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SURVEYS OF HARBOURS, RIAS AND ESTUARIES IN SOUTHERN BRITAIN

EXE ESTUARY

Volume 1 - Report

by

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EXE ESTUARY

SYNOPSIS

The Exe estuary is situated in southeast Devon and opens into the western side of Lyme Bay in the English Channel. The estuary is approximately 10 km in length and between 1 and 2 km in width at the high water mark. Most of this area dries at low water leaving a channel of less than 500 m width at its widest point. The estuary is sheltered from prevailing winds and wave action to a large extent by Dawlish Warren, an unusual double spit which has been formed across the mouth of the estuary. This feature, together with an area of shoaling sand called Pole Sand, restricts the sea opening of the estuary to a long narrow channel. Currents are rapid as a consequence of river and tidal flow being restricted to a narrow channel for much of the tidal cycle. In addition, salinity is reduced over most of the estuary, particularly at low water after significant rainfall. On these occasions, the water at Topsham may be almost fresh. Benthic habitats are sedimentary in nature with extensive mud and sand flats intertidally. Patches of saltmarsh and swards of *Zostera* spp. occur in the muddier reaches. There are no rocky shores within the estuary and what little alternative hard substrata there is consists of stones and small boulders concentrated around the high water mark. Stone-faced railway embankments down either side of the estuary occasionally fall within the upper intertidal zone. Subtidally, habitats are also predominantly sedimentary, ranging from sand, stones and boulders at the mouth to mud at the head. Outcrops of flat bedrock occur in the narrow channel entrance. Outside the main estuary basin, rocky shores occur east of Exmouth at Maer Rocks, and at Orcombe Point and beyond.

There is little commercial fishing within the estuary, apart from netting for salmon, trout and eels. Shellfish, mainly oysters but also including some mussels and manilla clams, are also grown-on at sites within the estuary.

The area is used intensively for recreation, including most watersports, and the sandy beaches on the open coast are popular with tourists. In addition, many visitors are attracted specifically by the overwintering populations of waders and wildfowl for which the Exe is of international importance.

The area has long been of scientific interest, both biologically and physiographically, and is currently used for both educational and research purposes. The geological, ornithological and marine biological importance of the estaury is well recognised and is detailed in the notification of both Dawlish Warren, and the rest of the estuary, as SSSI's. In addition, Dawlish Warren is a Local Nature Reserve and the western half of the estuary from Dawlish Warren up to Turf has been designated a wild bird sanctuary.

The present survey, carried out in August 1985, aimed to collect information on the variety of intertidal and subtidal habitats and communities present. The last descriptive marine biological survey covering the whole estuary took place in 1901. In order to determine what changes, if any, had taken place since that time, many of the old sample sites were re-visited. A total of 47 sites were sampled, of which 34 were intertidal and 13 subtidal. At each intertidal site the abundance of epiflora, epifauna and conspicuous

infaunal species was recorded in situ. Sediment cores were taken and sieved over a 1.0 mm mesh to obtain samples of the macrofauna. Subtidal areas were sampled using a combination of trawling, pipe-dredging and diving.

During the survey, a total of five intertidal and four subtidal habitats were distinguished. Epifaunal and algal diversity was generally low due to the scarcity of stable hard substrata. However the infauna was richer and was typically estuarine in nature with dense populations of species such as Nereis diversicolor, Scrobicularia plana and Lanice conchilega to be found locally. Diversity tended to be higher in the heterogenous muddy sand areas of the middle and lower reaches of the estuary. Further north, sediments were of uniform mud and were influenced by reduced or fluctuating salinities. Around the estuary mouth, faunal populations in the tidally swept clean sands were often comparatively sparse, but notable for including the polychaete Ophelia bicornis which has attracted much scientific study since the 1940's.

The main characteristics of the communities found do not appear to have changed significantly since the turn of the century. However, in contrast to previous records, neither Nucella lapillus or Sabellaria alveolata were found during the present survey. The former species appears to have declined dramatically in southwest Britain recently, and organotin compounds in antifouling paint are suspected as a possible cause. The latter species has been shown to fluctuate widely in abundance at any one site, and it is possible that trampling pressure plays a part in such variation. Alien species are also present including Sargassum muticum on rocky shores just outside the main estuary.

The scientific interest and nature conservation importance of the area has been assessed using standard criteria and the conservation importance of the habitat and communities in the area have been provisionally graded as of Local, Regional, National or International importance. Species of particular scientific interest identified during survey work have also been noted and their conservation importance provisionally graded as of Regional, National or International importance. The Exe estuary is considered to be of high scientific interest for its populations of Ophelia bicornis and because it supports infaunal communities that are representative of their type in south west Britain. This is in addition to the well recognised importance of the area for estuarine birds. Furthermore, much scientific study has been, and still is, carried out here alongside its continuing use for educational purposes.

Potential threats to these interests are all associated with the recreational usage of the estuary which is already high. These include the proposals to build marina facilities, the effects of organotin antifouling compounds and bait digging.

