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NATURAL ENVIRONMENT RESEARCH COUNCIL LONDON (ENGLAND)
THE SEVERN ESTUARY AND THE BRISTOL CHANNEL.(U)
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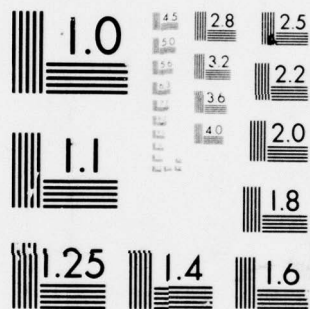
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An Assessment of Present Knowledge

compiled by:

University of Bristol
University College, Swansea
and NERC's

Institute of Coastal Oceanography and Tides
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Unit of Coastal Sedimentation

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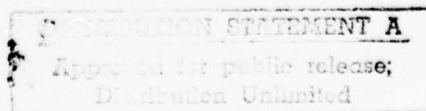
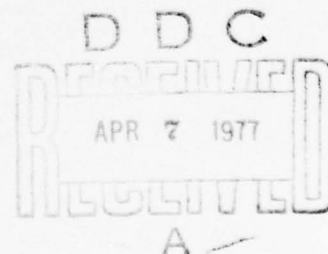
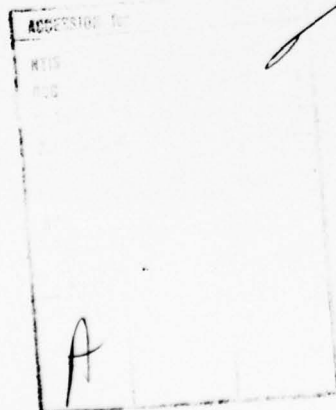
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Aerial view of the Severn Estuary (photo Airviews Ltd).

PREFACE

Estuaries have attracted much attention recently and an increasing research effort is being directed to their problems. There are many reasons for this, stemming from the developing needs of new industries and new conurbations for marine access, for industrial and domestic water supply, or simply for new land sites. At the same time, estuaries are a major pathway by which materials reach coastal seas and, ultimately, the oceans. In its task of encouraging and executing research in the natural environment, the Natural Environment Research Council has underlined the need for more basic and background information about how estuaries work, what fauna and flora they support, and how estuarine systems are likely to respond to the uses we make of them.

Among British estuaries, that of the Severn, which together with other contributory rivers, develops into the more complex Bristol Channel, is one of the largest. Historically, it has played an important part in the development of the major industrial centres of Bristol, Gloucester, Newport, Cardiff and Swansea. Proposals for future development, notably expressed in the Severnside Feasibility Study (1971), suggest a much greater potential utilisation of the estuary and its hinterland. The geomorphological characteristics of the area, and especially the high energy conditions of the estuary, make it of singular scientific interest.

An initiative in promoting scientific study of the area was made, early in 1970, by the University of Bristol, with the formation of the inter-disciplinary 'Sabrina Group' which asked NERC for support of a number of research projects in the whole watershed area. As a part of its response to this initiative, but in this case limited to the estuary proper, NERC called a meeting on the 3rd December 1970 of representatives of the University of Bristol and of Council's component institutes engaged in estuarine research. The meeting was chaired by Professor R. W. Edwards, Department of Applied Biology, University of Wales, Institute of Science and Technology, and a member of Council. The meeting recognised that an essential first step in formulating a research programme was the collation and evaluation of existing information about the estuary.

Both 'Sabrina Group' scientists and those from NERC institutes contributed papers to cover the major aspects of the estuary and subsequently, University College, Swansea, were also involved in the exercise. Individual contributions were then compiled as a unified report.* For the purposes of this report, the Severn Estuary was defined as the tidal part of the Severn River, downstream to a line from Brean Down, through Flat Holm and Steep Holme to Lavernock Point. The seaward boundary of the Bristol Channel was taken as a line between Hartland Point, Lundy Island and Milford Haven.

*A number of people have assisted, but particular

mention should be made of Mr. D. Hamilton (University of Bristol.), Dr R. Kirby (UCS) and Dr G. W. Heath (IMER.).

It is not the purpose of this review to assess the use of the natural resources of the area, nor to offer judgment or views on the control of activities, that might give rise to pollution or physical interference with the estuary. However, it is recognised that planning and control of such activities will require a sound basis of physical, chemical and biological knowledge. The report attempts a critical assessment of the information available; its conclusions show where present knowledge is inadequate and where further research is called for.

Since this report was completed (June 1972), two other reports of relevance have appeared. One of these is the Department of Environment's Report on 'Water Quality in the Severn Estuary and Recommendations for Future Investigation', prepared by the Water Pollution Research Laboratory. This 'desk study' has examined data on the water quality characteristics: freshwater flow, salinity, dissolved oxygen, biological oxygen demand, nitrogen compounds and some information on heavy metals content of muds. The aim of the reports is to formulate a predictive mathematical model for the distribution of pollutants which can assist management of the estuary. Focusing, as it does, on the upper end of the estuarine system and on the composition and flow of tributaries and effluent outfalls, the report does not overlap with the one presented here, the two being complementary. In addition, in pursuing the aim of model-making on the basis of physical and chemical data, the WPRL Report does not include considerations of a biological nature, other than those implicit in the oxygen demand.

Secondly, the Royal Commission on Environmental Pollution has recently published a Third Report entitled 'Pollution in some British Estuaries and Coastal Waters' (Command No. 5054). In their conclusion to a most informative report on the state of our estuaries and coastal waters, the Commissioners stress the need for more background knowledge of estuarine systems, particularly the need for more knowledge and understanding of the long-term toxicity of pollutants in the aquatic environment, effective mathematical models, more knowledge of coastal hydrography, accumulation processes, and development of the use of biotic indicators of pollution.

On behalf of NERC, I would like to express the hope that this report, and others to follow, will contribute to the task of gathering relevant information to a single locus, of identifying gaps in knowledge and of stimulating the development of further research to provide a scientific base for the wise use of the estuary as a major natural resource.

