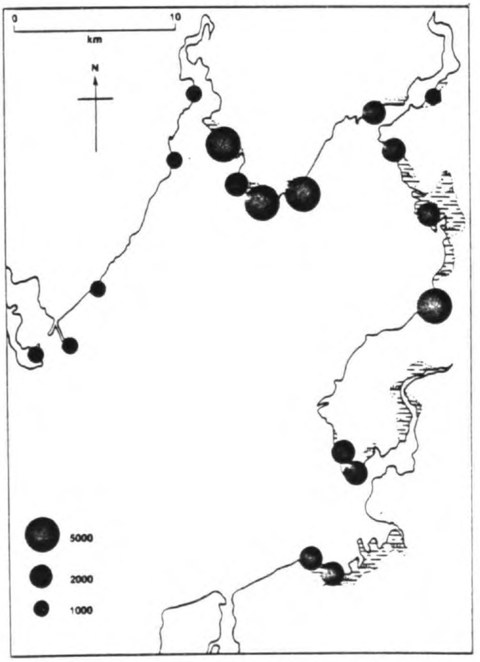

Figure 9.6: Dunlin

Mid-Winter Distribution of Waders, 1969-1970

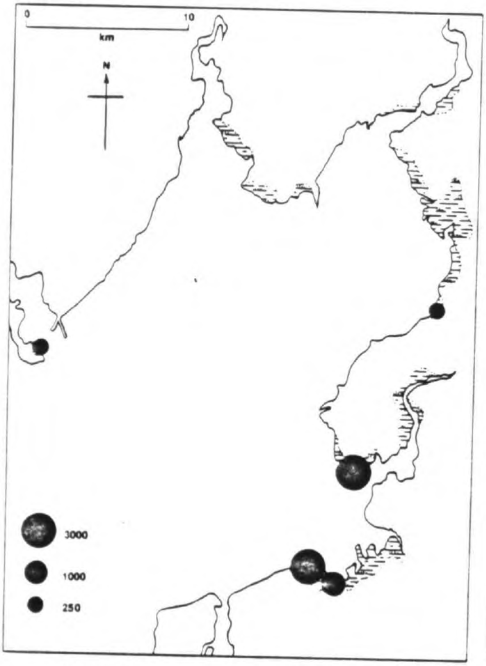

Figure 9.7: Bar-tailed Godwit.

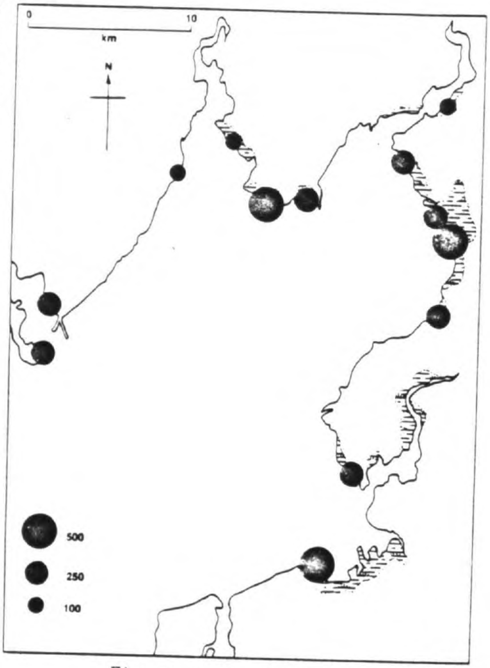

Figure 9.8: Curlew

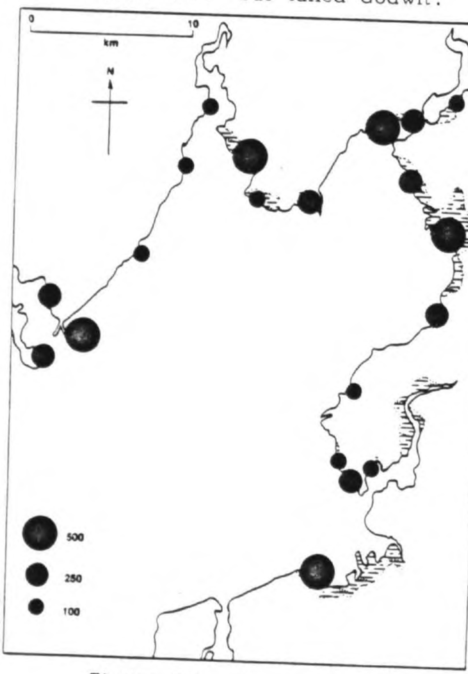

Figure 9.9: Redshank.

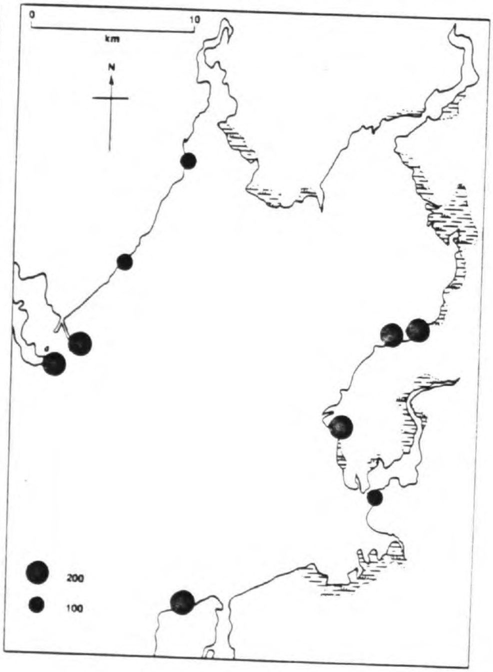

Figure 9.10: Turnstone.

In recent years the autumn passage has seen the population peak at about the 50,000 mark usually in the period late August to early October, when c. 45% of the population feeds in the upper Bay mainly on the Kent and Leven estuaries. From October the numbers start to decline and by mid-winter the population is normally in the 30,000 - 40,000 range with only c.25% in the upper Bay. Dare (personal communication) links the decline each year in the upper Bay to a parallel decline in young cockles, the birds that remain in the upper Bay feeding mainly on Macoma. The bulk of the population in winter is centred on the three large mussel beds in the lower Bay. Numbers decline rapidly in February and March leaving a summering population of c. 6000. Ringing recoveries show that wintering birds are drawn from the breeding populations of North Scotland, Faeroes, Iceland and Norway, with smaller numbers from Northern England and Southern Scotland (Dare, 1970).

Food and Feeding Behaviour. As shown above the food taken varies with the season and in different areas within the Bay.

Dare and Mercer (1973) have shown the marked differences between oystercatchers feeding on the mussel skears and those feeding on the sand flats. The former feed almost exclusively on mussels with 1% specialised on periwinkles (Littorina sp.). On sandflats cockles (Cerastoderma edule) are taken when available but recently the Baltic tellin (Macoma balthica) has been the most important food with a few birds taking small crabs (Carcinus maenas) and occasionally shrimps (Crangon crangon). Birds feeding in the fields fed almost entirely on earthworms with a few tipulid larvae and noctuid caterpillars.

Oystercatchers cease to feed once the feeding grounds are covered, gathering in flocks on an adjacent area which is used as a roost on neap tides or a gathering ground on spring tides. Feeding usually stops by mid-tide and often does not start again until mid-tide so this species is the first wader to come to roost and the last to leave.

Ringed Plover (Charadrius hiaticula)

Breeding Population. 73 pairs were located in a census in 1978 (K. Briggs, personal communication). Concentrations were 15 on South Walney, 28 on Foulney and 18 on the Lune Estuary, almost all were on shingle beaches, few now nest on salt marshes. There were also 42 pairs inland on the shingle banks of the River Lune.

Passage and Wintering Populations. This species is mainly a passage migrant through the Bay, highest numbers occur in spring with a peak of 7000-12000 usually in late May. This represents about 40% of the British population at this time (Clapham, 1978). The autumn passage is more protracted starting in late July, peaking at 1,600 to 4,500 usually in late August and continuing until early October. During passage periods the population is well distributed throughout the Bay with the smallest numbers on the upper parts of the estuaries. The wintering population is very low with usually between 150-200 birds, mainly concentrated on the area from Bardsea to Walney and at Hest Bank. Ringing recoveries show that the small wintering population breeds in Western Europe. The large passage population breeds in Greenland and winters in Southern Europe and Africa (Clapham, 1978).

Food and Feeding Behaviour. This species was not studied by Prater, but observational evidence suggests that Hydrobia, is probably the main prey, the birds resuming feeding as soon as the tide recedes. Passage birds feed avidly especially in spring and weight increases of up to 2g per day have been recorded (Clapham, 1978).

Golden Plover (Charadrius apricarius).

This species is not normally an intertidal species, though it occurs in large numbers on the low-lying fields around the Bay and at times feeds on a few of the salt marshes. No figures are available for the toal population around the Bay but the bulk of the population appears to use the shingle and mussel scars around the Bay as nocturnal roosting sites.

Grey Plover (Charadrius squatarola)

This is not an important species on the Bay and is mainly confined to the Lune. Total numbers in late summer and autumn usually reach 100-200 birds with similar numbers in most winters and 100-150 in spring. There was a slight increase in the late 1970s and some extension of the regular range, with small numbers in the Keer areas.

Lapwing (Vanellus vanellus)

Total breeding population on the salt marshes is probably c. 100-120 pairs. 68 of these bred in 1979 on the R.S.P.B. reserve area.

The mid-winter population feeding on the field around the Bay is very large, but numbers only occur on the intertidal areas during the autumn migration, the largest numbers occur on the upper estuaries of the Leven, Lune and Kent.

Knot (Calidris canutus) (Figure 9.5)

Passage and Wintering Populations. This is the commonest wintering wader, but numbers and distribution within the Bay have varied considerably from year to year. The first arrivals occur in late July and usually between 10,000-20,000, mainly adult birds, are present in August and September. These moult on the Bay and are confined almost exclusively to the Lune estuary. During the 1970s there was a gradual change in the timing of the arrival of the main wintering population. Early in the period numbers started to increase in late September with the bulk of the wintering population arriving in October and November and all present by early December. Later in the period the arrival became much later in the year, often not until late November, and peak numbers have not occurred until January or even early February. The wintering population has normally been c. 60,000-70,000 but was reduced by 10,000 lower towards the end of the decade. Distribution has also varied from year to year, only the Lune and Keer areas have regularly held large populations. Elsewhere large numbers may appear for a period or a season but then be absent the next year.

The timing of the spring passage is also variable, starting in March in some, often mild, springs, but in other years delayed until late April. The largest flocks occur in spring and the peak population can reach 75,000-85,000; again the Lune and Keer areas support the largest numbers. Numbers decline very rapidly and only c. 2000 are present by early May. Ringing recoveries show that the whole of the wintering population breeds in Greenland and north-east Canada. Many moult in late summer on the shores of the North Sea before moving across to the west coast.

Food and Feeding Behaviour. Prater (1972a) found that in winter *Macoma* forms the majority (65.6%) of the diet and is taken throughout the tidal cycle. *Hydrobia* was the second commonest prey at 17.4% and was taken mainly during the two hours either side of high tide. *Mytilius* constituted 8.9% of the diet in winter, but observations suggest that this is an important food in spring. *Tellina*, *Corophium* and *Cerastoderma* each provided c. 2% of the diet.

On neap tides knot roost adjacent to the feeding grounds and spend c. 30% of their time roosting. On spring tides the neap tide roosts act as gathering grounds and from these the knot fly directly to the main roost, often arriving up to two hours before high tide, although some feed during this period at the tide edge. A few also follow the tide out but the bulk wait for up to two hours before starting to feed.

Sanderling (*Calidris alba*)

Passage and Wintering Populations. This is a scarce wintering bird with a total population of only 50-80 but common on passage. Autumn passage commences in late July with a peak early in August of c. 1,500-3,000, although in August 1974 9,500 were recorded. The autumn passage is largely confined to the Lune area. Numbers usually fall to c. 500 in September and the small wintering population is left by mid-October. Spring passage starts in mid-April but the largest numbers occur during the second half of May with 10,000-15,000 at peak mainly on the east and upper Bay. Ringing recoveries show that the large passage populations breed in Greenland and winter in Africa.

Food and Feeding Behaviour. This species was not studied by Prater but feeding behaviour suggests that Hydrobia and Corophium are important at least on the ebb and flood. During this period many sanderling feed at the tides edge until on spring tides they are forced onto the salt marshes.

Purple Sandpiper (*Calidris maritima*)

This occurs only regularly on the west coast of Walney Island where between 75-100 occur from October to mid-April. A small number, usually under 10, occurs irregularly at South Walney and on the shingle spit at Red Nab, Heysham.

Dunlin (*Calidris alpina*) (Figure 9.6)

Breeding Population. One or two pairs usually nest on the larger salt marshes.

Passage and Wintering Population. This is an important species on the Bay and the second commonest wintering wader. Numbers start to arrive in mid-July rising to a peak of c. 19,000-26,000, almost all adults, by late July or early August. This is followed by a decline to 10,000-15,000 in September, many of them moulting adults. The bulk of the wintering population of 45,000-58,000 arrive in the Bay in late October or early November. The largest numbers occur in the upper Bay with up to 25,000 roosting on the Flookburgh marshes. Numbers remain stable throughout the winter with the exception of severe cold weather when there is a movement out of the Bay and to the mouth of the Bay. Wintering distribution remained virtually unchanged during the 1970s and there have been only small changes in the total population. Spring passage starts in March with the departure of wintering birds and by early April only 12,000-15,000 are present. Passage of birds which have wintered further south occurs from late April to early or mid-May with peak counts of 20,000-38,000 mainly on the Lune and Keer areas: numbers drop quickly in late May to leave a few hundred summering birds. Ringing recoveries show that the wintering population comes from the breeding areas in Northern

Europe and Russia. The Greenland and Icelandic populations occur in large numbers on passage (Hardy and Minton, 1980).

Food and Feeding Behaviour. Dunlin feed over a large tidal range, spending 93% of their time feeding on neap tides and 85% on springs. Prater found that in winter Hydrobia (38.6%) and Macoma (34.2%) make up the bulk of the diet. The other important items were Corophium (9.5%), Cerastoderma (4.2%), Salicornia (5.0%) and Nereis (3.9%). Dunlin feed for much of the tidal cycle, during the period either side of high water. They are usually to be found feeding near the water's edge. On neap tides they roost in small flocks near the feeding grounds at high water. On spring tides they are, with redshank, the last species to enter the roost and the first to leave it.

Bar-tailed Godwit (Limosa lapponica) (Figure 9.7)

Passage and Wintering Populations. This is an important species with an interesting limited distribution. Numbers start to arrive in late July and by mid to late August 2,000-3,000 are present, almost all on the Lune. Numbers continue at this level throughout September, with a marked arrival in early October and on into November to reach the mid-winter population of 7,000-8,000. Except for c. 750 on the Keer and c. 250 in the Walney area the bulk of the population is confined to the Lune estuary. Early in the winter the majority roost on the south bank of the Lune, but there is a gradual shift to the north bank during the winter. Numbers decline rapidly in March leaving only a few hundred summering birds.

Food and Feeding Behaviour. Bar-tailed godwits spend up to 42% of their time roosting and the whole of the non-roosting period is spent on the low water feeding grounds, feeding at the lowest tidal level of any species studied, almost all feed on wet sand with only a very few at the water's edge or on dry sand. The bulk of the population feed on the Lune but there is a significant movement at low water across to the lower parts of Cartmel Wharf. Prater only examined two gizzards, these contained Macoma, Tellina, Cerastoderma and Hydrobia. Observations however suggest that the above molluscs are taken along with probably larger quantities of polychaetes. It is unfortunate that more data on the diet of this species is not available especially in view of its limited distribution within the Bay.