1. INTRODUCTION AND HISTORICAL PERSPECTIVE

The Exe Estuary is situated in southeast Devon (National Grid Ref. SX9885) and opens into the western side of Lyme Bay in the English Channel (Fig. 1). It was formed through the drowning of the lower Exe River valley, during the post glacial rise in sea level and now occupies a basin of about 10 km in length and 1-2 km in width. This is the focus of a drainage area of 1,462 km^2 (Walling, 1978) bounded by Exmoor and the Brendon Hills to the north; the Blackdown Hills and Otter Catchment to the east; and Dartmoor and the Haldon Hills to the west and southwest. Within this area there are three main catchments, the Exe, Creedy and Culm which meet north of Exeter and flow into the estuary as the River Exe. A further sub-catchment, that of the Clyst, outfalls to the northeast corner of the estuary at Topsham. The estuary is made unusual by the presence of a double spit across the mouth, Dawlish Warren, which together with an area of shoaling sediment, Pole Sand, restricts sea access to a long narrow channel with fast-flowing tidal currents.

Historically, the Exe Estuary has figured largely on both national and international sea trading routes in common with other inlets in southwest England which in the days of sail offered the first landfall and shelter and thus commanded the western approaches. However, development of the region (and the Exe in particular) in terms of port facilities, major industry and population did not occur during the industrial revolution for two main reasons. Firstly the comparative isolation of the southwest peninsula and the advent of steam power and large steel ships meant that trade tended to be directed to other major centres with the necessary facilities and infrastructure. Secondly the area around the Exe offered none of the natural resources fuelling the industrial revolution such as coal or iron. Therefore the catchment has retained its rural nature to the present day with dairy farming, market gardening and mixed farming. Market gardening in particular grew with the arrival of railways in the 1840's which also opened up the area to tourism, now a major industry.

There are two main urban areas bordering the estuary; Exeter at the head of the estuary on the lowest bridging point, and Exmouth, situated at the mouth on the eastern side (Fig. 1).

Exeter, with a population of 95,300 in 1976 (South West Water Authority, 1978), is the largest of these and serves as the capital and administrative centre of Devon. As a consequence of its geographical position it sits on the major rail and road routes between the whole of the Southwest and the rest of England. It has therefore long been the focus of trading activity in the region and was the centre of the important West country woollen and serge industry which peaked in the 18th century. The city also functioned as a port, and navigation between Exeter and the estuary has been actively maintained and improved since 1566 when the first canal section was completed. Nowadays it carries very little commercial traffic (Devon County Council, 1975) and the present day light industry of the area is served mainly by rail and road.

Exmouth, on the coast on the eastern side of the estuary mouth, is the second largest town in the area with a population of about 26,600 in 1976 (South West Water Authority, 1978). It dates from the Roman times as a fishing village, but, by the end of the twelfth century was one of Devon's main ports. With its extensive sandy beaches it is now primarily a seaside resort, and has been since the eighteenth century when many fine Georgian