December 1972

R. J. H. Beverton, Secretary of Council



1. SYNOPSIS

1.1. Boundaries of the Area—The Severn Estuary is funnel-shaped and extends from Upton-on-Severn to Flat Holm and Steep Holme, a distance of 90 miles (150 km). The Bristol Channel is 60 miles (100 km) long, is 8 miles (14 km) wide at the Holms and reaches a width of 45 miles (70) km at its western limit at Lundy Island. Nearly one sixth of the land area of England and Wales drains into the Severn Estuary, whilst the Bristol Channel receives only limited freshwater inflow.

1.2. Geology and Sedimentology—The coastline of the Bristol Channel is predominantly rocky, which contrasts with the generally unconsolidated sediments forming much of the coastline of the Severn Estuary. Although some preliminary mapping of the solid geology and the bedrock surface morphology has been carried out in both the Channel and Estuary more detailed knowledge, particularly in the Severn, is required. The nature of the unconsolidated sediments in the Severn Estuary and Bristol Channel is known only for limited areas.

The major channels are flanked by large shoals, some of which are known to be unstable. There are insufficient data relating to the causes and processes of this instability and equally little information is available on the nature of the extensive marginal tidal flats. Their role in the sediment budget of the estuary is unknown.

1.3. Water Movements—The estuary has the greatest diurnal tidal range in Britain—over 40 feet (12 m) at Avonmouth, a range of about 10 feet (3 m) between equivalent spring and neap tides, and

a geographical variation in tidal range throughout the length of the estuary. Tidal stream velocities are known but the dynamics of the system, including circulation, salinity and temperature patterns are inadequately understood.

1.4. Chemistry—Materials carried into the Estuary in fresh water discharges are subjected to interaction with saline water. Resuspended sediments are important as buffers, stores and catalysts. Studies of these sediments and their organic and inorganic processes are vital to a sound chemical understanding of the capacity of the estuary to accept, degrade and tolerate the pollution load.

1.5. Biology—There is little information about biological aspects of the unconsolidated sediments of the Severn Estuary—particularly of those in the sub-littoral zone. Rather more is known about the benthos of the rocky intertidal surfaces, some sandy shores and certain sub-littoral regions of the Bristol Channel. Attached algae have hardly been studied.

The distribution of invertebrates reflects salinity regimes and suspended sediment content. Fish in the area are mainly known from records of commercial fisheries, dating from the fifteenth century. Some species have declined in recent times.

Marine plankton diminish in variety of species and abundance with distance upstream from the mouth of the estuary. Abundance appears to be influenced by the turbidity of the water.

Work on salt marshes has emphasised the important role of *Spartina* grass in retarding currents and thereby trapping sediments.

2. GEOLOGY AND SEDIMENTOLOGY

2.1. Geological Setting—The solid geology influences both the orientation and shape of the Bristol Channel and Severn Estuary. The present coastline in the Bristol Channel is predominantly solid rock while in the Severn Estuary/Bridgwater Bay, the coast is mainly unconsolidated sediments.

2.1.1. Bristol Channel—The land area adjacent to the Bristol Channel has been mapped by the Institute of Geological Sciences and other research workers, mostly on the scale of 1:10,560 and in parts on 1:2,500. Therefore the basic onshore geology is quite well known but data derived from boreholes on land allow only limited extrapolation offshore.

In contrast, only limited areas of the offshore surface geology have been mapped in comparable detail. To date, preliminary mapping of the solid geology in the Bristol Channel has been done by means of continuous seismic profiling, gravity coring, side-scan sonar, gravity, magnetic, and seismic-refraction techniques. This work has been

carried out by the University College of Swansea, University College, London, and the National Institute of Oceanography.

2.1.2. Severn Estuary—The solid geology marginal to the estuary has been mapped by the Institute of Geological Sciences and other workers on the scale of 1:10,560.

Detailed studies have been made of certain areas, such as the M4 Severn Bridge, Severn Tunnel, Central Electricity Generating Board Tunnel, power station sites and other civil engineering sites.

Much more borehole information is available along the margin of the Severn Estuary than along the Bristol Channel, despite the disparity in the geographical size.

In the Severn Estuary solid rock is exposed on some wide shoals, on islands and in some tidal channels. The Unit of Coastal Sedimentation and the University of Bristol have carried out preliminary continuous seismic profiling and gravity coring surveys, between Avonmouth and the Holms. Some information is available from site investigation reports.

2.1.3. Morphology of the Bedrock Surface—

The bedrock surface is mostly a buried channel system of Pleistocene to Recent age. This channel system extends beyond the limits of the present Severn Estuary/Bristol Channel. Continuous seismic profiling surveys, carried out by Swansea University, have produced an outline of the buried relief between the Holms and the Lundy/Caldy region, amplified by more detailed surveys of certain areas. This work is being supported by surface sediment sampling and bedrock coring. Preliminary seismic surveys have been carried out in the Severn Estuary.

2.2. The Unconsolidated Sediments—The sedimentary environment of the Severn Estuary and Bristol Channel is greatly influenced by the high energy conditions resulting from the high tidal velocities.

The thickness of offshore sediments is known only from the few geophysical records already obtained. The data are restricted in areal extent, as well as by the techniques and equipment used. Interpretation is tentative since it has not proved possible to calibrate these records by sampling in depth. There is a most marked contrast between the coastal and offshore sediment bodies in the two areas. In both areas, information is available from hydrographic surveys and a limited number of site investigations.

Only a little knowledge exists of the spatial distributions of lithologies on a regional scale and of the surface features of individual sediment bodies. Meaningful information is entirely inadequate for the regional assessment of sediment types, internal structures, geotechnical properties, mineralogy and the occurrence of natural and industrial tracers. The effects of biological activity, (binding, pelleting, etc.) on the mobility of sediment in this area is largely unknown.