Curlew (Numenius arquata) (Figure 9.8)

Breeding Population. One or two pairs breed rather irregularly on the salt marshes.

Passage and Wintering Populations. The curlew is an important species with large numbers present in winter, spring and especially late summer. Large, but varying numbers, feed inland especially in winter in the valleys of the Lune, Keer, Kent and Leven. These birds fly back to the Bay at dusk and so are missed on the coast counts. Autumn passage often starts in late June and peak numbers of 12,000-22,000 occur in late July or early August. These large numbers resort to roosting on the larger salt marshes remote from human disturbance especially on Carnforth Marsh, the Flookburgh Marshes and the Lune area. Numbers decline slowly in autumn to reach the wintering level of 4,000-8,000 by November, these are well distributed around the Bay with the largest numbers on the Leven and Keer areas. Spring passage is evident by mid-March with a peak of 6,000-9,000; smaller numbers are present in April but only the summering population of c. 1000 birds remain in May. Ringing recoveries indicate that wintering birds are drawn from North Britain and Northern Europe.

Food and Feeding Behaviour. Curlew roost for c. 39% of the tidal cycle, with most not starting feeding until mid-tide when they move onto the wet sand areas. Prater was only able to obtain six gizzards and then only from the Cartmel Wharf area. This small sample gave Macoma at 44.6% as the dominant food with Tellina 17.6%, Mytilus 13.4%, Carcinus 12.6% and Nereis 4.2%. Observations however suggest that Nereis is taken in much larger quantities especially on the upper estuaries than this small sample suggests. Carcinus is also taken in large quantities on the mussel beds.

Redshank (Tringa totanus) (Figure 9.9)

Breeding Population. About 75 pairs breed on the salt marshes, with 35 of these on the R.S.P.B. Marshes, especially Carnforth Marsh. Numbers have declined somewhat in recent years, probably due to increased sheep grazing.

Passage and Wintering Populations. A common shore wader; although at times large numbers feed inland especially on flooded fields, these usually return to the Bay in the evening or at low water. Autumn passage starts in late July and continues well into October. Peak numbers usually occur in late August or early September when between 12,000-20,000 may occur. Numbers then settle to the mid-winter level of 6,000-9,000 in recent years, an increase of c. 2,000 on the late 1960s. Spring passage commences in March and reaches a peak of 8,000-10,000 by mid or late March. In early April 4,000-6,000 are present but numbers decline rapidly late in the month and only a small summering population remains. Ringing recoveries show that the wintering population is drawn mainly from the British and Continental populations with a few Icelandic birds, the latter occurring in larger numbers on passage.

Food and Feeding Behaviour. On neap tides redshank roost for only 3.3% of the available time, increasing to 13.3% on spring tides. They therefore feed over almost all the tidal cycle. As the tide ebbs they take mainly Hydrobia and Corophium. At low water they take a large range of prey species with Macoma, Hydrobia, Nereis and Carcinus all taken in similar quantities. With the tide flooding they revert to mainly Hydrobia and Corophium. Taking the tidal cycle as a whole Prater found from gut analysis that Hydrobia formed 49% of the diet with Corophium 19%, Macoma 10.8%, Nereis 8.3% and Carcinus 4.6%.

Greenshank (Tringa nebularia)

This is a regular autumn passage migrant, much rarer in spring, with an occasional bird wintering, mainly on the pools and creeks of the salt marshes. Greenshank pass through from mid-July to late October with a peak of 70-100 birds in late August and early September. One or two birds have wintered almost annually at Walney and in the Kent. Spring passage usually produces under 10 birds at any one time in late April and May.

Common Sandpiper (Tringa hypoleucos)

This is a regular spring and autumn passage migrant in small numbers. It usually occurs in the creeks and pools on the salt marshes so is easily missed, but numbers rarely exceed 50.

Turnstone (Arenaria interpres) (Figure 9.10)

Passage and Wintering Populations. This specialised wader feeds mainly on the mussel beds and so occurs predominantly at the mouth of the Bay. Autumn passage numbers have varied between 1,500 and 3,800 with peak populations usually occurring in late August or early September. Wintering numbers increased by c.250 in the 1970s and have usually ranged from 1,500 to 1,750. Spring passage starts in late March and peaks at 2,000-2,500 in late April or early May. Ringing recoveries show that the wintering population is drawn from Greenland, North-East Canada, and Northern Europe (Clapham 1979).

Food and Feeding Behaviour. Limited work on the food of this species was done by Prater (1972b). He found that three prey species form more than 80% of the diet; Balanus (41.8%), Carcinus (32.2%) and Mytilus (10.2%). Turnstone spend c. 90% of their time feeding, feeding first on the sand as the tide ebbs, but the bulk of the feeding takes place on the mussel beds and stoney scars.

WILDFOWL

Introduction

The study of wildfowl on a large estuarine complex presents many difficulties. Because of the problems of access and the large distances involved counting is not feasible on neap tides or at low water. At high tide the wildfowl mainly congregate off-shore and the higher spring tides produce the best counts. However weather conditions are also important, the ideal conditions being a reasonably calm sea with good visibility, but even on such days in a few areas wildfowl spread right out into the Bay and some are not specifically identifiable. On windy days many are lost to sight in the waves especially where an elevated observation position is not possible. With stormy conditions many wildfowl appear to be absent, probably seeking shelter inland. Table 9.3 gives the average figure for mid-winter counts in the six sectors of the Bay from 1967-1980. Only counts when counting conditions have been considered good have been included. Wildfowl concentrations within each sector are detailed below and in Figure 9.11. The Latin names of species mentioned in the text are given in Table 9.3.

Walney

The sanctuary area on the South Walney Reserve provides a sheltered haven on the southern tip of the island and in the gravel pits, particularly for wigeon and teal. In addition eiders use the spit at high tide and can also be found on Sheep and Piel Islands, but the largest numbers for much of the year are to be found on Foulney Island with a drift to Walney in early spring. Foulney also supports a good sea duck population, mainly common scoter and goldeneye with the occasional velvet scoter (Melanitta fusca) and long-tailed duck (Clangula hiemalis), while the marsh between Foulney and Rampside holds many wigeon and shelduck. Numbers of these two species also occur along the inner shore of Walney and Rooscote where there is much flighting onto the freshwater area of Cavendish dock.

Leven

The sector from Rampside to Greenodd has few large concentrations, but numbers of shelduck, wigeon and mallard can regularly be seen off Aldingham, the Old Mill/Priory Point area and the Upper Leven. One of the most interesting features is the regular flock of scaup between Priory Point and Chapel Island feeding around the mussel beds. The three saltmarshes south of Flookburgh all hold considerable concentrations although numbers vary from year to year. Sandgate Marsh usually holds the best variety with numbers of wigeon, pintail,

Table 9.3

AVERAGE WILDFOWL NUMBERS IN MID-WINTER IN DIFFERENT SECTORS OF MORECAMBE BAY 1967-1980

Species	Sector					
	Walney	Leven	Kent	Keer	Lune	Total
Greylag Goose *Anser anser*			150-300	150- 300		300- 600
White-fronted Goose *Anser albifrons*					- 10	10
Pink-footed Goose *Anser brachyrhynchus*					1-2000	1-2000
Mallard *Anas platyrhynchos*	250- 300	700- 900	550-650	350- 550	1250-1500	3100-3900
Pintail *Anas acuta*	5	550- 825	10- 15	150- 200	30- 50	745-1095
Wigeon *Anas penelope*	1000-1250	950-1300	300-350	650-1250	1850-2500	3750-6650
Teal *Anas crecca*	750- 900	90- 125	100-175	25- 50	50- 75	1015-1325
Shoveler *Anas clypeata*		55- 80		15- 30	30- 50	100- 160
Shelduck *Tadorna tadorna*	750- 850	2250-3325	750-850	950-1500	950-1150	5650-7675
Scaup *Aythya marila*	5	65- 80		5	5	80- 95
Goldeneye *Bucephala clangula*	50- 70	70- 80	20- 30	110- 130	20- 30	270- 345
Common Scoter *Melanitta nigra*	85- 120					85- 120
Eider *Somateria mollissima*	1750-2000	100- 200				1850-2200
Merganser *Mergus serrator*	40- 50	55- 75	10- 15	120- 150	50- 60	275- 340
Goosander *Mergus merganser*	5		10	5		20

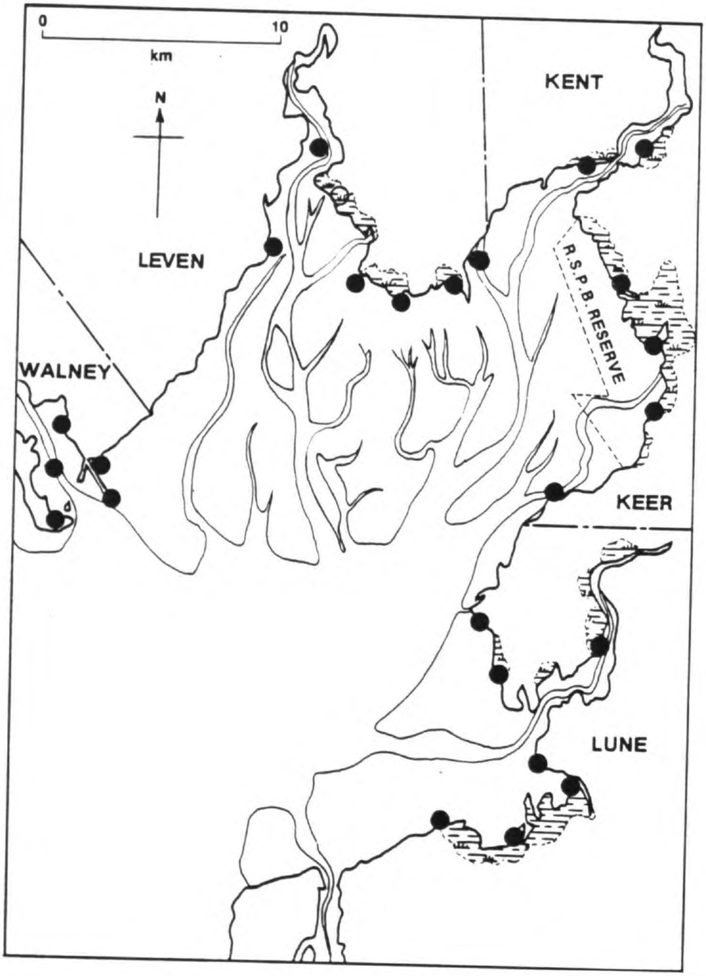

Figure 9.11: Major concentrations of wildfowl on mid-winter spring tides, and sectors of the Bay.

mallard and at times shoveler. The largest concentrations of shelduck and wigeon are off West and East Plain marshes. At times pintail also occur there and under certain conditions also between Kents Bank and Humphrey Head, an area also well frequented by shelduck.

Kent

The main concentrations are to be found off the saltmarshes of Silverdale and Meathop especially shelduck, mallard and wigeon. In the late 1970s there has been a marked change as the Kent channel has moved close to Silverdale Marsh, rapidly eroding the saltmarsh (see Chapter 4) and more duck are now found on the Meathop side or have moved to the Jenny Brown's Point area. Numbers vary above the viaduct where the teal are to be found and also in earlier years the graylag goose regularly roosted on the sand flats there and fed during the day on Brogden and Meathop marshes but in recent years they have only irregularly used these areas.

Keer

Much of this area is now part of the R.S.P.B. Reserve and is a sanctuary area; numbers have increased recently especially wigeon which occur in the largest numbers off Jenny Brown's Point. Shelduck favour the Keer estuary where there is also a regular flock of pintail. Greylags have taken to roosting on the Keer sand banks and later in the winter often graze on Carnforth Marsh. Numbers of merganser and goldeneye frequent the area off Morecambe Promenade.

Lune

This sector holds the largest concentrations on the Bay, especially the Pilling-Cockerham area where there are large numbers of mallard, wigeon and shelduck. The pink-footed geese roost on the sand banks of the south Lune where they are protected by the Wyre/Lune Sanctuary. They feed inland on the farmland, with largest numbers usually occurring from late January to early March. There is also much flighting of duck inland to the farmland. Other concentrations of duck occur off Sunderland Point and further up the river.

Centre of the Bay

Few observations have been made on seaduck in the central areas of the Bay. A limited number of aerial surveys have revealed only small flocks of common scoter and the occasional diver, though large numbers of common scoter were reported on one occasion in mid-winter.

Feeding Ecology

No full scale study has been made to date of the food and feeding behaviour and the following rather general comments are based on personal observations and on those of Ruxton (1970). In most species there is considerable seasonal and probably annual variation in the foods taken. A further complicating factor is that the flighting patterns from the daytime roost to the night-time feeding areas can be considerably modified by wildfowling which is practised over much of the shoreline. It has little effect on the daytime roosting patterns other than to make the birds sit further off shore but has considerably modified the feeding behaviour of several species; indeed without such disturbance daytime feeding would be much more widespread.

Grazing of both Puccinellia and Agrostis sward of the saltmarshes is important for wigeon and greylag. Disturbance is a significant factor and it is noticeable how daytime grazing has increased on Carnforth Marsh since shooting ceased there. Wigeon also feed in many areas on Entermorpha. Many of the mallard, teal and shoveler on the Bay regularly flight inland to feed. These flights vary from season to season depending on the available food. Ruxton gives details of some of these flights in the Kent estuary. Stubbles and potato fields are visited in autumn, while rivers provide washed-down acorns and alder seeds again mainly in autumn. Temporarily flooded grassland is also attractive and there is much regular flighting between the permanent freshwater areas around the Bay, especially the larger ones such as Leighton Moss and Cavendish dock where the main food is seeds and leaves of a wide variety of freshwater plants. These species also feed on the intertidal areas especially around the mussel beds and such areas become important during periods of frost when inland areas are frozen over. Hydrobia is taken by pintail and also by large numbers of mallard in late summer especially those which congregate at Leighton Moss at this time, flighting out in the afternoon to the Bay.

Shelduck appear to feed largely on Hydrobia taking them mainly on the wet areas of sand as the tide recedes. Eider take mainly Mytilius at low water and on an ebbing and flooding tide. The beds off Foulney are their main haunt, it is perhaps surprising that they have not spread to the Heysham beds. It still remains a rare bird on the west of the Bay.

Breeding Populations

The saltmarshes and shingle beaches support only a small population of breeding mallard with the occasional pair of shoveler. Shelduck now nest widely in natural holes in the ground or among rocks, their former preference for rabbit holes having been restricted since myxomatosis. The one species which has an important breeding population on the coast is the eider. After first colonising Walney in 1949 its population has increased to at least 500 pairs, mainly on South Walney, but also now on the other islands in the Barrow area.

GULLS AND TERNS

These two groups provide the contrast of the most well-documented breeding populations and the least well-documented patterns of occurrence at other times of the year, of all the species in the Bay, due to severe difficulties in monitoring. Tern passages cannot be talked about in terms of 'norms' and 'averages' as the numbers visible depend on the strength and direction of the wind with large numbers of most species being blown into the Bay on south-westerly gales in August/September. The problem at roosts of a significant number not having arrived at the onset of dusk, or the light becoming too poor for identification, prevents accurate counts of gulls outside the breeding season. Similarly there is no data from Cumbria on the catchment areas of gulls roosting in the Bay and those roosting on the larger lakes.

Little Gull (Larus minutus)

This is an erratic and rather scarce passage migrant. Immatures have summered in the area. The most regular coastal site in spring is the Lune Estuary/Conder Green where up to 10 have been seen in April/May especially after south to south-east winds. In autumn the species is much scarcer and appears irregularly during strong onshore gales especially when there is more of a south than west component in them, usually in August/September, but four were blown in during the

November 1977 gales. This autumn status applies to the south side of the Bay - the species is an exceedingly rare vagrant to the Walney area. This species has recently been noted off Heysham Harbour (up to 80 per day) during westerly gales in winter.