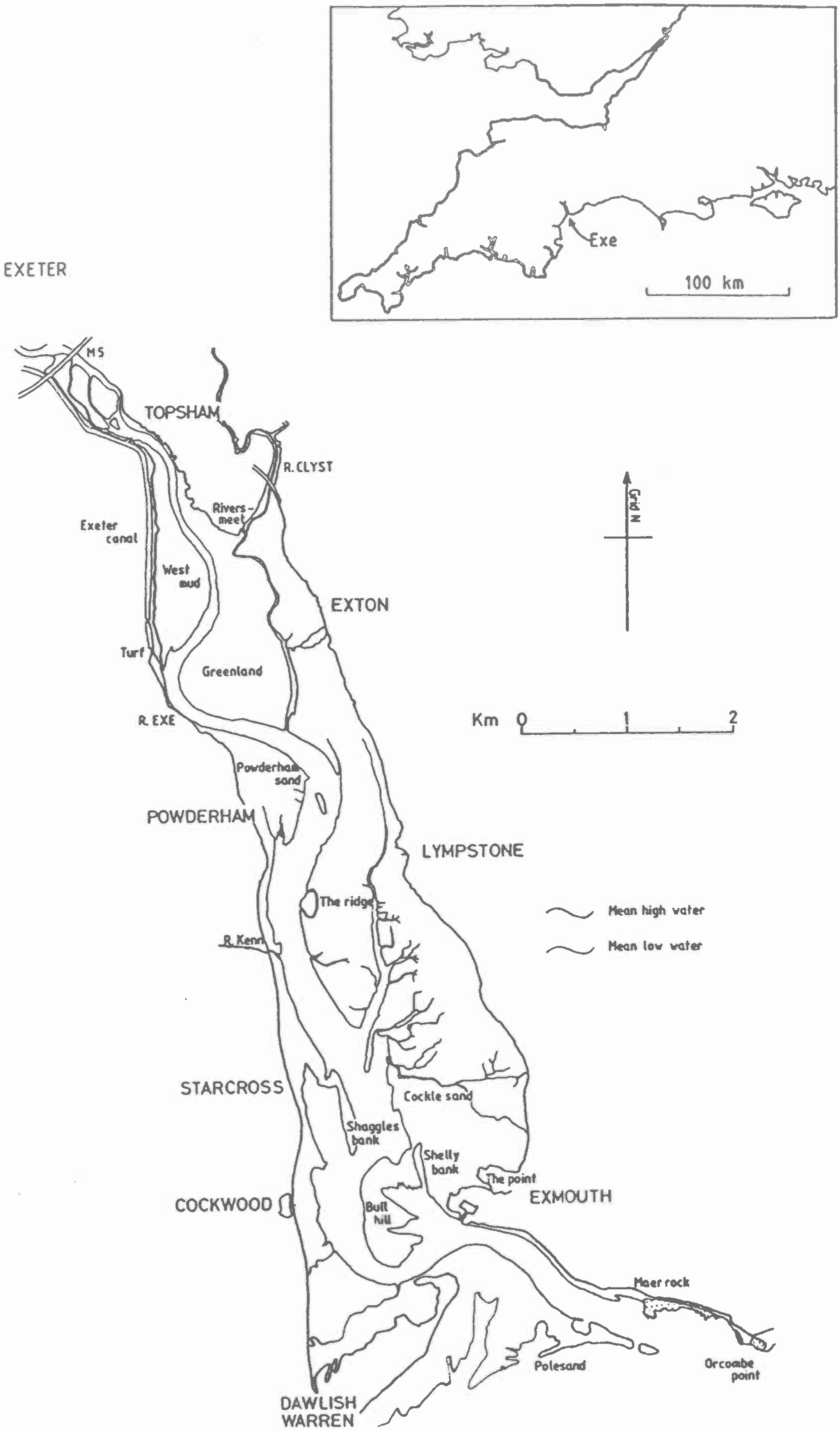

Fig. 1. The Exe Estuary.

houses were built. During summer months the town's population may increase by up to 60% (excluding day visitors). Exmouth has a working dock which handles local fishing boats.

Other small settlements bordering the estuary are Topsham, situated at the head of the estuary below Exeter, Lympstone and Exton on the eastern shore, and Starcross, Cockwood and Dawlish Warren on the western shore. Starcross was the site of one of the ten pumping stations used to operate Brunnel's atmospheric railway between Exeter and Plymouth in the 1840's. Topsham has its origins as a port in Roman times and once had important boat-building and fishing industries, both now reduced. Many of the buildings now used as private dwellings were originally built as storehouses for the port including the Dutch-style houses built with materials brought back by merchant ships delivering wood and serge to Holland in the eighteenth century. Commercial vessels now no longer use the quay. Lympstone was also a thriving fishing community and a local centre for the shellfish industry which was based on oysters, mussels and winkles. In the 18th and early 19th centuries, salt works were located in salt marshes near Topsham and on the northern side of Dawlish Warren. It seems that rock salt, imported from Liverpool, was dissolved in seawater to make 'salt upon salt' for the curing of fish (Parkinson, 1980). This industry, together with the building of the Exeter canal, the construction of railway embankments down both sides of the estuary, and the marsh reclamation for agricultural purposes (that has taken place since at least the 12th century) has considerably reduced the original area of saltmarsh (Parkinson, 1980) and also changed the nature of the upper shoreline.

2. PHYSICAL CONDITIONS

2.1. Geology and Topography.

The Exe estuary is situated roughly 10 km to the east of the so called Tees-Exe line which marks the boundary between highland Britain, to the north and west, and lowland Britain to the south and east. The Exe system therefore straddles this line, with the estuary itself and the River Culm (rising from the east) situated on low-lying Permian and Triassic deposits while the remaining catchments rise from the older Devonian and Carboniferous measures which form highland Devon to the north and west (Fig. 2).

The underlying structure of Devon is a west to east aligned synclinorium of Carboniferous rocks flanked, to the north and south, by older Devonian measures (Edmonds et al., 1975). During Permian times, southwest England was still part of the interior of an extensive continent and lay very close to the equator. In a desert climate, the screes and other erosion products from highland Devon were deposited as breccias and breccio-conglomerates close to the base of the mountain range. These formed the basis of the New Red Sandstone series, the deposition of which continued until the end of the Triassic period. In general, the deposits near the mountains and at the base of the series are coarsest (the breccias and conglomerates), but away from the range to the east, and higher in the sequence, they consist of progressively finer sandstones and mudstones (Durrance, 1980) (Fig. 3). During Jurassic, Cretaceous and Tertiary times, the continent was moving northwards and experiencing more humid conditions. In the lower Cretaceous period, uplift occurred and the whole areas was tilted towards the east. Then after a period during which easterly-flowing rivers built up large deltaic swamps over southern England, the sea advanced as far as Dartmoor and the Greensands of Gault were laid down unconformably over the earlier, tilted, strata.