2.2.1. Bristol Channel—In the Bristol Channel unconsolidated sediments occur as linear banks resting on bedrock. There are also large sediment bodies in the major embayments. The linear sandbanks, some Gower beaches and superficial deposits in the Loughor Estuary, are being studied at University College of Swansea, particularly the spatial distribution of lithologies, sediment thickness and internal structures.

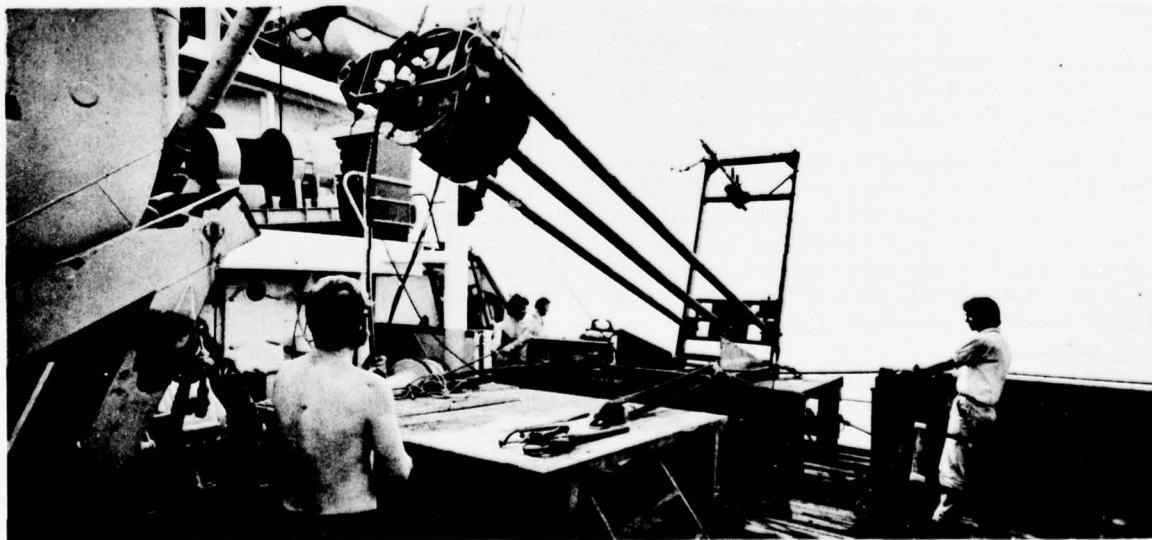
2.2.2. Severn Estuary—In the Severn Estuary unconsolidated sediments form banks and intertidal flats over the larger part of the estuary. A study of these sediments is in progress at the University of Bristol and supported by NERC. Some parts of the area have been under investigation since 1961 and the work is expected to continue for another 5–10 years. The Unit of Coastal Sedimentation has obtained vibrocore samples from Newport Deep and the Bridge area.

2.2.3. Morphology of the sediment surface—

Knowledge of the seabed morphology is derived principally from hydrographic surveys, and comparison of these yields valuable information about changes. Care should be taken in using this information as only the most recent surveys are based on adequate positional control and in many cases these still lack the tidal datum control necessary for detailed comparisons. These limitations are particularly important in the Severn Estuary because of its very large tidal range. The Unit of Coastal Sedimentation and University of Bristol have undertaken side-scan sonar surveys in the navigable channel and these are proving a useful addition to hydrographic surveys.

2.2.4. Tidal Flats—Erosion and accretion occur at some places along the margins of the channel and

The Unit of Coastal Sedimentation's vibrocorer in use during a sedimentological survey in the Severn Estuary.



estuary, leading to long term changes. These changes form an integral part of the sediment movement pattern within the estuarine system. Pierce *et al.* (1970) have assessed the stability of some intertidal estuarine muds under experimental conditions. The influence of the flora and fauna on erosion and accretion of the tidal flats in the region of high energy is unknown; it could be important and should be assessed.

2.3. Mobility of Sediments—An historical analysis of some long term changes in the shape of the sea bed recorded in hydrographic surveys has been made from records obtained during the last 150 years (Hawkins, 1971).

The extreme tidal variations cause considerable transport of sediment both within the water mass and as bed load. Only an insignificant amount of definitive information exists on this topic.

Three artificial tracer tests in Swansea Bay, Newport Deep and Portishead, have added to our knowledge of sediment circulation, but these few tests have been of limited value. A study of suspended sediment transport and deposition has been carried out in Swansea Bay by the University College of Swansea.

Although there is considerable mobility of a wide range of sediment types, there is apparently a high degree of retention of sediment within the Severn Estuary. Information is required on the sediment budget, i.e. the rate of input of sediments and the loss, if any, to the sea. The effects of changes in salinity on the clay mineralogy are also imperfectly understood.

It is known from other estuaries that, in some cases, the morphology of the sea bed and sediment transport regime varies in response to single tidal cycles, with spring/neap alternations, with seasonal changes, with longer term fluctuations, and with effects from random meteorological causes. Little or no precise data are available for these changes in either the Bristol Channel or the Severn Estuary.

3. WATER MOVEMENTS AND OTHER PHYSICAL

3.1. Tides—The Severn Estuary has the greatest tidal range of any estuary in Britain. (See Table below.)

The predominantly semidiurnal tide has a mean spring range of 6 m at Milford Haven, increasing progressively up the converging estuary to 12 m at Avonmouth. Reliable harmonic constants exist for only six stations throughout this changing tidal regime.

Tidal stream observations are scanty; the tidal streams are generally rectilinear, lead the elevation by $2/2\frac{1}{2}$ hours, generally reach 5–7 knots in the main channels and up to 10 knots in The Shoots. Estimates of tidal friction by Taylor (1921) and Grace (1936) are the only theoretical studies known. The bulk of tidal data reside at the Tidal Branch of the Hydrographic Department and the Institute of Coastal Oceanography and Tides.

Very little is known of (i) the distribution of shallow water tides, (ii) the vertical structure of tidal streams and variability of non-tidal currents, (iii) tidal heights in mid-channel.

No comprehensive scientific study has been mounted of the tidal regime in the area. Coriolis effects remain to be determined but are unlikely to be substantial.