Black-headed Gull (Larus ridibundus)

The main coastal breeding colony is now on Foulney Island where numbers have increased from 15 pairs in 1976 to 300 pairs in 1978 and 525 pairs in 1980. This is thought to be significant in relation to the protection from larger gulls which this species gives to the terns, especially sandwich, breeding at the same site. Small numbers (less than 50 pairs) breed on Colloway Marsh on the Lune Estuary in association with common tern. Huge numbers roost at night on the Bay during the winter months and there are significant day-time counts from some areas notably Carnforth Marsh (e.g. 2850 in September 1978). Continental immigrants provide an unknown percentage of the wintering population with tideline corpses bearing rings from Finland, Sweden, and Norway being recorded in recent years.

Common Gull (Larus canus)

This is mainly a passage migrant and winter visitor in large numbers. Counts from Carnforth Marsh have revealed 500-600 October-February, with 20 in April, 10 in May, then numbers climbing rapidly from mid-July to 430 in August, and 400-500 in September. However these figures are insignificant compared to the number feeding inland in fields and roosting in the Bay at night. Adults, as might be expected, are very scarce between April and late June. There are no breeding records from the Bay.

Lesser Black-backed Gull (Larus fuscus)

The huge colony at South End Haws on Walney has been intensively studied during the 1960s and 1970s by the Oxford University research group and others. The population rapidly increased up to about 1970 since when it has oscillated in the region of 21,000-25,000 pairs. All birds of the year and the vast majority of adults/sub-adults migrate south to the Iberian peninsula/North West African coasts during August-October returning February-April. An increasing number have, however, remained in the Bay during the winter and it appears to be the largest winter concentration of lesser black-backed gulls in Britain, with 2,750 present at the Keer Estuary evening roost in the 1974/5 winter. Small numbers have bred or attempted to breed on the large relatively undisturbed saltmarshes such as Carnforth and Colloway, and several pairs have nested on buildings at Heysham Harbour in recent years.

Herring Gull (*Larus argentatus*)

Large numbers breed with the lesser black-backs on Walney Island - in the region of 20,000-25,000 pairs. This species is much more sedentary than the lesser black-backed gull and more sedentary than, for example, the Northern Irish herring gulls, with the vast majority of ringing recoveries being within the counties of Lancashire and Cumbria. Critical examination of herring gulls, at Salt Ayre Tip, Lancaster, during the 1978-9 winter produced several *Larus argentatus argentatus* type, one *L. argentatus 'thayeri*-type variant' and two colour-ringed birds ringed on the Firth of Forth and Firth of Clyde as pulli. The presumed North Scandinavian origin of the first two forms is discussed by Hume (1978). On the basis of this 'winter visitor from elsewhere in significant numbers' can be added to the status. Rubbish tips provide the largest concentrations of wintering birds especially Salt Ayre and Walney.

Great Black-backed Gull (*Larus marinus*)

This species is mainly a winter visitor including birds from as far away as the Barents Sea, U.S.S.R. (from ring recoveries). Under 50 pairs breed on Walney. The wintering population for the south side of the Bay (Keer - Knott End) has been estimated at 1,000-1,200 with the largest single concentrations at Salt Ayre Tip (up to 200) and Carnforth Tip (up to 250). Small numbers of immatures are present in the Bay during the summer.

Sandwich Tern (*Sterna sandvicensis*)

There are three closely interrelated breeding sites in Cumbria, two of which (Walney and Foulney) are within the study area, the third is at Drigg (Ravenglass). In 1969, 75 pairs were successful out of 250 pairs attempting to nest at Walney on the shingle spit. There then followed a period when Walney spit became unsuitable and Foulney was rat-infested. In 1976, 150 pairs nested on Foulney, by which time large gulls had made Walney unsuitable for all tern species, along with 15 pairs of black-headed gull. This was maintained in 1980 with a high degree of breeding success which may be attributed to a combination of wardening and rat control by the Cumbria Trust for Nature Conservation, together with the vigilance of the black-headed gulls in keeping the large gulls away. This increase at Foulney has been accompanied by a drop in the numbers at Drigg. There is very little data on passage movements.

Roseate Tern (Sterna dougallii)

Occasional individuals and pairs used to occur around the Walney and Foulney Tern colonies but there are no recent records of suspected or confirmed breeding. Elsewhere this is a vagrant with two records in the last two decades for the south side of the Bay.

Common Tern (Sterna hirundo)

The main breeding colonies are at Colloway Marsh on the Lune Estuary, where numbers vary between 125-200 pairs, and the Walney/ Foulney complex. The last breeding attempt on Walney was 35 pairs in 1972; 1973 saw a transference (and increase in breeding pairs) to Foulney with 130 pairs. Breeding pairs thenceforth have remained between 130-150 pairs until 1980 when the figure was 100 pairs. There is little discernable passage in spring but there are sometimes large influxes during September gales, after most of the local birds have left, involving up to 300 birds.

Arctic Tern (Sterna paradisaea)

40 pairs bred on Foulney in 1972 and the species steadily increased there to 70 pairs in 1976, 100 in 1978 and 150 in 1980. Single birds and occasionally breeding pairs have been noted on Colloway Marsh. An increase in sightings on the south side of the Bay during the summer months is probably attributable to the increase in breeding pairs on Foulney Island.

Little Tern (Sterna albifrons)

The only breeding site is at Foulney Island with four breeding pairs 1972-80 and at least three successful breeding pairs 1978-80. Post-breeding flocks of up to 100 used to occur in the Fluke Hall-Middleton area but in recent years the species has been very scarce away from the breeding area, with no noticeable passage.

SEABIRDS (other than Gulls and Terns)

This section includes only three species for which the total numbers recorded justify a degree of importance being attached to their status. The first two, cormorant and great crested grebe, occur in significant numbers outside the breeding season (mainly winter months); the third, Leach's petrel, occurs in large enough numbers during periods of persistent westerly gales in September-November to justify mention in reports concerned with status on a national scale. However the Bay is of no significant conservation value to this species, nor to the other species mentioned in this section.

Divers

The red-throated diver (Gavia stellata) occurs as a passage migrant and is especially regular off Walney in February-April. Occurrences in the Bay are erratic and the species is very scarce in the inner Bay regions, with the 5-6 noted off Morecambe in October 1980 being exceptional. Strong winds increase the number of sightings and contribute to occasional winter influxes such as 16 south of Heysham on 13 January 1974. The black-throated diver (Gavia artica) and great northern diver (Gavia immer) are very scarce winter visitors to the Barrow/Walney area and winter vagrants to other areas of the Bay. All three species are very rarely found as tideline corpses.

Grebes

Great Crested Grebe (Podiceps cristatus). This species is a common winter visitor. Few well co-ordinated counts could be traced but counts from the south side (Heysham-Hest Bank) suggest that there has been either a decrease since the early 1960s or the species is subject to marked annual fluctuations in numbers. 500 were noted off Morecambe in November 1962 (N.B. pre-1962/3 severe winter), 138 on 1 January 1976 but only 40-70 in the two winters 1978/9 and 1979/80 when counts were made regularly during the winter. Numbers do not noticeably increase during hard weather presumably because there are no large nearby inland winter populations to be displaced by severe conditions. On the north side of the Bay the most important area appears to be Cavendish Dock, Barrow, with up to 60 noted during the last 5 winters. The Foulney/Piel/Walney complex is very difficult to count, but the area contains at least 30 birds during the winter months.

Recent information suggests 100-200 birds present during winter in the Kent Channel. These can only be seen from land in the calmest sea conditions.

Other Grebe Species. All are vagrants to the Bay with individual records for any given area worthy of mention in the relevant annual reports. Records of red-necked grebe (P. grisegena), black-necked (P. nigricollis) and Slavonian (P. auritus) barely average one each year for the whole Bay. The little grebe (Tachybaptus ruficollis) occurs in insignificant numbers on the upper tidal reaches of the local rivers, but is a vagrant to the open areas of the Bay. Up to 30 occur on Cavendish Dock in winter.

Petrels and Shearwaters

Fulmar (Fulmarus glacialis). This has been seen regularly off Walney on seawatches for many years. In the inner Bay it was formerly very scarce, but regular spring seawatching off Morecambe/Heysham during 1978-80 suggests that it occurs in varying numbers during strong winds from February to early August, though no more than 25 were noted on a single high tide period. The near absence in spring, during regular seawatches off Morecambe in the mid-1960s, suggests that the increase in sightings can be related to the rapid increase as a British breeding species during these intervening years. Records from Walney are too temporally erratic for analysis. It was also noted in small numbers during the severe 'Leach's petrel' gales in 1978 and 1980.

Manx Shearwater (Puffinus puffinus). This is seen regularly off Walney and Rossall/Blackpool during spring and summer with occasional counts (of up to 200) during strong winds, but very few find their way into the Bay. Nine seen off Morecambe (including one Balearic) on 14 June 1979 was exceptional.

Leach's Petrel (Oceanodroma leucorhoa). Observations of the most recent influxes suggest that a westerly airflow for a few days followed by a vigorous depression, results in numbers of this species being blown into the Bay on the south-westerly component of the depression (generally speaking the warm sector and the period when the wind is in the process of veering north-west) e.g. 15 September 1978, 29 September 1978 and 21 September 1980. The peak days for the better known and documented Hilbre/ Wirral influxes tends to be the following 2 days or so when the wind has veered west-north-west to north-west. Thus Morecambe Bay birds could be some of those seen off Cheshire on subsequent days. This implies that the two recent major influxes in 1978 and 1980 must have involved a large percentage of the birds within the catchment area of the gales as they swept across the mid-North Atlantic.

Gannet (Sula bassana)

It is strange that this species should be so scarce within the Bay considering the regular passage off Walney and Rossall/Blackpool. Sightings of healthy individuals on the south side of the Bay amount to an average of one every three years in 1969-80. Tideline corpses are almost annually reported, but are few in number.

Cormorant (Phalacrocorax carbo)

This is a common winter visitor to the Bay and the tidal reaches of the local rivers; some regularly commute inland to local lakes and reservoirs and the larger lakes have winter populations which also roost there. Probably about 250 winter on the south side of the Bay between Knott End and the Kent Estuary with notable concentrations off Morecambe/Heysham (up to 100), Kent viaduct (up to 42), Silverdale (50) and Skerton Weir (up to 25). Large numbers roost at Cavendish Dock at Barrow, with up to 250 noted, but what percentage of these are also birds regularly seen feeding offshore on the north side of the Bay is not known.

Shag (Phalacrocorax aristotelis)

This winter vagrant is most commonly seen, usually as single birds once or twice per winter, in the Walney/Cavendish Dock areas. On the south side of the Bay it is most regularly seen at Heysham Harbour, the records suggest that one can be expected each late autumn/winter although there are no recent records of individuals staying for more than a couple of days.

Skuas

Arctic skua (Stercorarius parasiticus). This is regularly reported in small numbers off Walney and Foulney during strong winds April-November with one early December record. During the summer, off-passage birds are sometimes seen around the Foulney tern colony or off Walney.

Great Skua (Stercorarius skua). This is annually reported from the Walney area in ones and twos, usually in autumn.

Auks

In contrast to the fulmar, the numbers of razorbill (Alca torda) and guillemot (Uria aalge) seen in the Bay appear to have generally decreased in recent years and in terms of comparing the numbers seen on seawatches in the mid-1960s with those seen 1978-80 off Morecambe/Heysham there has been a definite decrease. This especially relates to birds which used to be found around Heysham Harbour in small numbers during the winter months - the winters 1978/9 and 1979/80 produced none (if one excludes the handful of transient birds seen on seawatches). Numbers were never large enough previously to read any significance into this change of status but it obviously may be related to the declining fortunes of these two species as British breeding birds. Numbers are still seen on seawatches off Walney with three figure counts regularly during onshore winds.

An interesting situation may be developing concerning the black guillemot (Cepphus grylle) which has recently become a regular winter visitor in ones and twos to the Walney area. In the summer of 1980 there were two adults and a juvenile (after the theoretical breeding season) giving rise to possibilities that it was reared locally. There are only 2 records of this species this century on the south side of the Bay.

PASSERINES (and other groups)

This account is restricted to passerines which utilise habitat around the Bay that can be described as strictly coastal. Into this category comes saltmarsh, shingle spits and islands, sand dunes, the intertidal areas of the local rivers and the open sand or mud flats of the Bay itself. The significant feature in relation to the use of these habitats by birds is the lack of shrubs such as sea buckthorn (Hippophae rhamnoides) on for example Walney Island, or Suaeda maritima fringing salt marshes and sand dunes, which in other areas provide refuge and food for migrating passerines requiring a degree of cover. So, while Walney receives large falls of willow warbler (Phylloscopus trochilus), and whitethroat (Sylvia communis), only a very small percentage of these birds remain to eke out a temporary existence in the windblown bushes. Therefore around Morecambe Bay coastal habitats provide off-passage feeding areas, wintering grounds or nesting habitats for only a limited number of open-ground species. Diurnal migrants, such as the tree pipit (Anthus trivialis) which frequently use the coastline as a guide but rarely the strictly coastal habitats as a feeding area, are omitted from this account.

The skylark (Alauda arvensis) is perhaps the typical passerine of the grazed saltmarshes characteristic of Morecambe Bay. It is by far the commonest breeding passerine and large numbers are noted on passage and in winter. The meadow pipit (Anthus pratensis) is a common breeding bird on the inner saltmarshes where Juncus spp. is present and an abundant spring and autumn passage migrant. Passage birds showing characteristics of the Icelandic race are fairly common during the winter in certain areas. The rock pipit (Anthus spinoletta) is a scarce (perhaps overlooked) passage migrant and very small numbers winter on the piers and groynes around the Bay, especially in the Walney area. The water pipit (Anthus S. spinoletta) has been occasionally noted on Carnforth Marsh. The grey wagtail (Motacilla cinerea) is a frequent passage migrant, usually occurring singly, most regularly in inshore salt marsh gutters and on the river estuaries where very small numbers may be found during the winter (e.g..Lune). The yellow wagtail (Motacilla flava) breeds on the inner salt marshes in very small numbers and is frequent on passage, especially in autumn, feeding on damp grazed salt marsh. It is usually outnumbered in this habitat by pied wagtail (Motacilla alba), groups of which contain variable numbers of the continental race, white wagtail. The wheatear (*Oenanthe oenanthe*) is a common passage migrant to all the coastal habitats and a few pairs breed annually on Carnforth Slag Tips. Magpie (*Pica pica*) and carrion crow (*Corvus corone*) scour the saltmarshes for breeding wader pulli, dead sheep and other carrion, while flocks of rooks (*Corvus frugilegus*) and jackdaws (*Corvus monedula*) are occasionally seen, usually in association with large flocks of starlings (*Sturnus vulgaris*) on the open grazed saltmarsh. Hirundines and swifts (*Apus apus*) feed on the insect life provided by the various habitats, both on passage or as part of the daily feeding routine. The damp inner saltmarshes appear to be the most preferred areas and the number of swifts over Carnforth Marsh has reached 2,000. Linnets (*Carduelis cannabina*) are abundant utilisers of such foodplants as ragwort (*Senecio jacobaea*) e.g. on Walney and thistles (*Cirsium spp*) on inner saltmarshes, their peak passage season (August- early October) coinciding with seed-production. They are often found in association with goldfinches (*Carduelis carduelis*) in the latter habitat. Greenfinch (*Carduelis chloris*) flocks are regularly encountered outside the breeding season especially in areas where thrift (*Armeria maritima*) seed is abundant. The twite (*Carduelis flavirostris*) has been increasingly noted in spring on the well-watched R.S.P.B. salt marshes. Reed buntings (*Emberiza schoeniclus*) are associated with inner saltmarshes containing communities of the larger *Juncus spp.* e.g. Carnforth Marsh. Small numbers breed, spring and autumn passage is on a small scale and the species is scarce in winter. Snow buntings (*Plectrophenax nivalis*) are casual winter visitors or passage migrants to especially Carnforth Slag Tips, Foulney and Walney. They rarely stay for the whole winter period. The creeks of the upper estuaries and saltmarshes, especially those near the two main heronries at Dalham Tower and Levens, provide feeding grounds for Herons (*Ardea cinerea*).