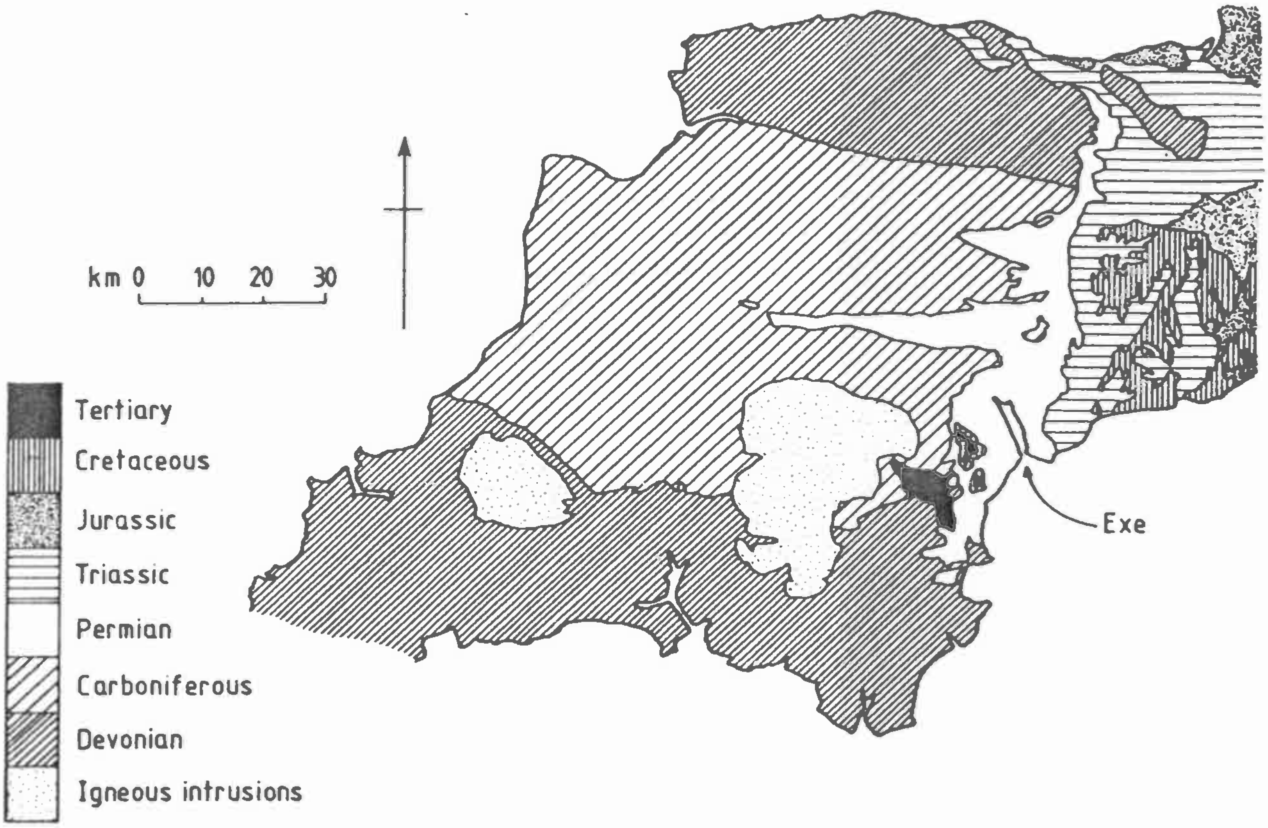

Fig. 2. The Exe Estuary in its geological context.