3.2. Storm Surges—The natural causes and frequency of positive surges in the area are quite well known (Heaps, 1967), and would be accurate with little extension for most major studies; no studies have been made of negative surges. Seven surges exceeding 1.8 m at Avonmouth occurred between 1920 and 1955, generated by secondary depressions travelling eastwards over Ireland (Lennon, 1963a). Dynamic amplification seems important. The converging nature of the Bristol Channel further amplifies and sharpens surges which are mainly generated seaward of the Channel.

3.3. Surface Waves—Very little data exist for the area. The National Institute of Oceanography have done some work off Land's End and from the Helwick Light Vessel (Draper and Fricker, 1965). A little work has also been done in conjunction with port and power station development (Hartland Point, Hinkley Point, Oldbury, Newport), but only to check conditions for construction. Maximum wave height recorded at Helwick in the period September 1960–February 1961 inclusive was 10.4 m with most frequent height 3.0 m and period 5–6 secs.

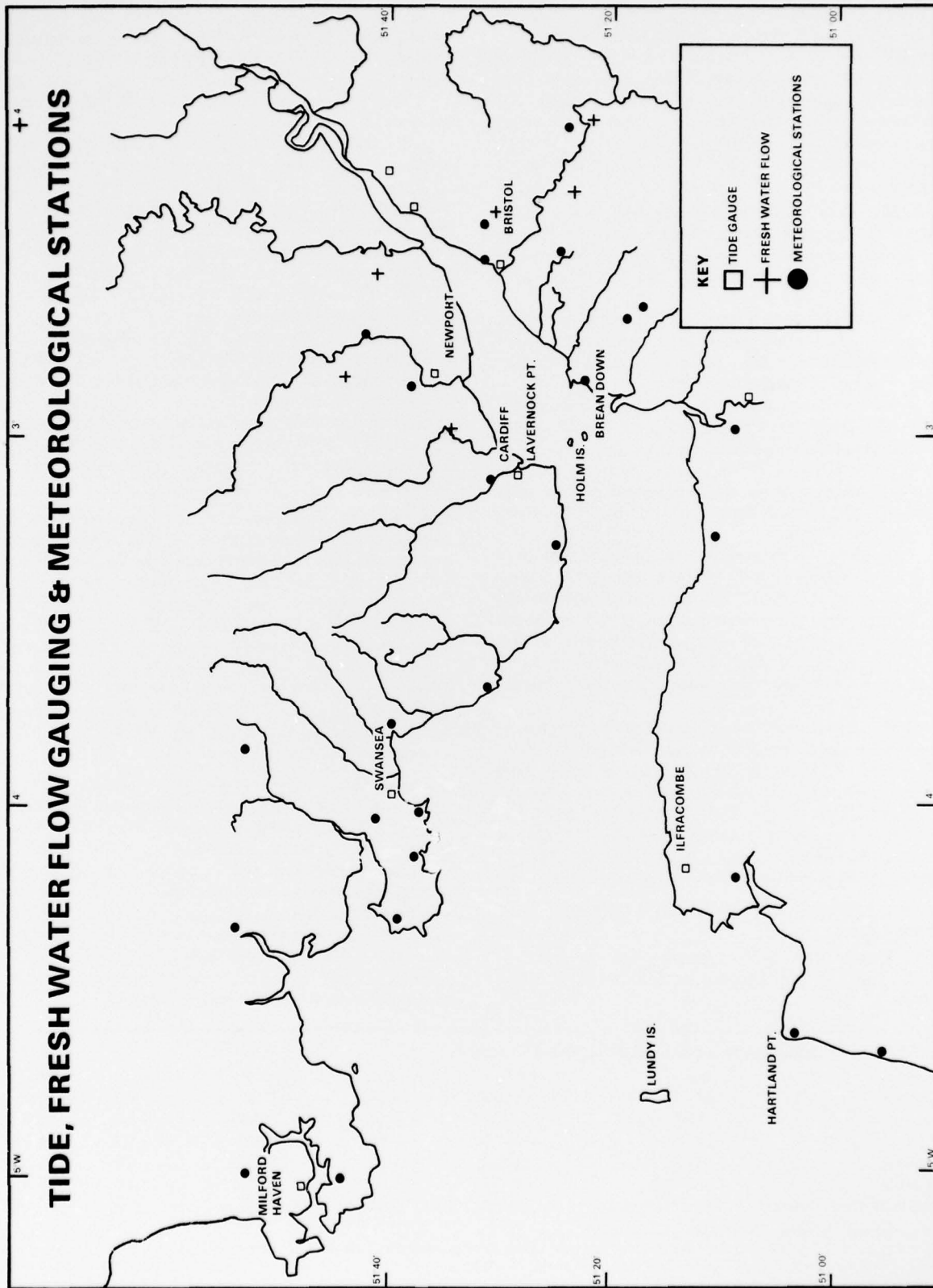
Tidal Range in some estuaries around Great Britain (metres)

Estuary	Port	LAT	MLWS	MHWS	HAT	MSTR
Severn	Avonmouth	–0.34	+0.58	+12.90	+14.15	12.31
Mersey	Liverpool	–0.68	+0.46	+8.86	+9.80	8.38
Forth	Leith	–0.18	+0.68	+5.40	+5.94	4.79
Humber	Immingham	–0.58	+0.34	+6.68	+7.46	6.37
Thames	Sheerness	+0.30	+0.58	+5.73	+6.16	5.15
Southampton Water	Southampton	–0.30	+0.46	+4.54	+4.94	4.08

From Table 5 Admiralty Tide Table. Vol. 1, 1970

LAT – Lowest Astronomical Tide – MLWS – Mean Low Water Springs; MHWS – Mean High Water Springs;

HAT – Highest Astronomical Tide; MSTR – Mean Springs Tidal Range.