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Chapter 10

FISH AND FISHERIES

A. MARINE FISHERIES

J. Corlett (Ben Fold, Outgate, Ambleside, Cumbria).

The large areas of intertidal sand and mud in Morecambe Bay suggest that there is a potential for a large production of bivalve molluscs, and this is indeed so. In general in British waters the most important molluscan species for fisheries are cockles (*Cerastoderma edule*) and mussels (*Mytilus edulis*) and both these species have been exploited in Morecambe Bay (Driver, 1977).

Cockles live buried in the sand and are most prolific in medium and fine sands about half tide, although they may occur lower down the shore and in the channels. (See also Chapter 8.) The spatfall is irregular, being very successful in some years and often poor for several years in succession: so the fishery may be dependent for several years on cockles of one particular year class. Cockle fishing flourished in Morecambe Bay, although with varying annual catches, until the cold winter of 1962-63 when most of the stocks were wiped out. For some years after that there were no very successful spatfalls and the fishery collapsed until the late 1970s when some moderate year classes allowed a resumption of fishing on the old prolific grounds of Cartmel Wharf and the Silverdale area. In 1975 there was a very successful spatfall further south in the Irish Sea, particularly off Southport, and since then there have been some good years for spat in Morecambe Bay, with a particularly good settlement in 1982. The traditional method of fishing was with a three pronged fork, known as a "hand craam", and a "jumbo", which is a wooden platform with handles which is rocked on the sand as it is drawn forwards: this liquifies the sand and brings the cockles to the surface. At the end of the last century the annual landing was between 3,050 and 4,060 tonnes (Franklin, 1972), in 1955 it was about 1,230 tonnes, in 1962 it was 650 tonnes and in 1975 63 tonnes. More recent figures are contained in Table 10.1.

Table 10.1

ANNUAL LANDINGS OF FISH AND SHELLFISH IN MORECAMBE BAY AT STATIONS BETWEEN ROA ISLAND AND KNOTT END

Weight in Tonnes. (Data from M.A.F.F.)

	White Fish	Whitebait	Shrimps	Mussels	Cockles
1951-1953 mean	42.9	0	93.4	55.4	149.9
1956-1958 mean	104.0	0.2	351.1	60.8	12.1
1961-1963 mean	41.9	15.0	223.9	275.7	385.0
1966-1968 mean	41.5	37.5	202.0	20.6	0
1971-1973 mean	59.0	53.2	139.6	15.4	0
1976	66.4	58.1	143.4	0.4	85.0
1977	89.4	47.7	143.2	0.5	77.1
1978	88.1	11.7	141.5	8.0	58.7
1979	71.3	22.9	139.8	9.2	71.9
1980	126.2	24.6	108.1	1.8	105.8
1981	168.6	32.3	134.1	0	127.4
1982	216.2	69.6	162.0	0	67.3
1983	334.9	30.7	142.3	34.6	76.8
1984	42.9	74.5	114.7	28.2	75.3
1985	117.4	7.5	83.8	40.6	343.4

Mussels need a hard substrate for attachment and can only live on bare sand or mud in quiet shallow areas where they are not likely to be moved by tidal or river currents or waves. They are absent from the intertidal sands in the centre of Morecambe Bay, but there are large areas of mussel beds in the south west off Roosebeck and in the south east off Heysham, on the extensive areas of large stones and boulders which are locally known as "skears" or "scars". (See also Chapter 8.) There was formerly an important fishery for mussels for human consumption off Morecambe and Heysham, and between 1900 and 1905 about 2,030 tonnes were taken annually by about 100 fishermen. The beds off Heysham were considered over-crowded and a programme of relaying to more sheltered waters off Morecambe was undertaken. However, sewage contamination, public health regulations and difficulties of cleaning and marketing led to a decline of the fishery for human consumption between the World Wars and it was prohibited. In 1983 a new cleansing unit was opened in Morecambe, and about 35 tonnes a year are processed there. Some mussels continued to be taken for bait and between 1963 and 1971 an average of 15 tonnes a year was taken from the Rampside area. During the early 1970s there was a revival of interest in the collection of seed mussels suitable for transport and relaying on cleaner grounds such as the Menai Straits where they are sheltered and faster growing. For many years until 1977, when the channel changed position and the skears were covered with sand, the area off Roosebeck had a prolific and regular spatfall each spring: by 1980 the sand had moved and settlement was again taking place although there was not a prolific settlement until 1985. Most of the young mussels are destroyed each year either by starfish in the summer, or the gales of the following winter (Dare, 1976). The North Western and North Wales Sea Fisheries Committee has a Regulating Order in this area so that if there is a revival of interest in the collection of seed mussels, the Fishery can be controlled.

The third of the main shellfisheries in Morecambe Bay is the shrimp fishery based on the common brown shrimp *Crangon crangon*. During the warmer months there are large shoals of shrimps in the inner half of the Bay spread out over the shallows during high water but concentrated in the channels as the tide ebbs (see also Chapter 8). Fishing for shrimps is by trawling and two methods are used in Morecambe Bay. The Flookburgh fishermen use tractors to tow their nets in water up to 2 metres deep in the Kent and Leven channels to the east and west of Yeomans Wharf over the low water period. Most of the fishing by this method takes place in the Ulverston Channel and its branches. The Morecambe fishermen tow their nets from boats and fish in depths down to 4 metres mainly in the Kent and Keer channels and their branches, but also in the Heysham Channel and Heysham Lake and in the Ulverston Channel. Shrimp fishing has a seasonal pattern: it is often good in late spring, moderate in the summer, when there may be large numbers of small shrimps and young flatfish in the catch, and good again in the autumn. The success of the fishery varies from year to year, depending on several factors including breeding success, the flow of fresh water in the rivers and water temperature (Driver, 1977). In the mid-1960s the average annual catch was about 180 tonnes, but in the mid-1970s it had declined to about 140 tonnes mainly due to a decline in landings at Morecambe because of a reduction in the number of shrimps available and a diversification of the fishing effort. In the autumn of 1979 there was a glut of top quality shrimps in the Bay followed by a scarcity in 1980. The pattern continued with good catches in 1982 and very poor ones in 1985.

The shallow waters of Morecambe Bay are an important nursery ground for young fish of many species. Two groups are of particular importance. The first is the flatfish: plaice, dabs, flounders and soles. Large numbers of these species in the first year of life live on the sand and mud flats and are concentrated in the channels at low water. In late summer and autumn they are caught in large numbers in the shrimper's nets to the detriment of the shrimp catch and possibly the future strength of the fish stocks in the Irish Sea. Observations in 1978 and 1979 gave a mean number of 55 young fish, mainly plaice in each kilogram of riddled shrimps. There is some segregation of the species: young plaice and dabs are found on the sandy areas throughout the middle and outer parts of the Bay; their depth ranges overlap, but the plaice occur right to the waters edge while dabs are found in slightly deeper water. Flounders are most common in the upper parts of the estuaries where there is most freshwater influence, while soles are found in the outer more muddy areas such as Heysham Lake and the Walney Channel.

The other group of young fish which are abundant in the Bay are the pelagic herring and sprat. Together they are known as "whitebait" in their first year and they are subject to commercial fishing from Morecambe and Flookburgh. Whitebait are present in the Bay throughout the year and their abundance varies considerably from year to year. From Morecambe the fishery takes place mainly in late winter/early spring using stow nets and moored filter nets in the Keer Channel and off Heysham. From Flookburgh whitebait are mainly caught in early summer on Cartmel Wharf and Ulverston Channel grounds, where nets are set in the drainage channels and the fish are caught as the tide recedes. It appears that most of the whitebait in winter are sprats, whilst in summer most are herring.

Few adult fish are fished commercially in the inner part of the Bay and most of the white fish catch is made up of flounders. They are caught, as the tide recedes, mainly in fixed nets such as the stake nets which are set in long lines intertidally on the sand banks and mussel scars. Some plaice also are caught occasionally by this method. Recently there has been an occasional fishery for grey mullet and bass using seine nets and gill nets on the edges of the channels, and also by drifting with gill nets worked from punts. Catches of bass were particularly good in the early 1980s, based on a very good 1976 year class.

On the outer part of the Bay there is a trawl fishery in the deeper channel between Heysham and Fleetwood, mainly for plaice and soles by boats from Morecambe. Other species which are caught occasionally include skates, rays and cod. On the south-west there is also some trawling in the Walney Channel by small boats from Barrow. While most of the commercial fishing inside Morecambe Bay takes place from Morecambe and Flookburgh, the main fishing port in the Bay is Fleetwood. The smaller boats from Fleetwood fish in the outer parts of the Bay as well as in the coastal areas of the Irish Sea, while the larger boats fish out in the Irish Sea and beyond. Scattered around Morecambe Bay and in the estuaries such as the Lune there are small groups of fishermen, many of them part-timers, who help to exploit the fish and shellfish stocks.

Table 10.1 shows the changing pattern of the fishery in Morecambe Bay.

B. MIGRATORY FISH

D. Cragg-Hine (North West Water Authority, P.O. Box 30, New Town House, Buttermarket Street, Warrington, WA1 2QG).

Virtually all the rivers draining into Morecambe Bay have runs of salmon (Salmo salar L) and/or sea trout (Salmo trutta L) and eels (Anguilla anguilla L). The River Lune is one of the major salmon and sea trout rivers in England and supports extensive commercial and sport fisheries. The Kent and Leven also have significant runs of salmon and sea trout, which are exploited both commercially and for sport, although stocks in the latter river have declined appreciably in recent years. The Wyre has both salmon and sea trout, and there is provision for a commercial fishery in the estuary although this is suspended for the time being by North West Water Authority (N.W.W.A.) Byelaw with the aim of allowing stocks to improve. Recruitment of salmonids is generally poor in the Wyre, and this is attributed to its high silt loading in times of flood which tends to smother spawning redds. Sea trout and occasional salmon occur in the smaller rivers: the Crake and other lower Leven tributaries, Eea, Winster, Gilpin, Keer and, to a very limited extent, the Conder. The Bela has a few migratory fish, but the impassable weir at Beetham prevents access to most of the potential spawning and nursery areas.

Thus the Bay is extremely important as a migratory route for salmon and sea trout, and is probably an important feeding area for the latter.

Fishing for salmon and sea trout in the Bay and associated estuaries and rivers is regulated by the N.W.W.A. In the case of commercial fishing, the types of nets which may be used, the areas in which they may be fished (Figure 10.1) and the manner of their use, are specified in the Authority's Fishery Byelaws, and the numbers of nets which may be used in each area are restricted by Net Limitation Orders made by the Authority and approved by the Minister of Agriculture, Fisheries and Food. Thus in the Lune Estuary the nets currently permitted are 10 drift nets (known locally as hang or whammel nets) which operate seaward of Sunderland Point, 26 haaf (or heave) nets which operate seaward of Carlisle Bridge at Lancaster, and one seine net (draft or draw net) which operates

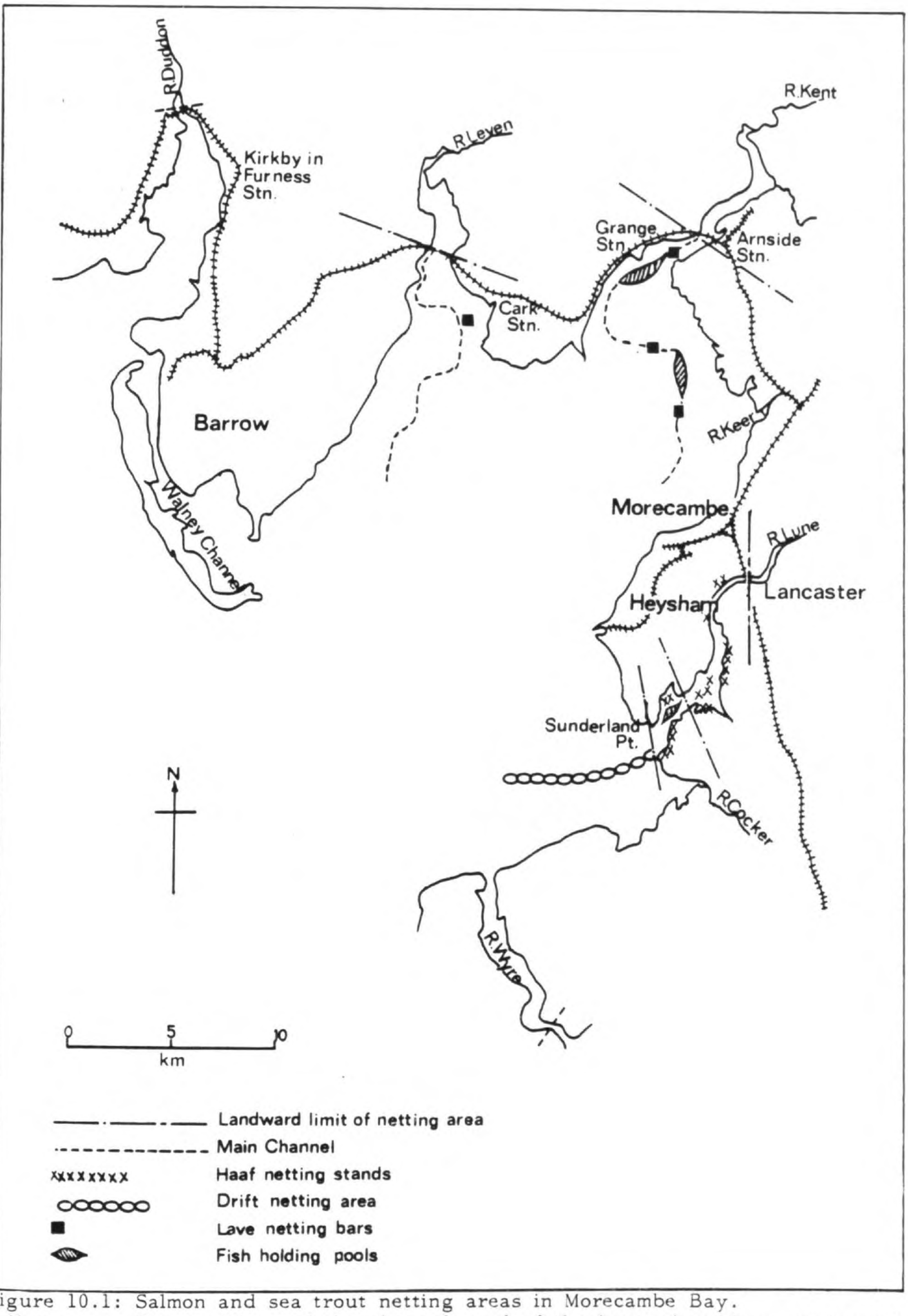

Figure 10.1: Salmon and sea trout netting areas in Morecambe Bay.
Note: The positions of the channels and of the bars where lave netting takes place vary from year to year, thus the positions shown are only approximate.

seaward of Bazil Point. The Lune Net Limitation Order was recently revised to reduce, as a conservation measure, the number of nets allowed. The Lune, in common with many other rivers, was badly affected by an outbreak of the epidemic disease known as Ulcerative Dermal Necrosis (U.D.N.) in the mid-1960s. This drastically reduced the spawning stocks, and although a partial recovery has occurred in most of the rivers which were affected, in the case of the Lune a significant recovery has not been evident. Because there is concern about the long term future of the salmon stock, this conservation measure has been adopted. In the Kent Estuary, fishing with lave nets (which are in effect large landing nets) is permitted seaward of a line drawn parallel to and 365m below Arnside Viaduct. The number of nets is limited to 8. Lave nets can also be used in the Leven Estuary, seaward of a line drawn 365m below Ulverston Viaduct; the number is limited to 6. There is provision for 4 haaf nets to operate in the estuary of the River Wyre, but as mentioned above, this is suspended for the time being as a conservation measure.