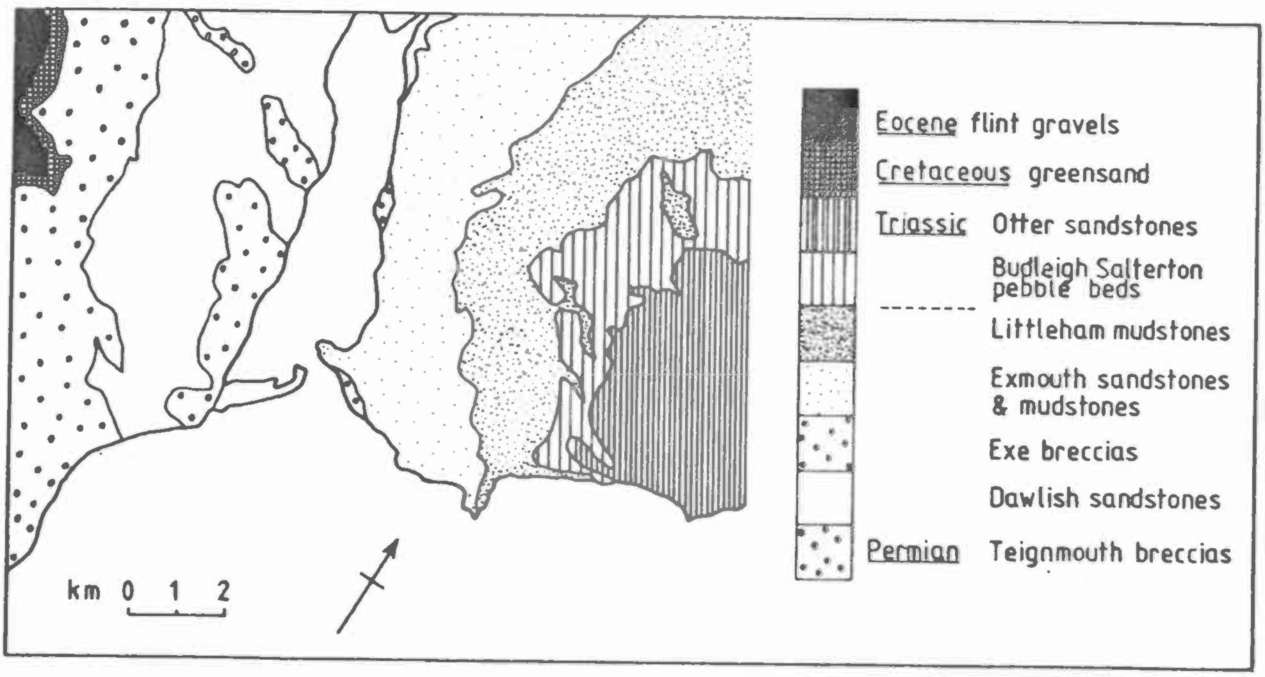

Fig. 3. Detailed coastal geology around the Exe Estuary.

Following erosion of this landscape to low relief, further inundation occurred and, in place of significant riverborne terriginous inputs, large quantities of calcareous ooze were deposited which became consolidated into chalk (Edmunds et al., 1975). In Tertiary times, the landmass was tilted to the south and then further warped along east-west lines (Durrance, 1980) causing the formerly east-flowing drainage patterns to be directed southwards. With a general lowering of the sea level during this period, the Exe catchment became superimposed onto older rocks as erosion progressed. The present form of the estuary itself however was mainly determined by the large variations in sea level that occurred during the Pleistocene ice ages.

Throughout the Pleistocene the sea level continued to fall. However, during the five glacial regimes that occurred in this period, the drop in sea level was accentuated by large volumes of water being locked up in the ice caps. This meant that rivers, including the Exe, excavated valleys to a depth below that of present sea level. Following glaciation the sea level rose and these valleys were drowned, thereby becoming depositional environments.

Nowadays, as a result of Tertiary superimposition of the drainage pattern and subsequent erosion during the Pleistocene, little remains in the Exe region of the Cretaceous and Tertiary deposits. The Exe estuary is now situated in Permian deposits between the Cretaceous Greensand of the Haldon Hills to the west and the Pebble bed ridge of Budleigh Salterton and Woodbury Common to the east. (The Budleigh Salterton Pebble Beds are conventionally taken as the dividing line between Permian and Triassic strata within the New Red Sandstone sequence (Durrance, 1980)). On a traverse from west to east across the estuary the sequence of Permian deposits starts with Dawlish Sandstones (formed by fluvial and aerolian reworking of the underlying Teignmouth Breccias) through Exe/Langstone Breccias, to Exmouth Sandstones and Mudstones (Fig. 3). The Dawlish Sandstones form the major part of the gentle landscape west of the estuary. The Exe and Langstone Breccias, which overlie the Dawlish Sandtones, form the higher ground extending from behind Starcross down to Langstone Rock at Dawlish Warren. In addition, they outcrop as red exposures on the east side of the estuary at Lympstone, Exmouth, and in the narrow entrance to the estuary off Exmouth beach. Overlying the Breccias are the Exmouth Sandstones and Mudstones which form most of the low relief landscape to the east of the estuary. They outcrop principally along the coast between Exmouth and Straight Point as red cliffs.

The red colouration characteristic of the New Red Sandstone formations is due to the presence of ferric oxide both within the sediment matrix and as haematite coatings around the grains. The origin of the haematite is controversial but is discussed by Durrance (1980).

The geological exposures at Langstone Rock, Lympstone and Orcombe Point have been specifically included in the notification of the Exe estuary as a Site of Special Scientific Interest (SSSI).

2.2. Hydrography.

2.2.1. Bathymetry and tidal heights. Depth contours within the estuary, and for the immediately adjacent area of Lyme Bay outside, are shown in Fig. 4. The mean tidal range at Exmouth is 3.8 m for spring tides and 1.5 m for neap tides. Admiralty tide tables indicate a similar range at Topsham near the head of the estuary while local tide tables quote a time lag of 20 minutes between heights at Exmouth and Topsham. The normal tidal limit is at St James Weir in Exeter.