3.4. Temperature, Salinity and Suspended Solids Distribution—Cooper (1967) has shown that at the entrance to the Bristol Channel it is possible to distinguish not only gradients of salinity and temperature, but also of phosphate, etc. Similar gradients may be expected in the middle and upper reaches of the Channel and seasonal variations are also probable. The delineation and extent of these will help to determine dispersion patterns. The studies of Bassindale (1943), extending from Avonmouth to The Holms, include data on temperature, salinity, suspended solids, pH and dissolved oxygen and hence their relationships to water mixing. The Hydraulics Research Station in collaboration with the Central Electricity Generating Board have collected and analysed extensive data on the conditions in the neighbourhood of some of their power stations.

The 1927 Admiralty Survey gives salinity and suspended solids at four stations between Avonmouth and Sharpness. Salinity charts for the area, particularly above English Stones, have been prepared by H.R.S. while the Ministry of Agriculture, Fisheries and Food have recorded salinities in the Bristol Channel and above the Severn Bridge.

All these recordings are largely unco-ordinated.

3.5. Circulation Patterns and Mixing—C.E.G.B. and H.R.S. have used temperature measurements (and hydraulic model studies) at the Berkeley and Oldbury power stations to give an indication of water mixing. Radioactive tracer experiments have been used to study channel stability, in Newport Deep (British Transport Docks Board), Swansea Bay and off Portishead (British Steel Corporation). The H.R.S. report for the I.C.I. Avonmouth outfall includes float tracking, current metering and suspended solids records close to the mouth of the River Avon. Recently the Water Pollution Research Laboratory has been assessing available information with a view to predicting large-scale effluent dispersion patterns (WPRL, 1972).

Notwithstanding these activities, we still have only an elementary understanding of the hydrodynamics of the Bristol Channel, Severn Estuary.

3.6. Hydraulic Model Studies—Gibson's model (Gibson, 1933) for tidal power studies reproduced the Severn Estuary and River Severn. While designed to a very small scale, and with severe vertical scale distortion, it was deemed adequate for the study, although a larger model was advocated for siltation studies. H.R.S. used a much larger and more satisfactory model of the Estuary above English Stones, for C.E.G.B. cooling water studies. This model was subsequently employed also for local sedimentation studies. The H.R.S. has also constructed models of restricted locations for specific studies, e.g. the approaches to Avonmouth Docks, but no large models have been built of the areas below English Stones.

3.7. Monitoring Stations (See map opposite).—Permanent automatic tide gauges exist at Milford Haven*, Swansea*, Cardiff, Newport (up-river), Narlwood Beacon (HW only), Berkeley Jetty, Avonmouth, Bridgwater (up-river), and Ilfracombe*. There is a gap in this chain from Ilfracombe to St. Mary's, Scillies*. At present, Port of Bristol Authority maintains the Clevedon gauge, although the future of the pier is in doubt.

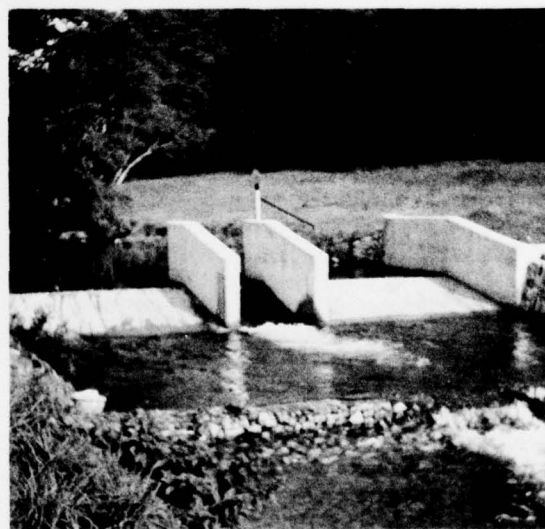
Stations monitoring freshwater flow into the Severn estuary and Bristol Channel are shown below.

<i>River</i>	<i>Station</i>
Bristol Avon	Bath
Severn	Bewdley
Avon	Evesham
Stour	Kidderminster
Chew	Compton Dando
Salwarpe	Hartford Hill
Parrett	Chiselborough
Usk	Chain Bridge
Teme	Tenbury Wells
Leadon	Wedderburn Br.
Ebbw	Rhiwderin
Frome	Frenchay
Wye	Cadora
Taff	Tongwynlais

Some 30 land meteorological stations in the vicinity of the Severn Estuary and Bristol Channel complete climatological returns. Specific features, particularly rainfall, are recorded by local authorities, by schools and by individuals; most of these are daily gauges, the results from which are largely uncorrelated.

A detailed study of dynamic rainfall is in progress in the Gloucester/Cheltenham area using autographic gauges and incorporating daily gauges (Waller and Shaw, 1970).

A river gauging station.



*Stations in national tide gauge report.

4. CHEMISTRY

4.1. Chemical and Biological Oxygen Demands (C.O.D. and B.O.D.)—Measurements of this type are made in the tributary rivers by the River Authorities but there is little published information for the estuary itself.

4.2. Sediment Composition—In general, the concentrations of chemicals other than soluble ionic species, are likely to be much lower in estuarine waters than in the highly adsorptive muds. Some measurements have been recorded for pesticides in the estuarine muds, and there is information for pollutants such as cyanide and phenol, in the possession of the River Authorities.

4.3. Nature of Sediments—The sediments are important from the chemical standpoint for undoubtedly they act as buffers, stores, catalysts and sites for microbial, microfaunal and mesofaunal activity.

The few available analyses of the muds show them to be alkaline, reducing and high in clay minerals such as illite and kaolinite. There is no comparative survey of the chemistry and microbiology of the muds around the estuary.

4.4. Chemistry of Water/Sediment Interaction

—This is largely the field of colloid science for which there is considerable literature on the behaviour of minerals in relation to pH, salinity changes, etc. The various phenomena are incompletely understood and each environmental situation requires individual assessment. Studies underway at Bristol University (Chemistry, Geology and Geography) are concerned with the physical and chemical processes leading to the flocculation, precipitation and deposition of sediment, using the mouth of the Wye as a test-site. An investigation into the adsorption and release of humic acids and other organics is proceeding.