Salmon and to a lesser extent sea trout catches have declined since the early and mid-1960s. This is attributed largely to the effects of U.D.N., and in the case of salmon to increased exploitation by high seas netting. Increased land drainage and water abstraction affecting inflowing rivers, increased effluent discharges, and increased poaching in the headwaters during autumn have also been blamed for declining stocks, but it is impossible to assess the significance of such factors.

The average annual reported net catches of salmon from the Rivers Lune, Kent and Leven over the 6 years 1980-85 have averaged 1616, 56 and 37 respectively. For comparison, the average annual catch figures for the 6 year period 1962-67 were 4,126, 394 and 95 salmon respectively. Annual net catches of sea trout over the six years 1980-85 from the Lune, Kent and Leven averaged 1406, 23 and 19. Virtually all the commercial catch is made during the months of June, July and August with July generally being the peak month.

The Lune and the Kent account for most of the rod caught salmon reported from the rivers entering the Bay. During the period 1980-85, the average annual catches from these two rivers were 426 and 105 respectively. Comparative figures for 1962-67 were 958 and 128. The only other rivers where salmon are caught regularly are the Leven (including the Crake) and the Wyre, with average annual catches of 68 and 15 fish respectively. The total annual reported rod catch of sea trout from rivers entering the Bay over the period 1980-85 has averaged 1932. This compares with a figure of 4364 for the period 1962-66. Most of these fish are taken from the Lune, Kent, Leven and Crake. Details of both commercial and rod catches are published each year in the annual 'Summary of Fisheries Statistics , published by the N.W.W.A.

In recent years about 60% of the salmon caught have been grilse, i.e. adult fish which are returning to fresh water after spending only one year plus a few months feeding in the sea. Because of this, and also because of a general tendency evident nationally for salmon to run later in the year, the rod catches are concentrated in the last few months of the fishing season, which ends at the end of October. Up to about the mid-1960s, both the Lune and the Kent had significant runs of spring salmon which entered the rivers during February-April, but this is no longer the case.

Very little is known about eels, Anguilla anguilla in the Bay. There is, however, increasing interest in commercial fishing for eels in the region, and several fishermen are now operating fyke nets under licence from the Water Authority to fish for eels in the estuaries of the Lune and Wyre.

Investigations into migratory fish within the Bay itself have been restricted to compilation and analysis of catch data, which are now reported in the N.W.W.A. Annual Reports and Summaries of Fisheries Statistics. However, work on migratory fish is going on in the estuaries and lower reaches of rivers flowing into the Bay. There is considerable concern about the decline of migratory fish runs in the River Leven, and the view has been expressed locally that poor water quality conditions in the lower estuary may be causing both salmonids and estuarine fish such as flounders to avoid the estuary. However, intensive water quality and fish sampling surveys, carried out jointly by the N.W.W.A. and the Lancashire and Western Sea Fisheries Joint Committee during the late spring and early summer of 1980, have not provided evidence to support this view. Whilst the various possible causes for the decline were being investigated, an attempt was made to alleviate the situation by rearing salmon smolts at a nearby site, marking them by freeze branding so that they could be identified on their return to fresh water, and releasing them into the lower reaches of the River Leven. However very few recaptures of marked fish were reported.

The N.W.W.A in collaboration with the Water Research Centre and Aberdeen University, has been investigating the migration of adult salmon and sea trout through estuaries, particularly that of the River Ribble, by tracking fish tagged with sonic transmitters. Some preliminary work has also been done on the Lune. In the past there has been some concern about water quality in the Lune estuary, although there was never any evidence that passage of salmon and sea trout was prevented. The completion of the Stodday Sewage Treatment Works has resulted in an improvement in the estuary, as the effluent now goes through additional stages of treatment and is only discharged on an ebb tide. The interest in migration of fish through the Lune Estuary is linked more to the requirement to have an adequate residual flow of freshwater to the estuary after the N.W.W.A.'s Lancashire Conjunctive Use Scheme (L.C.U.S.) abstraction at Halton-on-Lune and the industrial abstractions at Lancaster. The L.C.U.S. abstraction from the Lune transfers water to the River Wyre at Abbeystead to support an abstraction for supply further down the Wyre at Garstang. To protect fishery interests and water quality in the estuary, abstraction at the Halton intake has to cease when the flow at Skerton Weir (the normal tidal limit) falls to 365 Ml/d (the Prescribed Flow). There are also restrictions on abstraction during small summer spates when these occur after the flow has been below 365 Ml/d for a prolonged period.

The freshwater flow requirements needed to encourage migratory fish to move through the estuaries and into freshwater are also being investigated by the use of electronic fish counters. This work was begun by the Lancashire River Authority and is being continued by the N.W.W.A. Electronic fish counters operating on the resistivity principle, have been installed in the lower reaches of the Rivers Leven, Lune, Kent and Wyre and upstream movement of salmon and sea trout, together with various environmental parameters, is monitored continuously. The Leven counter has been in operation since 1965, the counter at Halton-on-Lune since 1973, the counter at Skerton Weir on the Lune since 1979, the Kent counter since 1979, and that on the Wyre since 1983. The counter on the Wyre is downstream of the abstraction point at Garstang. River interests downstream of this abstraction are protected by prescribed flow conditions on the abstraction, and the purpose of the counter is to monitor the effectiveness of these protection measures as far as migratory fish are concerned.

Initial conclusions drawn from some of the early work with the fish counters have been published by the Fishery Officer to the former Lancashire River Authority (Stewart 1966, 1969, 1973). A more detailed analysis of both historical and current data is being carried out by the N.W.W.A. at the present time, and the information obtained has been used in the assessment of the flow requirements for upstream migration of salmonids (Cragg-Hine, 1985).

C. FISHES OF THE LITTORAL ZONE

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The distribution of littoral fish species is governed by the availability of suitable habitats. Within Morecambe Bay the only fish likely to be encountered in or on the vast areas of relatively unstable sand have usually been left stranded by the receding tide. In the upper regions of the Bay the brackish water of many of the estuaries appears to limit the number of species. The few rock pools tend to occur above M.T.L. and this in turn limits the range of species found in such habitats. It is therefore the skears (or scars) which offer the widest range of fairly stable habitats.

At Heysham the skears extend from H.W.N.T. to E.L.W.S.T. and beyond. Here, the substrate consists of small stones with scattered larger stones and boulders interspersed with pools. This offers a variety of habitats suitable for littoral fish. However, heavy mussel spat settlement on the lower areas of these skears (Dare, 1973; O'Sullivan, 1968) effectively limits fish distribution from time to time (Jones and Clare, 1977). The range of habitats encountered, together with the position of these skears in relation to the relatively saline water of Heysham Lake and a possible migratory route for fish to the upper eastern regions of the Bay, makes the area an important habitat for intertidal species.

The annual and long-term fluctuations in the abundance of all the fish species inhabiting the Heysham skears has been studied since 1956 (Jones and Clare, 1977; Jones and Miller, 1966), and in this chapter the summarised results obtained from this on-going survey are presented, together with notes and observations from other areas within the Bay.

Geographical and Vertical Distribution

The common goby, *Pomatoschistus microps*, has been recorded as the most abundant intertidal goby along the entire eastern seaboard of the Irish Sea (Jenkins, 1925) and in Morecambe Bay it is the most abundant intertidal fish. While common gobies may be found in saltmarsh pools and on occasions at E.L.W.S.T., they are most frequently encountered in pools between M.T.L. and M.H.W.N.T. It is within the latter area that almost all of the nests are made, the eggs being deposited on the undersurfaces of shells and stones in pools usually with a sandy substrate, pool depth being seemingly unimportant. Juveniles returning from the plankton may remain swimming in shore pools until the tide returns, indicating that only a partial metamorphosis has taken place. Even at this stage their apparent habitat preference is the same as that of the adult population.

It is not only the common goby that appears to prefer the zone above M.T.L. shannies, Blennius pholis, under 50mm in total length are more frequently found in the upper pools of the skears, though their distribution is limited to the more saline regions of the Bay. Adult shannies have been found at Heysham and Roa Island between M.T.L. and E.L.W.S.T.

In contrast to the vertical distribution of the common goby, the population levels of the butterfish, Pholis gunnellus, and the five-bearded rockling, Ciliata mustela, increase as shore height decreases. Both species are rarely found above M.T.L. even when common or abundant on the lower areas of the shore. The butterfish is the second most common littoral fish at Roa Island and Heysham, yet its geographic distribution on the eastern side of the Bay appears to be limited to the skears south of Morecambe, with occasional individuals being found at Sunderland Point in the Lune estuary. The more estuarine five-bearded rockling has, in addition to the sites listed above, been found at Bare and on the skears adjacent to Knott End. Little is known of either species' distribution on the northern shores of the Bay.

The vertical and geographical distribution of the much more infrequent juvenile and adult sea scorpions, Acanthocottus scorpius, and Taurulus bubalis, and sea snails, Liparis liparis, and Liparis montagui, is similar to that described for the butterfish. At Heysham, egg masses are occasionally laid by sea snails on stones and on the hydroid Campanularia gelatinosa, and by the short-spined sea scorpion Acanthocottus scorpius on rocks from M.T.L. down. At Roa Island, not only have the egg masses of the latter been found together with the adult fish at E.L.W.S.T., but also a butterfish and lumpsucker, Cyclopterus lumpus, have been recorded guarding a nest and egg mass respectively.

Of the remaining fish to be found, possibly only the rock goby, Gobius paganellus, and worm pipefish, Nerophis lumbriciformis, can be regarded as truly littoral fish. The rock goby has been described as "seemingly wholly dependent on rocky shores" (Holt and Byrne, 1903). However, immature individuals have been recorded from Lancashire and Cheshire where stones and weed occur on the predominantly sandy coastlines (Ellison and Chubb, 1962). At Heysham such immature individuals have been recorded from H.W.N.T. to L.W.S.T. and juveniles, together with the very occasional adult, between M.T.L. and M.L.W.N.T. on the western side of the Bay. The one worm pipefish found at Roa Island was located in a similar habitat to that reported from the Menai Straits, that is below a stone at L.W.S.T. Since Ellison and Chubb (1962) report another taken from the Walney Channel, it seems possible that an extensive and detailed search may reveal more specimens of this small and rather inconspicuous fish.

In addition there remain a number of fish whose presence within the littoral zone of Morecambe Bay, either in pools or beneath stones, is, or has been, recorded with some regularity. These are the pleuronectids (flatfishes), common eel, Anguila anguila, conger eel, Conger conger, and three-spined stickleback, Gasterosteus aculeatus. Of these, the three-spined stickleback appears to be limited to the saltmarsh pools and estuaries where it breeds, and congers have only been found at Heysham from M.L.W.N.T. down. However, the ubiquitous common eel occurs from saltmarsh pools to E.L.W.S.T. as do the sometimes abundant pleuronectids of less than 50mm in length. The latter are stranded in pools as the tide recedes and may also be stranded on the sand. If this happens they bury themselves before too much water has drained from the substrate. At Heysham they are more commonly found in pools above M.T.L., whilst the larger flatfish, flounders, Platichthys flesus, and plaice, Pleuronectes platessa, are found either in pools at E.L.W.S.T. or in the edge of the tide. (Occasional flounders have also been recorded from saltmarsh pools.)

The greater pipe-fish, Syngnathus acus, Nilsson's pipe-fish, Syngnathus rostellatus, three-bearded rockling, Gaidropsarus vulgaris, dragonet, Callionymus lyra, painted goby, Pomatoschistus pictus and Norway bullhead, Taurulus lillejeborgi, have been found stranded from time to time on the Heysham skears, and Clupeids and sand eels may be found on occasions in pools here and elsewhere in the Bay. In addition, the angler Lophius piscatorius has been reported stranded on the South America skears (P.J. Dare, pers. comm.) and lesser sand eel, Ammodytes tobianus, and lesser weaver, Trachinus vipera, have been recorded during benthic surveys on Heysham and Middleton Sands.

Reproduction and Seasonal Migration

The common goby is not normally found in spring until the edge of sea temperature is rising from 3° to 7°C, and is only rarely recorded after the autumnal/early winter temperatures have fallen below 5°C (Jones and Miller, 1966). The spring on-shore migration coincides with the commencement of reproduction. Although the occasional nest may be found in early April in some years, the greatest number of nests usually occurs between May and July. Thus, reproduction commences in spring when the temperature is rising from about 7° to 14°C, decreases during or after the summer temperature reaches its maximum, and ceases before the temperature falls below 12°C. Recruitment of juveniles to the seasonal population begins in June of some years and has always commenced by July. During the following two months the number of juveniles increases and recruitment ceases before November, when the average monthly termperature falls to 7°C.

A similar temperature orientated off-shore migration of rock gobies, common eels and conger eels may occur in Morecambe Bay. In the Isle of Man rock gobies remain on-shore in the winter months where the average temperature is between 5° and 9°C as opposed to the 3° to 5°C of the eastern Irish Sea (Bowden, 1955). However, in Morecambe Bay rock gobies are not generally recorded before July and are found no later than October, or after the temperature has fallen below 8°C. Elvers may be found on the shore in the spring when the average monthly temperatures are as low as 4°C, yet common eels above 125mm in length are not recorded until the temperature has reached 8°C. The population generally decreases as the temperature falls below 15°C and only two common eels have been recorded at temperatures below 12°C. Since none of the specimens found by the authors were considered to be sexually mature, Jenkins' (1925) statement on the migration of mature eels from the rivers of the Irish Sea basin in September and October should perhaps be extended to include a temperature orientated autumnal migration of fish from the littoral zone (Jones and Clare, 1977). Unlike the common eel, juvenile congers were not recorded until the temperature had risen above 14°C and not after it had fallen below 9°C.

Flatfish of between 20mm and 50mm in length are frequently recorded in April and always in May. By June their population is usually at its maximum and falls in the following two months. The lack of identification of individual fish makes any further precise comments impossible, but it is noticeable that fish above 55mm total length (all those examined were plaice or flounders) have not been recorded when the average monthly temperature falls much below 5°C, suggesting a temperature-related migration to deeper water. (Wheeler (1969) records such a migration in the dab, Limanda limanda.)

In addition to the above species, there may well be a migration into the shallower waters of the Bay of dragonets, pipe-fish and painted gobies and, since all have been found when the summer/early autumn temperatures are relatively high, a temperature-related migration cannot be ruled out. Although, similarly, the sea scorpions over 20mm in length are more frequently encountered during July, August and September, they have been recorded in every month. Their ova, together with occasional individuals, are found from October to February (rarely in March) when the temperatures range between 2°C and 6°C. Juvenile sea scorpions of less than 20mm in length are normally found between April and July, being more frequent in May and June.

Sea snails have, like the scorpions, been recorded in every month over a temperature range of 2° - 18°C, but the numbers encountered are always small. Juveniles, that is fish of less than 25mm length, are to be found between May and September but are more likely to occur in June and July. Fish above this size have only once been encountered in May and June and the egg-masses, though rarely located, do not appear until February and thereafter their numbers decline.