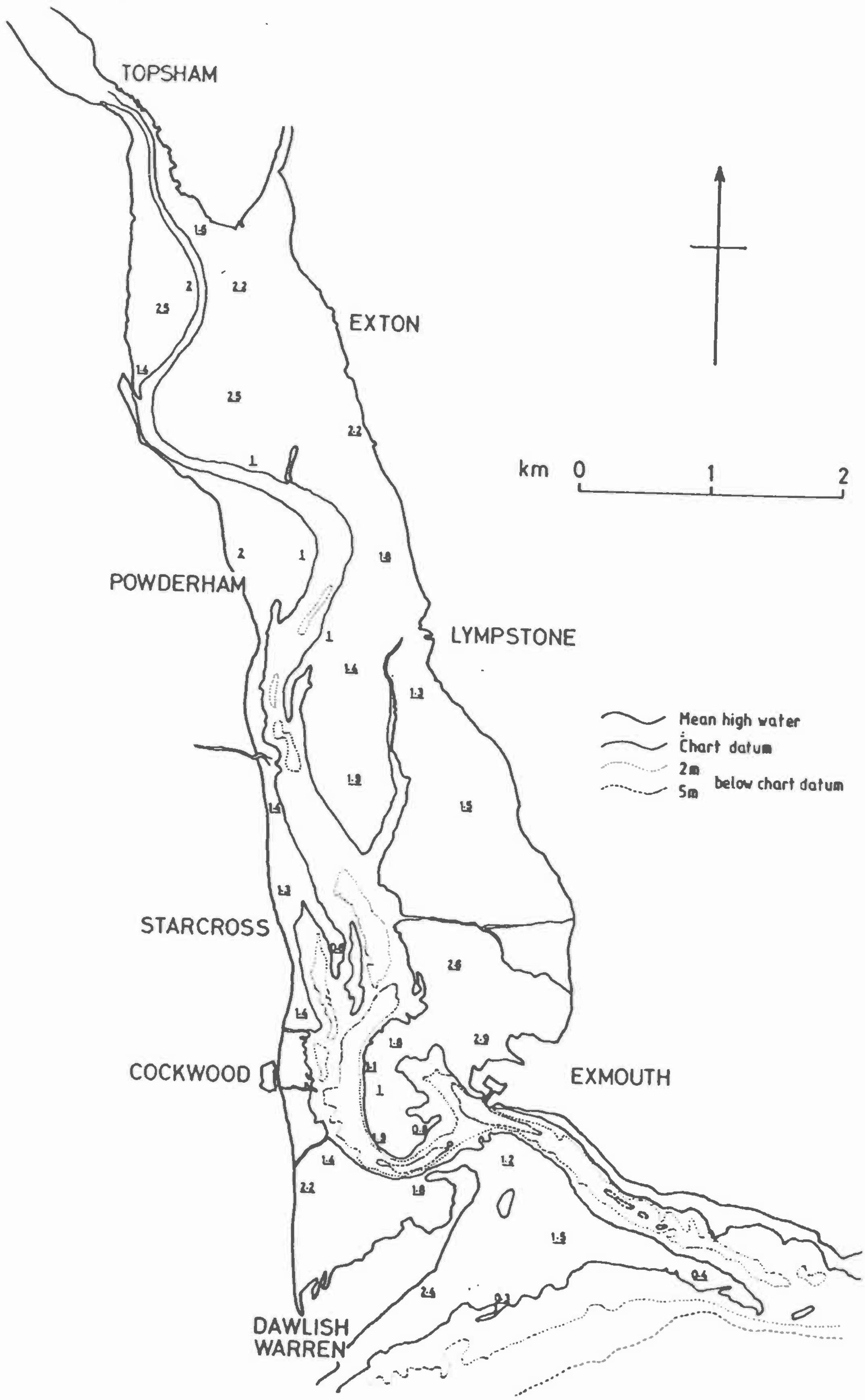

Fig. 4. Main features of the bathymetry and heights of mud flats in the Exe Estuary.

Basically the estuary consists of a narrow low tide channel meandering beteen extensive intertidal mud and sand flats. The greater part of this channel, between the M5 motorway bridge at Topsham and Dawlish Warren, has a depth of less than 1 or 2 m below chart datum (BCD) although depths of up to 5 m BCD may be found at isolated intervals. In the constricted estuary mouth between Dawlish Warren and Orcombe Point, the channel is only slightly deeper, but outside the entrance to Exmouth Dock there is a tidally excavated area with a maximum depth of just over 13 m BCD.

2.2.2. Temperature. In the Lyme Bay region of the English Channel mean monthly sea surface temperatures range from 7-8°C in February to 16-17°C in August (Crisp and Southward, 1958; Holme, 1961). No such long-term data has been seen for the Exe estuary. However Allen and Todd (1902) recorded surface temperatures at various points up the estuary over a seven hour period on December 12th, 1901. They recorded temperatures of between 8.4°C at Exmouth pier and 11.9°C at Topsham. Additionally Holme (1949) recorded surface temperatures in the main channel by Bull Hill Bank over a twelve hour period on August 19th, 1947. Temperatures ranged between 19°C at high tide in the morning to nearly 23°C at low tide in the afternoon.