4.5. Ecochemistry of the Estuary—The Bassindale papers were an early attempt to assemble a range of information covering physical, chemical and biological disciplines and the formulation of a view of the working of the Severn Estuary as a whole. Little chemical information was available at that time (1943) and this remains true today. The paucity of data makes it difficult to distinguish man-made pollutants and their chemical and biological degradation products from naturally occurring substances. The ability of certain organisms to rework, concentrate, synthesise or dispose of metal ions or organic compounds has been amply demonstrated in the literature. Any model of the Severn Estuary ecosystem would need to encompass these factors, but at the present time even the basic information on the nature, abundance and inter-relationships of the various chemical components of this model is not available. The River authorities monitor several sites in the tributary rivers, in general to measure a few

compounds and ions such as NH_4^+ , CN^- , phenol, Cl^- and, occasionally metals, such as arsenic, lead, zinc and cadmium. The Severn River Authority recently expanded its estuarine analysis programme.

4.6. Pollutants—Pollutants are probably the most extensively recorded of the man-induced factors, though they are measured mainly in the rivers rather than the estuary. No overall view of the situation in the Severn Estuary is available to our knowledge. Large volumes of both raw and treated domestic sewage enter the estuary through sewer outfalls while sewage sludge and other solid wastes are dumped within the Bristol Channel. These sources and the outfalls of industrial complexes such as those at Avonmouth, Newport, Cardiff, Milford Haven and along the coasts near Swansea and Port Talbot, are identifiable "hot spots". *E. coli* counts have been recorded for some specific sites along the estuary.

Pollutants of agricultural origin, such as pesticides and herbicides, enter the estuary in the river flows, but must also be contributed via atmospheric "fall-out", especially when crop-spraying is followed by rapid transport of particulate material during storms. Effluents from mines, tips and old smelting enterprises (e.g. in the lower Swansea valley) will also add to the pollutant load. Major accidents have led to oil and chemical spills both direct into the estuary and into the sewerage system. Warmed water is discharged from several Central Electricity Board power stations, (nuclear:— Berkeley, Oldbury, Hinkley Point) and coal-fired (Uskmouth). Large amounts of ash from coal-fired stations reach the estuary (e.g. Uskmouth). Stack discharges may also give variable levels of contamination, dependent on atmospheric conditions.

4.6.1. Fate of Pollutants—The opinion is held widely that pollutants in an estuary are carried out to sea on the outgoing tide. However, the complex hydrography of the estuary results in some areas of little net transport or dispersion. More important is the retarding effect caused by the adsorption by the muds and subsequent retention within the estuary for unknown periods. It is probable that pollutants are degraded more rapidly at one site than at another, and that incorporation into food chains differs from one site to another. Again, individual pollutants are known to vary greatly in their ease of degradation, though few studies have been made of the degradation of pollutants under environmental conditions.

4.6.2. Heavy Metals—Major industrial activity involving heavy metals both past and present, inevitably contaminates the environment. The Avonmouth complex and industries located near Swansea process large quantities of metalliferous ores and the effects of their discharges can be observed in both terrestrial and aquatic environments. Limited, but

significant, data (Butterworth 1970) are available for concentrations of copper, cadmium, nickel, lead and zinc in water samples, in sediments and in selected organisms gathered from the English shore, taken from points extending from the Severn Bridge at Aust down to Hartland Point in Devon. The high values (e.g. 800 ppm dry weight Zn for *Fucus vesiculosus* at Severn Beach and 900 ppm Zn and 500 ppm Cd for *Patella vulgata* at Portishead) near Avonmouth fall off towards the rural coastline of the West.

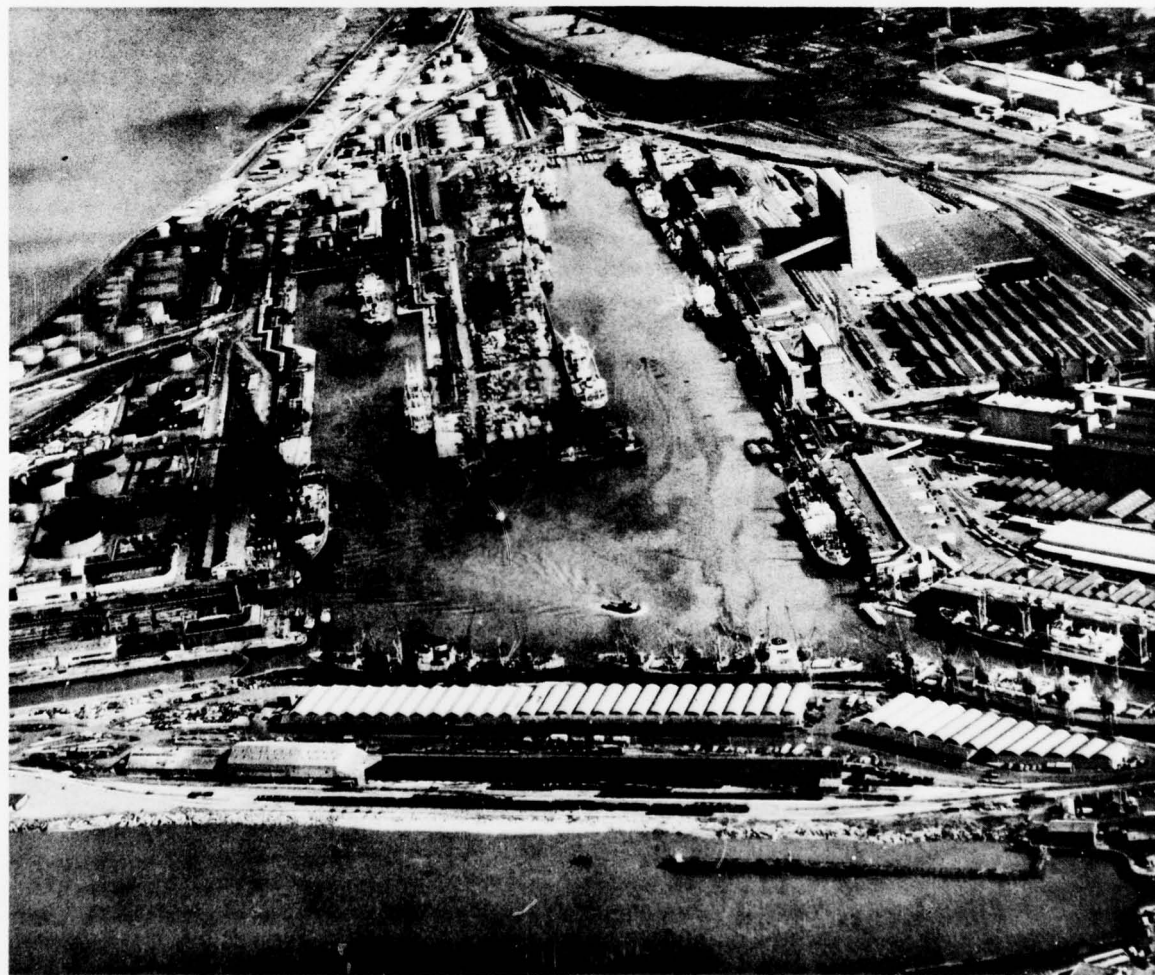
Data for heavy metal concentrations in commercial fish and shell fish species taken within the estuary have been reported by the Ministry of Agriculture, Fisheries and Food (H.M.S.O., 1971 & 1972).