A late autumn/winter off-shore migration of many of the larger five-bearded rocklings occurs immediately prior to the breeding period for the species (Jenkins, 1925; Bruce et al., 1963; Yarrell, 1841) and may well, as far as mature fish are concerned, be for this purpose. Their subsequent return to the shore in summer and early autumn indicates that spawning in or around Morecambe Bay has generally been completed by June and does not continue beyond August. The distribution of rocklings above 10cm in length is sometimes uneven with specimens tending to group beneath occasional stones at E.L.W.S.T. (up to 15 have been found under a single stone no more than 40cm in diameter). This grouping remains unexplained, but the months in which this phenomenon is recorded, November to February, may prove significant since it occurs prior to and during the suggested breeding period for the species.

There is also an incomplete off-shore migration of butterfish and shannies. The butterfish migration may commence as early as June (Gibson, 1969) and does not appear to be caused by the immediate onset of the suggested breeding period, December to March (Jenkins, 1925), January and February (Quasim, 1957), nor does temperature appear to play too important a part. However, it is mainly the larger fish which are concerned in this migration and these have returned on-shore by April, immediately after the suggested spawning period. Similarly, the shanny makes no apparent temperature-related offshore migration within the Bay, though generally the greatest numbers of fish are recorded between August and December. This appears to confirm the suggestion that no major migrations are undertaken by the shanny, but most fish leave the littoral zone in winter (Wheeler, 1969).

Long-Term Population Trends

Since the survey on the Heysham skears commenced in 1956, some intertidal fish populations have been directly affected by the two severe winters of 1962-63 and 1978-79. It was the first such winter which played the greater part in population reductions, with extremely low sea temperatures being recorded over a period of some months. In the second, the sea surface temperatures did not fall until January 1979.

Of the fish recorded prior to the 1962-63 severe winter on the Heysham skears, two species, the conger eel and rock goby, have not been found since. From January to March 1963, dead and dying congers were reported from as far south as Torbay (Crisp, 1964), and it is therefore likely that heavy mortalities occurred in the Morecambe Bay population. (Large dead or moribund congers are occasionally reported washed ashore in the winter months in Morecambe Bay.) The reduction of the rock goby population was also almost certainly due to temperature, with mortalities occurring in the same winter in the Isle of Man (Crisp, 1964) when the temperature fell to 3.5°C (-0.5°C at Heysham). As previously stated, no rock gobies have been recorded since 1962 on the eastern side of the Bay, but juvenile rock gobies were recorded in 1968 at Roa Island and adults in 1969; none have been found since 1978.

Two other littoral species encountered within the Bay are certainly affected by prolonged cold. These are the shanny and common goby. It is only the two cold winters which have upset to any great extent the relatively stable population of the common goby, with no nests being found in 1963 and only a few in 1979 on the Heysham skears. However, this species has an extremely short life-cycle and is mature after the first winter of life. Therefore, with adequate numbers of juveniles arriving in the summers following these severe winters, a comparable level of population to that previously found was fairly quickly restored (O'Sullivan, 1968; Jones and Clare, 1977). Dead shannies were reported from mid-Wales northwards in the 1962-63 winter (Crisp, 1964), and it was not until the summer of 1964 that any of these fish were again found at Heysham. On these skears, the species did not re-establish an annual population level comparable to that of the pre-cold winter years until 1972, and the juvenile population fell in 1978. No juveniles were found in 1979 or 1980 on the skears adjacent to Knott End, but it is felt that the 1978-79 winter had no effect on the Heysham population.

The heavy mussel spat settlements recorded in 1963 and again in 1964 reduced the number of habitats available for littoral fish and it is almost certainly this that was the cause of the apparent decline recorded for some species during those years. Thus, although the number of sucker fish fell in the first few years after the 1962-63 cold winter, no mortalities were reported from other areas. The population of the five-bearded rockling also declined, but a decline was again noted in 1970. Whilst these falls in the number of rocklings recorded are inexplicable, it is of interest to note that after each decline, no fish above 175mm total length were recorded from the Heysham skears for a number of years.

The population of flatfish of less than 50mm length varies, increasing in some years and decreasing in others. In 1963 they became abundant for the first time and were again found to be as numerous in 1968 and 1969. Of the other species fairly regularly recorded on the skears, the irregular occurrence of sea scorpions has continued and the butterfish has maintained a fairly constant population level.

Appendix 10.1

FISH SPECIES LIST - J. Corlett

This list is based on the preceding reports, with unpublished data from surveys carried out since 1965 by the Lancashire and Western Sea Fisheries Joint Committee and by J. Clare and D. Jones. Ellison and Chubb (1962) provide an annotated account of all historic and occasional records.

Petromyzon marinus	Sea Lamprey
Lampetra fluviatilis	Lampern
Scyliorhinus caniculus	Lesser Spotted Dogfish
Squalus acanthins	Spur Dog
Galeorhinus galeus	Tope
Raja clavata	Thornback Ray
Raja batis	Skate
Clupea harengus	Herring
Clupea sprattus	Sprat
Anguilla anguilla	Eel
Conger conger	Conger
Salmo salar	Salmon
Salmo trutta	Sea Trout
Osmerus eperlangus	Smelt
Nerophis lumbriciformis	Worm Pipe-fish
Syngnathus acus	Greater Pipe-fish
Syngnathus rostellatus	Lesser Pipe-fish
Gadus morhua	Cod
Trisopterus luscus	Pout
Trisopterus minutus	Poor cod
Trisopterus esmarkii	Norway Pout
Pollachius virens	Coalfish
Pollachius pollachius	Pollack

Merlangus merlangus	Whiting
Ciliata mustela	Five-bearded Rockling
Gaidropsarus vulgaris	Three-bearded Rockling
Morone labrax	Bass
Ammodytes tobianus	Lesser Sandeel
Trachinus vipera	Lesser Weever
Scomber scombrus	Mackerel
Potomaschistus minutus	Sand Goby
Potomaschistus microps	Common Goby
Potomaschistus pictus	Painted Goby
Gobius paganellus	Rock Goby
Aphia minuta	Transparent Goby
Callionymus lyra	Dragonet
Blennius pholis	Shanny
Pholis gunnellus	Butterfish
Mugil labrosus	Grey Mullet
Atherina presbyter	Sand Smelt
Trigla lucerna	Yellow Gurnard
Trigla gurnardus	Grey Gurnard
Myoxocephalus scorpius	Short-spined Sea Scorpion
Acanthocottus bubalis	Sea Scorpion
Taurulus lilljeborgi	Norway Bullhead
Agonus cataphractus	Pogge
Cyclopterus lumpus	Lumpsucker
Liparis liparis	Sea Snail
Liparis montagui	Montagu's Sea Snail
Spinachia spinachia	Fifteen-spined Stickleback
Gasterosteus aculeatus	Three-spined Stickleback
Scophthalmus maximus	Turbot
Scophthalmus rhombus	Brill
Limanda limanda	Dab
Pleuronectes platessa	Plaice
Platichthys flessus	Flounder
Solea solea	Sole
Lophius piscatorius	Angler

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Chapter 11

PHYTOPLANKTON

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Introduction

Until quite recently very little was known about the phytoplankton of Morecambe Bay. Plankton from the Lune Deep and off Piel Island had been examined by Scott (1906, 1907, 1908) over seventy years ago, but unfortunately the tow-nettings were few and qualitative in nature.

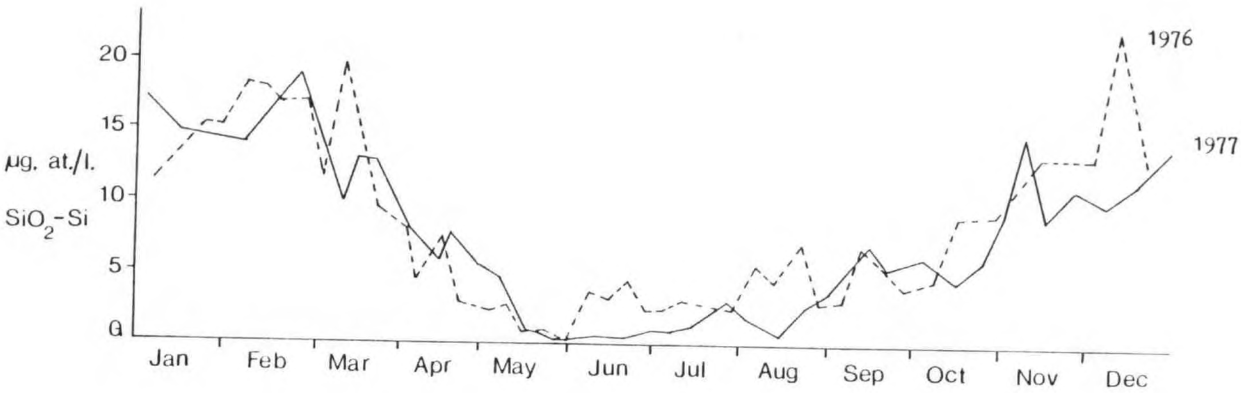
Over fifty years elapsed before further samples, designed specifically to monitor the distribution of the bloom alga *Phaeocystis*, were taken from the Bay) Jones and Haq, 1963). In the last decade phytoplankton data for the Wyre Estuary has been published (Evans, 1976a; Dussart, 1978), whilst the freshwater algae of some rivers flowing into the Bay have received attention (Wurthmann, 1970).

Water Quality

The mouth of Morecambe Bay, aptly described by Driver (1977) as a super-estuary, faces west and south-west towards the prevailing winds; winds from this quarter blow over a maximum fetch of 225km. This exposure and the Bay's shallowness ensure that the water is well mixed. Turbidity is consequently quite high; mean Secchi depths in Heysham Channel in 1976 and 1977 were 1.3 and 1.1 metres respectively.

The water quality of the Bay is modified by environmental parameters including land run-off, inflows of offshore water, tidal conditions, waste discharges, seasons and weather. The dominant influence on the nutrients is their uptake by the phytoplankton; this is responsible for a seasonal pattern of low summer and high winter nutrient concentrations. This pattern is exemplified by silicate (Figure 11.1).

Figure 11.1: Silicate concentrations in Heysham Channel, 1976 and 1977.



Significant negative correlations ($p = < 0.001$) between nutrient concentrations and salinity indicate that the main source of nutrients to the Bay is land run-off (Evans, 1979). This relationship is masked in summer by the uptake of nutrients by the phytoplankton.

Algal Standing Crops

Enrichment of the inshore water by fluvial inputs stimulates substantial increases in primary production such that algal standing crops are often an order of magnitude higher than those supported ten miles offshore, in impoverished seawater (Evans, 1979). The standing crops recorded in Heysham Channel in 1976 and 1977 are shown in Figure 11.2. The mean values in 1976 and 1977 were 3.43 and 2.86 mg/m^3 chlorophyll a respectively.

In the Bay itself standing crops in areas diluted by river water can be significantly different from those in the background water. The effects on the phytoplankton are variable in time, and depend largely on weather conditions, the existing nutrient status and the algal flora of the receiving water. Because mixing is continuous there is no major autumnal increase in diatoms in the Bay typical of stratified regions, e.g. English Channel.

Multiple linear regression analysis indicates that silicate and tidal amplitude are two important parameters in accounting for the variability of algal standing crops in Heysham Channel (Evans, 1979). The importance of silicate no doubt reflects its uptake by diatoms. The importance of tidal height (and hence current speed) probably reflects the degree of mixing, which in turn affects important factors such as light penetration, stability of the water column and nutrient concentrations.

Algae

From a floristic point of view, the phytoplankton of the Bay can be described as 'unremarkable' in the sense that most algal species are well-distributed throughout the coastal waters of the eastern Irish Sea and northern Europe (Drebes, 1974; Gieskes and Kraay, 1975; Kat, 1977; Evans, 1979). The plankton is neritic in character and typical of a turbulent open sea estuary. Species diversity indices are in the range quoted by Margalef (1958) for actively growing coastal populations and

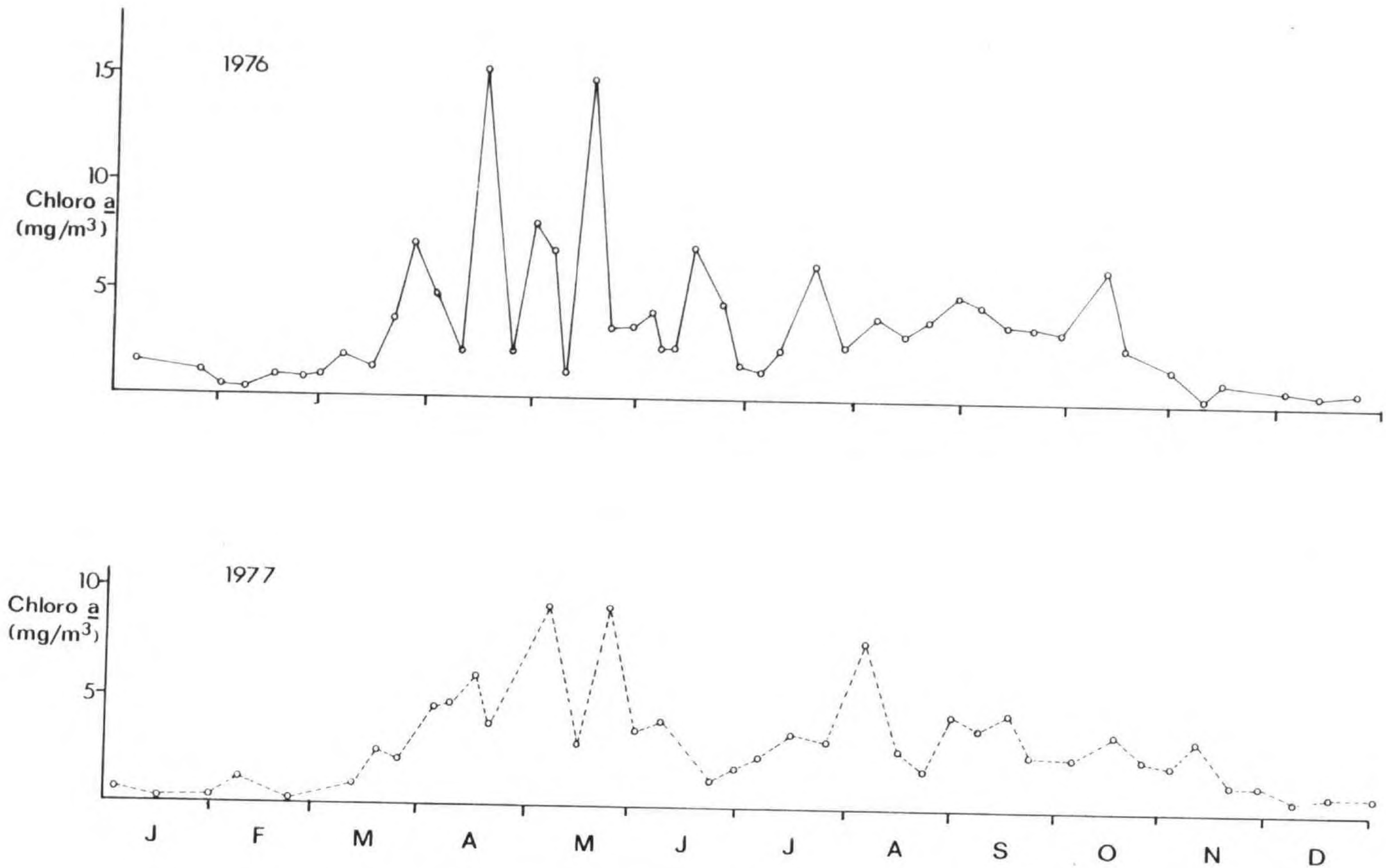


Figure 11 2: Algal Standing crops in Heysham Channel, 1976 and 1977.

show a predictable increase from 2.5 in the early stages of succession to 3.5-4.0 in the later stages.