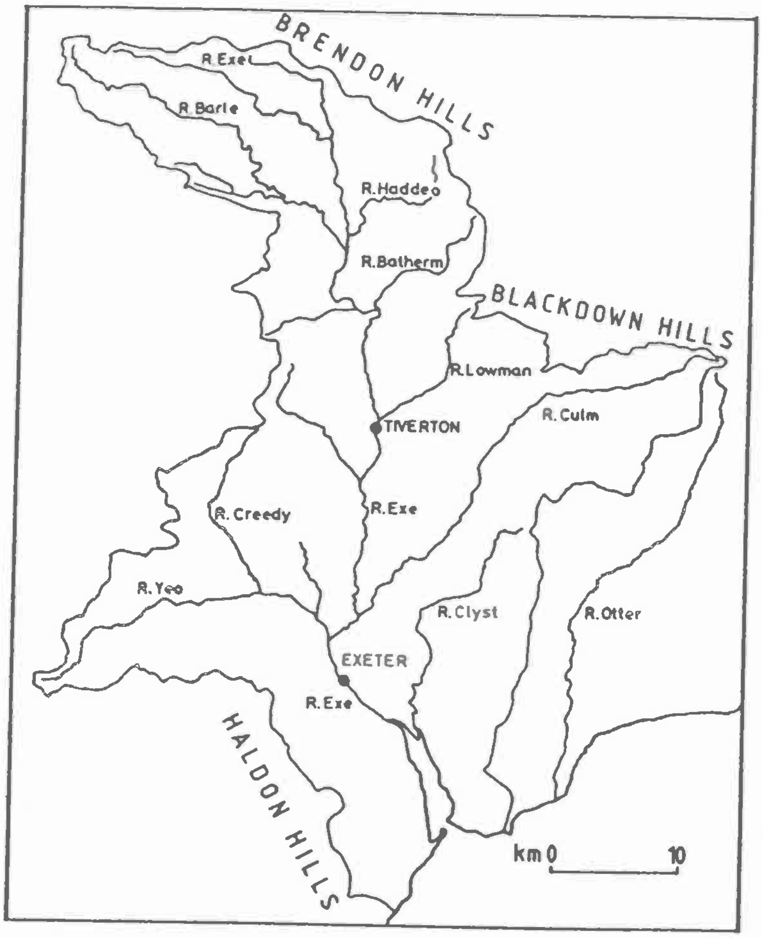

Fig. 5. The freshwater catchment area of the Exe Estuary.

2.2.3. Freshwater input and salinity. The main rivers draining the catchment area of the estuary are shown in Fig. 5. Quoted estimates of the estuarine catchment area range between 1462 km^2 and 1650 m^2 (Allen and Todd, 1902; Walling, 1978; South West Water Authority, 1980). Over this area, the average annual rainfall ranges from more than 1800 mm on Exmoor to less than 800 mm over the estuary (Walling, 1978). The main freshwater input comes from the Exe catchment. Measurements of the River Exe at Trews Weir in Exeter, taken by the South West Water Authority, indicated a mean flow rate of 2,160,000 m^3 per day over 1984. Data published by McCandlish (1980) showed seasonal variation in these flow rates in 1978 from 6,000,000 m^3 per day in February down to around 200,000 m^3 per day in September/October. For comparison, the combined average daily inputs of the Rivers Clyst and Kenn in 1984 came to less than 7% of that of the Exe.

Salinity is reduced, relative to outside seawater, throughout most of the estuary and this is particularly true at low water and during periods of high rainfall. Studies of salinity along the length of this estuary have been made by Holme (1949), Gilham (1957) and McCandlish (1980). The study of Holme found that on high spring tides in early autumn full salinity (34-35‰) was maintained as far as Powderham (nearly 5 km into the estuary) and dropped very gradually to 25‰ at Topsham (8 km into the estuary). Conversely on a low spring tide in summer, salinity at Exmouth was 32‰; at Powderham, 20‰ and at Topsham the water was almost fresh. Gilham (1957) divided the estuary into three zones based on surface salinity readings (Fig. 6). Theoretical considerations by Dyer (1980) and the depth profiles discussed by McCandlish (1980) suggest that the Exe could be classified in general as a partially mixed extuary. However, vertical and lateral salinity structure varies with tidal state, river flow, and position within the estuary, making such classification difficult.

2.2.4. Tidal streams. There are few data available for tidal currents within the estuary; the limited information published for the mouth of the estuary coming from the Admiralty chart for the area (No. 2290) and the Channel Pilot (1977 edition with 1982 amendments). Off the life boat station on Exmouth beach, maximum current speeds indicated for spring and neap tides are 3.3 kts and 1.5 kts respectively. However, higher current speeds may be recorded within the estuary during ebb and flood around low water when tidal flow is restricted to the narrow main channel. Currents tend to be fastest on the ebb tide and, in the narrows between Warren Point and Bull Hill, may reach 4.5 kts or more. During the second half of flood tides and the first half of ebb tides though, water flow is dissipated over the wider area of sand and mud flats resulting in lower current speeds.