4.6.3. Pesticides and Herbicides—Some data are available for the concentration of chlorinated hydrocarbons (dieldrin, DDT) in water and mud of the River Severn but values are variable due to dramatic seasonal changes, for this river drains areas of

intense agriculture and horticulture such as the orchards of Worcestershire and Herefordshire. At one point on the Severn, over one year the levels of dieldrin ranged from 73 to 4313 ng/l (parts per 10^{12}). Bristol University Agricultural and Horticultural Research Station at Long Ashton has long-term measurements on the throughput of DDT in an orchard in relation to levels in nearby stream, pond and river. Very few data are available for the estuary. Work is in progress at Bristol on the fate of DDT and other pesticides when deposited in the sediment; biodegradation is rapid although the metabolic products may also be toxic. Unfortunately, almost nothing is known of the microbiology of the estuary and its tributary rivers.

4.6.4. Oil—Over two million tons a year of petroleum products are carried in the estuary and oil spills have occurred. The slicks are difficult to track and deal with owing to the tidal streams, fast currents, mud flats, sand banks, etc.

Shipping and industry at Avonmouth (photo Airviews Ltd).



5. BIOLOGY

5.1. Plankton—5.1.1. Severn Estuary—The only published study is that of Rees (1939) in the estuary near Cardiff. He used one collecting station, but because of the movement of water up and down stream at various states of the tide, he effectively sampled from various regions of the water body a series of points along the channel. As is to be expected, the diatoms were almost entirely marine, and showed patterns of horizontal and seasonal distribution. The abundance of phytoplankton was low compared with that of the open sea, and this could have been caused by the opacity and turbulence of the water. Nutrients were not found to be limiting, and there was no evidence of a spring maximum as is usual in the sea.

5.1.2. Bristol Channel—Diatom counts and chlorophyll estimations (Moyse & Knight-Jones, 1966) suggested that the spring phytoplankton outburst is progressively later and smaller as one moves eastwards down the Bristol Channel. Incipient peaks appeared to be destroyed in windy weather. High turbidity must result in shallow compensation depths with production confined to the top few metres. Not surprisingly, minor spring peaks corresponded with calm weather. Some attention has been given to the plankton production of the Queen's Dock, Swansea, which is warmed by a power station effluent as well as being subject to oil spillages. The water off the Devon coast is much clearer, but conditions there are not well known.

5.1.3. Milford Haven—A regular series of plankton samples was taken in 1970 for comparison with a similar series taken in 1959/60 (Dias, 1961).

5.2. Fish and Fishery Data—5.2.1. Severn Estuary—Commercial fisheries here are long established, and mostly function as fixed-net fisheries, this method being facilitated by the extreme range of the tide. Records for these fisheries date back to the fifteenth century, and therefore pre-date all other biological records. The reports indicate that in recent times many fish have decreased in numbers, e.g. lampreys and herring. There are still profitable fisheries which take mainly sprats and salmon, although the catch of the latter is very variable.

Little is known of the details of fish movements within the Estuary, and the last analysis of the Weston fishery was made as long ago as 1941 (Lloyd, 1942).

5.2.2. Bristol Channel and Milford Haven—Records from the fishing ports of Swansea and Milford Haven provide the most extensive information. Besides these, the bionomics of flat fish populations in certain areas have been monitored in recent years (Ryland, in prep.), and the breeding population of herring in the upper reaches of Milford Haven has been the subject of a bionomic study (Nelson-Smith, 1964).

5.3. Sub-littoral Benthic Studies—The vast area of unconsolidated sediment in both the Bristol Channel and the Severn Estuary has been largely ignored by biologists because of the practical problems of sampling. University College, Swansea, has undertaken trawling and dredging studies but these have so far been confined to some special communities. Several autecological studies (see below) of individual invertebrates have entailed sampling over extensive areas. The shallow-water benthos of the Bristol Channel has also been studied in some sheltered areas by aqualung diving (Bailey *et al.*, 1967).

5.4. Intertidal Areas: Rocky Shores—These are the only environments to be investigated biologically in any detail.

5.4.1. Severn Estuary—General studies of the fauna and its distribution have been made (Bassindale 1941–1943). These accounts give a good picture of the factors correlated with the distribution of the fauna, i.e. mainly the salinity regimes and suspended silt. The fauna diminishes in variety of species from Ilfracombe, where it appears to be typically marine, to the reaches of the River Severn below Gloucester where no marine forms are found. Some species may be limited by the lack of appropriate food in the Estuary (Berry & Crothers, 1970). Over the last 30 years, student projects and some scattered observations have extended the information on species distribution along the southern shore, but this information is not available in any systematic way.