Evans (1979) lists 145 algal species, representing 63 genera, for the eastern Irish Sea; most species were also present in Morecambe Bay plankton. The flora is dominated by diatoms, plants ecologically well adapted to cool, turbulent waters (> 70% dominance). Common species include Asterionella japonica, A kariana, Leptocylindrus danicus, Skeletonema costatum and Navicula vanhoffeni. With two notable exceptions (see below) dinoflagellates are only common locally in summer. Nannoplankton (<50µm.) are easily the largest contributors to the primary production of the Bay.

Algal Blooms

Occasionally, almost invariably during periods of calm, warm weather and/or following river spates, algal blooms develop. However, these blooms tend to be less intense and occur later than the blooms supported in Liverpool Bay. They do however involve the same species, viz; the haptophyte Phaeocystis pouchetii, and the dinoflagellates Gyrodinium aureolum and Noctiluca scintillans.

Blooms in general are not recent phenomena to the Bay. For instance, an 'immense swarm' of Noctiluca was reported in Walney Channel over sixty years ago (Scott, 1920). It has been suggested that their overall occurrence in the eastern Irish Sea has increased in recent years and this has been linked to the possibility of eutrophication (Burrows, 1975).

Gyrodinium aureolum was first recorded in U.K. waters in 1971 (Ballentine and Smith, 1973). The subsequent mass occurrence of this species in Morecambe Bay in 1975 and 1976 was part of larger outbreaks throughout the inshore waters of the eastern Irish Sea. Associated with the red-tides were mortalities to the lug worm, Arenicola marina and other marine life. Maximum concentrations at the peak of the red-tides in Heysham Channel were estimated to be 920,000 cells/litre (October, 1975). Mass occurrences of Gyrodinium may be associated with upwelling at offshore frontal boundaries (Pingree et. al. 1975, Tangen, 1977), although it seems fairly clear that calm weather conditions and a rich supply of nutrients are essential for a bloom of red-tide proportions to build up (Ottway et. al, 1977, Evans, 1979).

Immediately following the seasonal collapse of the spring diatom outburst Phaeocystis pcuchetii blooms with varying intensity (Figure 11.3). Although this gelatinous alga has yet to be positively associated with adverse effects on marine life it does seem to be implicated circumstantially, e.g. other plankton organisms, including zooplankters, tend to be depressed, and herring shoals are known to avoid such blooms (Savage, 1932; Jones and Haq, 1963; Spencer, 1972). However, its occurrence in the Bay does not appear to produce anything more deleterious than periodic complaints by fishermen, of 'scummy' fishing nets. The ecology of Phaeocystis in the eastern Irish Sea has been the subject of a detailed investigation in recent years by Spencer and co-workers at the Marine Science Laboratories, Menai Bridge.

The tomato-soup appearance of the water produced by Noctiluca scintillans is a familiar sight in summer in the outer reaches of the Bay. Despite red-tide densities in excess of 500,000 cells/litre there has never been a mass mortality reported in British waters conclusively linked to this organism.

Finally, on a much smaller scale, transient blooms of cf . Chlamydomonas spp. are occasionally observed in the brackish waters of the upper estuaries, e.g. the Kent estuary at Arnside in 1976. These blooms appear to be triggered off in dry summers by a sudden increase in terrestrial enrichment following flash floods.

Seasonal Succession

A synopsis of the seasonal succession of algae in Morecambe Bay, as exemplified by the succession in Heysham channel is as follows:-

The spring outburst of diatoms commences in March and is dominated by filamentous algae. Common species, in order of succession, are Biddulphia aurita, Skeletonema costatum, Navicula vanhoffeni, Asterionella japonica, A kariana and Thalassiosira rotula. Biddulphia regia and Eucampia zodiacus can also be important in the early and late spring flora respectively following influxes of offshore water, e.g. 1976.

After the crash of the spring outburst in late May the phytoplankton is dominated by Phaeocystis and Nitzschia delicatissima, which is found attached to the periphery of the Phaeocystis bladders. A cryptomonad sp. is common during warm, settled conditions, e.g. 1976.

The summer succession includes the diatoms Rhizosolenia delicatula,

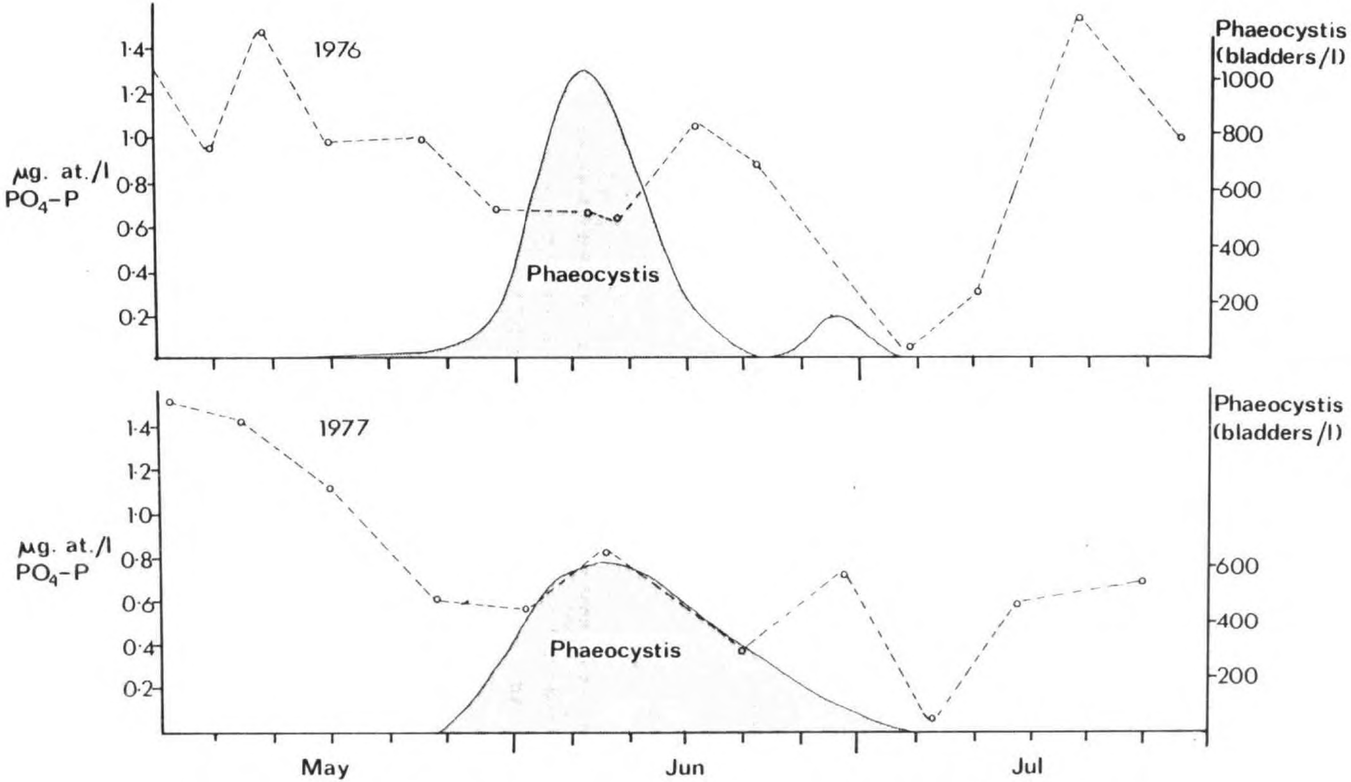


Figure 11.3: Phosphate and Phaeocystis pouchetii concentrations in Heysham Channel, 1976 and 1977

Leptocylindrus danicus, L minimus, and Chaetoceros spp. Various micro-algae and small dinoflagellates also increase in numbers. Noctiluca develops into blooms at the surface during hot, calm spells, e.g. 1975, 1976.

Asterionella japonica re-appears to dominate the late summer flora, together with Chaetoceros debile, C sociale and Leotocylindrue danicus. In recent years Cyrodinium aureolum has become a common component of the plankton during fine summers.

The autumn period can be dominated by Gyrodinium aureolum red-tides, or more normally in more unsettled conditions, a totally different flora, which includes Asterioneila japonica, Rhizasolenia dellcatula and a cryptomaonad sp. appears.

From November to February the sparse winter flora is composed chiefly of diatoms including large-celled Coscinodiscus and Biddulphia spp., together with Thalassionema nitzschioides and typical spring diatoms.

The distribution of Niteschia closterium is ubiquitous, and although never abundant is observed in Morecambe Bay plankton throughout the year.

Weather Effects

The seasonal succession and periodicity of the phytoplankton is strongly affected by the weather. For example, there was a marked contrast in weather patterns between 1976 and 1977, with light winds and a fine summer in 1976, and unsettled, windy conditions in 1977.

In 1977, water temperatures and light penetration were low, whilst turbulence, suspended solids and turbidities were high, compared with 1976 (Evans 1979). Low temperatures and light penetration delayed the timing of the spring outburst in 1977 by 2-3 weeks, compared with 1976 (Figure 11.2). Adverse environmental conditions continued through the summer, depressing algal growth and shortening the effective growing season. In short, the well-mixed cool water conditions in 1977 provided an ecological advantage to diatoms compared with other algal groups.

Nurtrient Limitation

It appears that algal growth may well be limited at different periods by particular nutrient deficiences (Evans, 1979). Thus it seems likely that the spring diatom outburst is limited in May/June by a shortage of silicate (Figure 11.1). On the other hand, the intensity of the succeeding Phaeocystis bloom seems to dependon phosphate availability (Figure 11.3). Negligible amounts of inorganic nitrogen are present in summer which suggests that a nitrogen deficiency may also limit algal growth. However, recent evidence suggests that in such situations only species with a specific requirement for inorganic nitrogen are limited, and that species capable of using organic nitrogen succeed them (Butler et. al., 1979). This hypothesis would account for the observed seasonal succession in Morecambe Bay. It should be emphasised though that the effects of zooplankton grazing have not been investigated to date.

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Chapter 12

NOTES ON THE DISTRIBUTION OF MACRO-ALGAE

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At the present time little is known of the distribution and identity of the macroscopic algae occurring on the saltmarshes and in many of the more estuarine regions of Morecambe Bay. This paper deals only with field records from a limited number of areas situated mainly towards the mouth of the Bay.

The distribution of the algae within these regions appears to be limited by salinity changes and the paucity of stable substrates. Whilst many are fairly generally distributed, others are found only in specific locations near the entrance to the Bay. Of these, Laminaria digitata, L. hyperborea, Delesseria sanguinea, Phycodrys rubens, Dilsea carnosa, Lithophyllum sp. and Corallina officinalis have been recorded from the less silty regions of the Walney channel, and Laminaria saccharina and Fucus serratus within the same area and at Heysham. Pelvetia canaliculata and Ascophyllum nodosum appear to have a similar distribution and in addition occur at Knott End.

Of the remaining species recorded, many may be found on the numerous small stones of the skears but the distribution of these is normally confined to the pools unaffected by mussel spat settlement. Ulva lactuca, Porphyra umbilicalis, P. purpurea, Pilayella littoralis and to a lesser extent Giffordia granulosa and Ectocarpus siliculosis may be found seasonally on the few boulders, stones and shells of the mussel beds proper.

In many pools the deposition of sand may result in algal holdfasts being covered. Cladophora sericea, Punctaria latifolia and Enteromorpha prolifera appear to be able to withstand such siltation but of these, only

E. prolifera is able to colonise the more stable regions of fine sand.

At one site, Roa Island, the lower areas of the shore are relatively unaffected by spat settlement and it is here that Polysiphonia urceolata and Chondrus crispus may be found exposed at E.L.W.S.T.

At Heysham some species may be found throughout the year with their numbers increasing particularly during the summer months. It is therefore of interest to note that although Enteromorpha compressa, E. intestinalis and E. linza may be found all year, E. prolifera displays a distinct seasonal pattern. Initial settlement commences no earlier than May and the species has not been recorded later than January. Similarly, of the two Ceramium species found, one, Ceramium rubrum, occurs between April and October whereas C. diaphanum is present all year.

Amongst the remaining algae found at Heysham which show distinct patterns of occurrence, Dumontia incrassata may be absent in May, June and July; Monostroma grevillei generally appears in February and has not been recorded later than May; Chorda filum occurs from March to October; Petalonia fascia and Punctaria latifolia appear in January and are absent after July; Ectocarpus siliculosis and Giffordia granulosa are found in May but no later than August and October respectively, and Bryopsis hypnoides has been recorded only from June to October.

Such seasonal increases in numbers and patterns of settlement have not been recorded from areas other than Heysham, but similar trends may occur elsewhere.

At present, a much more detailed survey of the seasonal and geographic pattern of distribution of algal species within the Bay as a whole, is required.

Appendix 12.1

SPECIES LIST OF ALGAE FROM SELECTED AREAS OF MORECAMBE BAY

Key

Area 1: Heysham flat and Knott End skears, Heysham.

2: Skears and sea walls in the vicinity of Knott End on Sea.

3: Roa Island.

4: Battery paddling pool, Sandylands promenade, Morecambe.

5: Throbshaw Point, Heysham.

6: West End Pier and paddling pool near Stone Jetty, Morecambe.

CHLOROPHYCEAE	AREA					
	1	2	3	4	5	6
Blidingia marginata				X	X	X
Blidingia minima	X	X	X	X	X	X
Bryopsis hypnoides	X					
Bryopsis plumosa				X		
Chaetomorpha linum	X	X		X	X	
Cladophora rupestris	X	X			X	
Cladophora sericea	X	X		X	X	X
Endoderma perforans	X					
Enteromorpha compressa	X		X			
Enteromorpha intestinalis	X	X	X	X	X	X
Enteromorpha linza	X					
Enteromorpha prolifera	X	X	X	X	X	X
Entophysalis conferta	X					
Monostroma grevillei	X				X	X
Prasiola stipitata	X				X	
Pringsheimiella scutata	X					
Rhizoclonium riparium					X	
Rosenvingiella polyrhiza	X					
Ulva lactuca	X	X	X	X	X	X

PHAEOPHYCEAE	AREA					
	1	2	3	4	5	6
Ascophyllum nodosum		X	X		X	
Chorda filum	X	X				
Cladostephus spongiosus	X					
Ectocarpus fasciculatus		X		X	X	X
Ectocarpus siliculosus	X					
Elachista fucicola	X					
Fucus ceranoides		X			X	
Fucus serratus			X		X	
Fucus spiralis	X	X	X	X	X	X
Fucus vesiculosus		X	X		X	
Giffordia granulosa	X				X	X
Hecatonema maculans	X					
Laminaria digitata			X			
Laminaria hyperborea			X			
Laminaria saccharina	X		X	X		
Mikrosyphar polysiphoniae	X					
Myrionema strangulans	X					
Pelvetia canaliculata		X	X		X	
Petalonia fascia	X			X	X	X
Pilayella littoralis	X	X	X	X	X	X
Punctaria latifolia	X					
Scytosiphon lomentaria	X			X		

RHODOPHYCEAE

	AREA					
	1	2	3	4	5	6
Audouinella floridula					X	
Audouinella purpurea					X	
Audouinella secundata	X					
Callithamnion hookeri					X	X
Catenella caespitosa					X	
Ceramium diaphanum	X	X	X	X	X	X
Ceramium rubrum	X	X		X	X	X
Corallina officinalis			X			
Chondrus crispus	X	X		X	X	X
Delesseria sanguinea			X			
Dilsea carnosa			X			
Dumontia incrassata	X	X				
Erythrotrichia carnea	X					
Griffithsia flosculosa	X					
Hildenbrandia rubra	X	X	X			
Lithophyllum sp.			X			
Polysiphonia elongata	X					
Polysiphonia macrocarpa					X	
Polysiphonia nigrescens	X	X	X	X	X	X
Polysiphonia urceolata	X		X			
Phycodrys rubens			X			
Porphyra purpurea	X	X				X
Porphyra umbilicalis		X	X	X	X	

The authors thank Dr Ian Tittley of the British Museum for permission to publish his records for areas 4, 5 and 6 in the above lists.