There is no information about the distribution of algae except for the observations made in primarily zoological investigations.

5.4.2. Bristol Channel and Milford Haven—Extensive general studies of the fauna of Milford Haven (Moyse & Nelson-Smith, 1963; Nelson-Smith, 1964, 1967) included quantitative recording of dominant shore animals and plants. Some shores have been re-surveyed more recently (Crapp, 1969, 1971) in connection with pollution studies.

Sea urchin, elephant hide sponge and dead man's fingers (photo Roger Swifen).





Cockle fishers on the Burry Inlet Cockle Fishery (photo MAAF, Lowestoft).

5.5. Intertidal Areas: Mud and Sand Shores—

5.5.1. Severn Estuary—Detailed studies of the extensive upstream mudflats of the Estuary are totally lacking, even though they occupy there the greatest fraction of the intertidal surfaces. Some brief investigations have been carried out, notably one by Haderlie & Clark (1959), that enabled the definition of marine, transitional and estuarine zones. This study also points out the importance of investigating the unconsolidated substrate in estuaries, simply because this occupies the greater part of such environments; rocky shores are to a great degree uncharacteristic here, and their fauna is therefore unreliable as an indicator of different zones. Detailed studies of the ecology of the mud-flats are lacking, except for one short preliminary examination, which highlights the importance of the 'micro-fauna' (Rees, 1940).

Even less is known about the benthic microflora. The only study refers to the Avon banks at Bristol (Round and Palmer, 1966).

5.5.2. Bristol Channel and Milford Haven—

Further west the fauna of seventeen sandy shores of the north bank has been surveyed recently (Withers, in press) including that of some sublittoral sediments. A general survey of the meiofauna of intertidal sands in the Gower area has been made (see Hickman, in prep.).

5.6. Intertidal areas: Salt Marshes—The various stages of succession in a salt marsh which developed at Berrow between about 1910 and 1920 were followed, up to about 1942, by which time the marsh had considerably decreased in size. More recent work, as might be expected with the planting of many marshes with *Spartina*, and the subsequent spread of this species, has concentrated on studies of *Spartina* marsh (Ranwell, 1964). This work was carried out in Bridgwater Bay, and there appears to be no general survey of the marshes in the Channel and the Estuary, either describing their distribution or the composition of the flora.

There are surprisingly few papers dealing with

zoological aspects of the large areas of salt marsh; one exception is that of Brough *et al.* (1960). A great deal of what was once 'general salt marsh' is now *Spartina* marsh, which appears to carry a sparse fauna.

Special attention has been directed to the susceptibility of salt marshes to oil damage (Baker, 1971).

5.7. Autecological Studies—A small selection of such studies of individual species appears in the bibliography. Certain taxonomic groups have been well-studied, but only in a few cases (e.g. Gee & Knight-Jones, 1961) do these studies seek to plot the detailed distribution of an animal over the whole area.

Observations by many zoologists have contributed to the revised Dale Fort Marine Fauna (Crothers, 1966), particularly from the upper reaches of Milford Haven and in certain specialist groups.

5.8. Pollution Studies—Studies on oil pollution have been concentrated in Milford Haven. Here the sensitivity of individual invertebrate species to oil and to emulsifiers has been examined (Nelson-Smith, 1968; Crapp, 1971). Attempts have been made to correlate changes in field populations of invertebrates with known oil pollution, both short-term and chronic.

The capacity of salt marshes to trap oil and to recover from the effects of both oil and emulsifiers has been investigated in detail (Baker, 1971).

The effects of domestic sewage have not been examined, but a limited study has been made of the effects of the effluent from an intensive dairying unit on a small rocky bay in South Pembrokeshire.

5.9.—Higher Vertebrates—There is an extensive literature about the birds of the whole area, and a few papers on the aquatic mammals, but it is beyond the scope of the present review to assess these adequately. Clearly predation by several carnivorous species must play a part in the population stability of lower forms, as in the case of oystercatcher predation on the cockle fishery of South Wales (Davidson, 1967).

6. GENERAL CONCLUSIONS

This assessment indicates that there is an inadequate knowledge of the estuary as a single natural system. Knowledge is insufficient either for the scientific understanding of the dynamics of the hydrosphere, the sediments and the biosphere of this estuary, or as a basis for planning economic expansion in the area in such a way as to reconcile its increased use with maintenance of the Estuary as a natural resource.

We have only an elementary understanding of the dynamics of a water body influenced by exceptional tides and currents, large fresh-water inflows, and high concentrations of suspended solids. Data on tides (especially away from the shore) on currents and on waves, are inadequate. As a result, the circulation, mixing and diffusion patterns taking place in the Estuary cannot be evaluated fully.

A large reservoir of mobile, sandy and muddy sediment is known to be present in the Estuary and similar material also occurs in the Bristol Channel. Quantitative information on the tidal excursion and settling sites of the sediments is required (a) to understand the mechanisms of channel and harbour siltation (b) for the investigation of pollution.

The need for adequate knowledge of the mineralogy, physics, chemistry and biology of the unconsolidated sediments is urgent because these sediments provide chemically unstable substrates which both adsorb and release pollutants and which are the sites of pollutant degradation and nutrient release prior to utilization by the phytoplankton.

Although the organisms of the Severn Estuary and Bristol Channel have been subjected to a good deal of autecological study, surprisingly few studies have been related to the overall estuarine ecosystem. A survey of the present distributions of the flora and fauna with quantitation of existing pollutant residue levels, would at least provide a base line for comparison of future changes.

The Severn Estuary and Bristol Channel are characterized by a wide range of environmental conditions. An integrated study of the water, the sediments and the organisms will lead to a fuller understanding of estuarine systems. Such a study should be carried out bearing in mind academic, governmental and commercial interests. A fuller understanding of this environment is vital for the conservation and intelligent exploitation of this important natural resource.

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