Chapter 13

THE NATURE CONSERVATION IMPORTANCE OF MORECAMBE BAY

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Wildlife and Countryside Act 1981

A number of areas in and around the Bay are notified by the Nature Conservancy Council as Sites of Special Scientific Interest (S.S.S.1.s) under Section 28 of the Wildlife and Countryside Act 1981, having previously been notified under Section 23 of the National Parks and Access to the Countryside Act 1949. Notification under the 1949 Act provided an early warning system through which local and other authorities were informed of their scientific importance and consulted the Nature Conservancy Council (N.C.C.) if developments were proposed so that the N.C.C.'s views could be taken into account. However it did not put any onus on the owners not to damage the scientific interest. The 1981 Act strengthened the legislation by in addition requiring the N.C.C. to inform the landowners of activities which could damage the site and by requiring owners to consult the N.C.C. if they propose to carry out any of these activities, thus giving the N.C.C. time to embark upon conservation measures.

The entire intertidal areas, fringing saltmarshes and (where they occur) sand dunes are covered by three Sites of Special Scientific Interest outlined and numbered in Figure 13.1: Morecambe Bay (1), Lune Estuary (2) and South Walney and Piel Channel Flats (3). These three areas constitute the Morecambe Bay Grade 1* Site described in 'A Nature Conservation Review' (Ratcliffe, 1977) as being of international importance by virtue of supporting the biggest wintering and passage population of wading birds in Britain. The capacity of these areas to support this population derives from the vast feeding grounds provided by the great expanses of sand-silt flats rich in invertebrates and on the fringing saltmarshes, shingle banks and scars which provide secure roosts for the waders at high tide.

The saltmarshes also have considerable importance as feeding

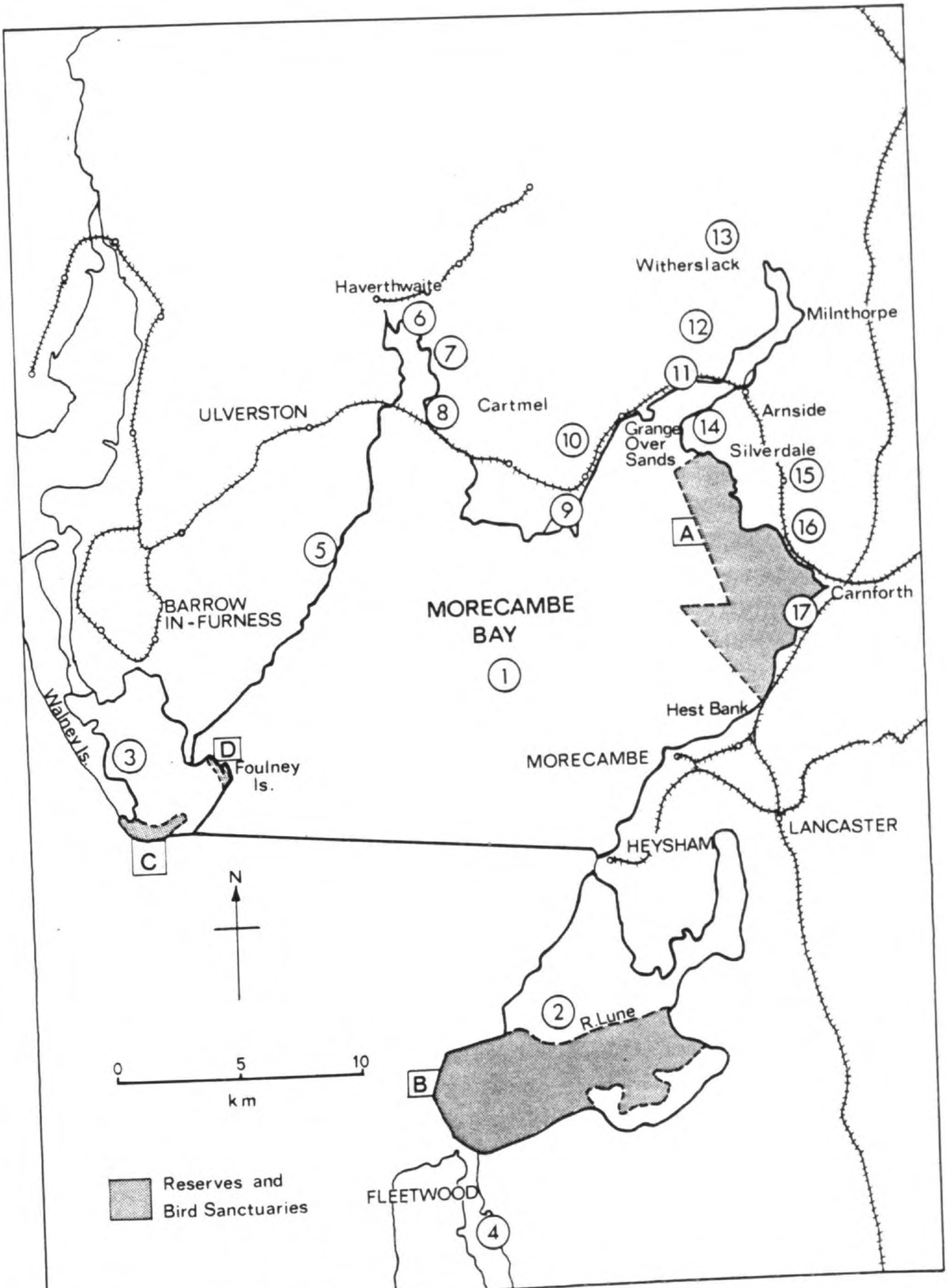

Figure 13.1: Nature Reserves, Bird Sanctuaries and Sites of Special Scientific Interest.

habitat for wildfowl, but they are so heavily grazed, and worked for sea-washed turf, that their value for breeding birds and their botanical interest are relatively low. The only ungrazed species-rich saltmarshes are to be found on Walney Island and two small saltmarshes in the Wyre estuary: Barnaby Sands and Burrows Marshes (4), all of which are S.S.S.I.s. The only sand dune system is South End Haws on Walney Island (C on Figure 13.1), which has many characteristic sand dune plants, a large nesting colony of Lesser Black-backed and Herring Gulls, and the southernmost breeding site of Eider Duck on the west coast. The shingle spit of Foulney Island (D) has the only colony of Sandwich Terns in the Bay, and Common, Arctic and Little Terns also breed here. The Oyster Plant (Mertensia maritima) has been recorded on shingle on Walney and Foulney at its southernmost station in England.

The nature conservation interest of Morecambe Bay is not confined to its littoral and intertidal zones, though the scale of its ornithological importance is inclined to dwarf other aspects, and there is a whole series of S.S.S.I.s clustered around its margins, most of which are identified as being of national importance (Grades 1 or 2) in the Nature Conservation Review (N.C.R.). Some, such as Sea Wood (5 on Figure 13.1) and Humphrey Head (9) actually make up part of the coastline, others like Meathop Moss (12) and Leighton Moss (15) owe their origins to post-glacial changes in sea level, but all must be influenced by the proximity of the Bay, and would be affected to some extent by major changes in the Bay. The Arnside-Silverdale peninsula in particular contains a rich complex of limestone habitats, represented by the Gait Barrows National Nature Reserve (N.N.R.) and 10 S.S.S.I.s. The unique ecological conditions of Roudsea Wood and Mosses N.N.R. (6 and 7) are contributed to by tidal influences on the water levels and composition in low lying parts of the woodland.

The main features of the S.S.S.I.s and National Nature Reserves (N.N.R.s) are summarised briefly below as numbered on Figure 13.1. Only sites adjoining or actually overlooking the Bay are included.

1. Morecambe Bay — c. 29950 ha NCR:Grade 1*

    Sand-silt flats, saltmarshes, shingle banks and scars.

2. Lune Estuary — c. 7928 ha NCR: Grade 1*

    Sand-silt flats and saltmarshes.

3. South Walney and Piel Channel Flats c. 2494 ha NCR:Grade 1*

Dunes, shingle spits, flats and saltmarshes.

4. Barnaby Sands Marsh 67 ha not NCR

Burrows Marsh 36 ha not NCR

Ungrazed, species-rich saltmarshes.

5. Sea Wood 25 ha not NCR

Oak-ash woodland on coast.

6.+7. Roudsea Wood and Mosses NNR 277 ha NCR:Grade 1

Oak, ash and yew woodlands on limestone and slate, and coastal raised peat mosses.

8. Barker Scar 18 ha not NCR

Relict sea cliff with geological exposures, grassland and woodland on limestone.

9. Humphrey Head 29.5 ha NCR:Grade 1

Richly fossiliferous limestone cliffs with rare plants.

10. Wart Barrow 15 ha not NCR

Limestone grassland and scrub.

11. Meathop Woods and Quarry 49 ha not NCR

Quarry with palaeontological and sedimentological features, and limestone woodland.

12. Meathop Moss 67 ha not NCR

Relic of coastal raised bog.

13. Whitbarrow 919 ha NCR:Grade 1

Largest and most scientifically valuable area of limestone pavement in the Lake District, also extensive native woodland and limestone grassland, cliffs and screes.

14. Arnside Knott 75 ha NCR:Grade 2

Limestone grassland and heath, screes, woodland.

15. Leighton Moss 125 ha NCR:Grade 1

Floodplain mire with reedbeds of exceptional importance for fenland birds.

16. Warton Crag 73 ha NCR:Grade 2

Limestone grassland, scree, pavement and woodland.

17. Crag Bank 4 ha not NCR

A small but exceptionally rich botanical site.

Protection of Birds Act 1954

The Wyre-Lune Sanctuary (B on Figure 13.1) became a statutory bird sanctuary by the Wild Birds (Wyre-Lune Sanctuary) Order 1963 made under the 1954 Act. Covering about 3,500 ha of the Lune Estuary S.S.S.I., its main function is to provide a protected roost for the Pink-footed Geese which winter in the Fylde. It is managed by a Sanctuary Committee on which local wildfowling and conservation bodies are represented, and is classed as a National Wildfowl Refuge. Foulney Island (D) was made a statutory bird sanctuary by the Wild Birds (Foulney Island Sanctuary) Order 1980 to protect the tern colonies. The status of these bird sanctuaries was not altered by the Wildlife and Countryside Act 1981.

The Wild Birds (Oyster-catchers) Order 1956 placed Oystercatchers on the Second Schedule for Morecambe Bay and the Lune Estuary, from Barrow to Fleetwood, which meant that they could be killed or taken by authorised persons (otherwise they were fully protected throughout the year). This action was taken in response to complaints of damage to cockle fisheries, but did not have any effect on the Oystercatcher populations. The Order was repealed on implementation of Part 1 of the Wildlife and Countryside Act 1981.

Nature Reserves of Voluntary Bodies

The Royal Society for the Protection of Birds (R.S.P.B.) Morecambe Bay Reserve (A on Figure 13.1) covers some 2,400 ha of the mudflats and saltmarshes stretching from Hest Bank to Silverdale and includes the main wader roost at Hest Bank. The R.S.P.B.'s Leighton Moss Reserve (15) which is less than 1 km from the Bay at its nearest point, is an extensive peat moss, formerly reclaimed for agriculture but now reverted to fen due to flooding with lime-rich water following failure of the pumped drainage system during the First World War. Large areas of reed-bed fringed with willow/alder scrub now surround pools of open water. The reed-beds are famous for their populations of Broadland-type birds such as Bittern and Bearded Tits and the site is also of importance for wildfowl.

South End Haws on Walney Island (C) and Foulney Island (D) are Reserves managed by the Cumbria Trust for Nature Conservation, as also is Meathop Moss (12) and part of Whitbarrow (13).

Ramsar Sites (Wetlands of International Importance) and Special Protection Areas (E.C. Directive)

The convention on Wetlands of International Importance especially on waterfowl habitat was adopted at a meeting of countries concerned with wetland and waterfowl conservation which was held at Ramsar, Iran in 1971. The objectives were to stem the progressive encroachment on, and loss of, wetlands (which can include intertidal and marine areas) now and in the future. The U.K. Government signed the Convention in 1973 and ratified it in 1976. In so doing it accepted a commitment to promote both the concervation of particular sites and the wise use of wetlands and is required to designate wetlands in accordance with agreed criteria for inclusion in a list of 'Wetlands of International Importance'.

As the U.K. is a member of the European Community, the Government is bound by the European Communities Council Directive of April 1979 on the conservation of wild birds. Member states are required to take special measures to conserve the habitat of certain rare or vulnerable species and regularly occurring migratory species, and to classify the most suitable areas for these species as Special Protection Areas.

Morecambe Bay and the Lune Estuary meet the criteria for both types of site and will be proposed for designation as Ramsar Sites and Special Protection Areas. The R.S.P.B.'s Leighton Moss Reserve, adjacent to Morecambe Bay, was designated a Ramsar Site and Special Protection Area in November 1985.

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Chapter 14

FURTHER RESEARCH NEEDS

(eds.) N.A. Robinson
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One of the objectives of the Morecambe Bay Study Group in compiling this assessment of the present state of knowledge about the Bay was to draw attention to fields where information was inadequate and further research needed. While compiling their papers contributors have identified the following areas where there is a need for further work or where the results of work which may have commenced are not yet available.

Geology and Quaternary Features.

- Sub-surface solid and quaternary geology.
- Evidence for pre-Devensian glaciation and interglacial stages.
- Dating the build-up of Devensian ice of local Lake District and foreign origin.
- The elucidation of pre-Flandrian marine episodes and the origins of 'sea caves' and elevated marine features.
- Mapping Flandrian marine sediments to shed light on early coastlines of Morecambe Bay and palaeotidal changes.
- The neotectonics of the Bay and adjacent areas, reversal of buried beach gradients, and subsidence.

Water and Sediment Movements.

- Collection of detained wave, tide and current data within the Bay.
- Study of the dynamics of sediment movement.
- Recording of sediment changes at specific locations and investigation of the controlling processes.
- Investigation of the physical processes leading to accretion and erosion of saltmarsh.

Water Quality

Distribution of radionucleides.

Long term effects of increased nutrient loadings on the productivity of the Bay.

Saltmarshes

Saltmarsh development and erosion.

Development of hummocky low marsh into smooth sward.

Effects of turf cutting on saltmarsh vegetation.

Effects of grazing on saltmarsh vegetation, and the relation to the value of saltmarshes for wildfowl and breeding birds.

The invasive spread of *Spartina*, and means of its control.

The conditions required by nationally rare plant species.

The role of algae in saltmarsh development.

Invertebrates.

The composition and seasonal variation in zooplankton.

Birds.

The identity and distribution of the food items of waders.

Wintering sea-duck in the mouth of the Bay.

Fish and Fisheries.

The source of Whitebait present in the Bay.

The source of Mussel spat.

The reasons for variation in cockle breed strengths.

Effects of Heysham Nuclear Power Station on fish.

Movement of migratory salmonids in estuaries particularly in relation to freshwater discharges.

Algae.

Detailed survey of geographical distribution of algal species within the Bay and its seasonal variations.