2.2.5. Exposure to wave action. The prevailing wind and wave direction at the coast is from the southwest or south southwest which means that the estuary is protected to a large extent by the land bordering the western side of Lyme Bay. In addition the Dawlish Warren spit, which was itself built up as a result of prevailing wind and wave action, offers a large degree of shelter to the estuary immediately behind. On occasion, gales blow from the southeast and swell from the sea may be felt at Starcross at high water. Holme (1949) reported an occasion when the railway embankment south of Starcross was damaged by wave action during a southeasterly gale. In general terms, however, the importance of waves in the shallow Exe estuary lies in the maintenance of sediment in suspension and in water column mixing (Thomas, 1980). In spite of the mixing arising from wave action and currents, stratification can occur and water density: depth measurements are quoted by Holme (1949) to show this.

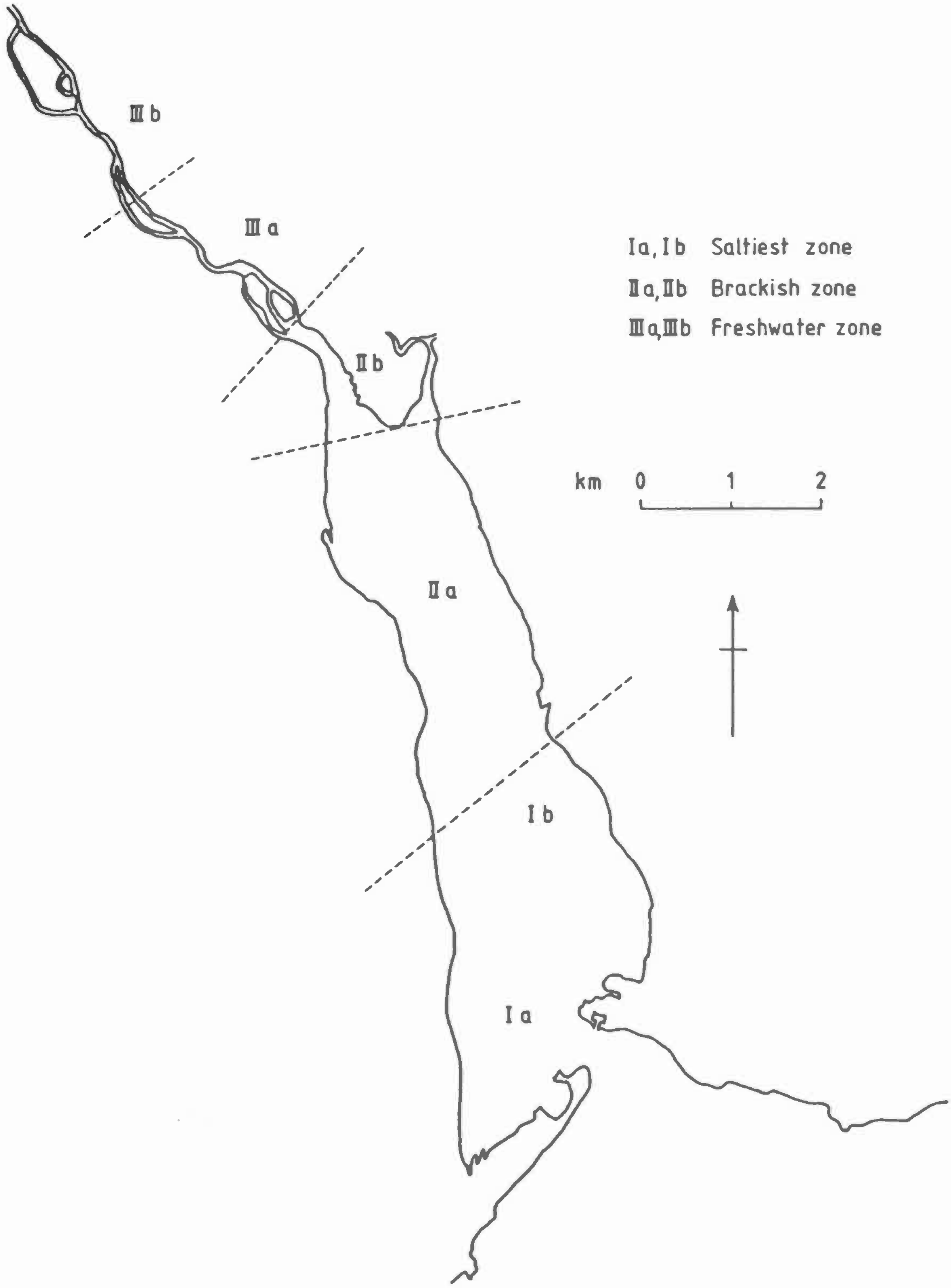

Fig. 6. The sub-division of the Exe Estuary on the basis of salinity by Gilham (1957).

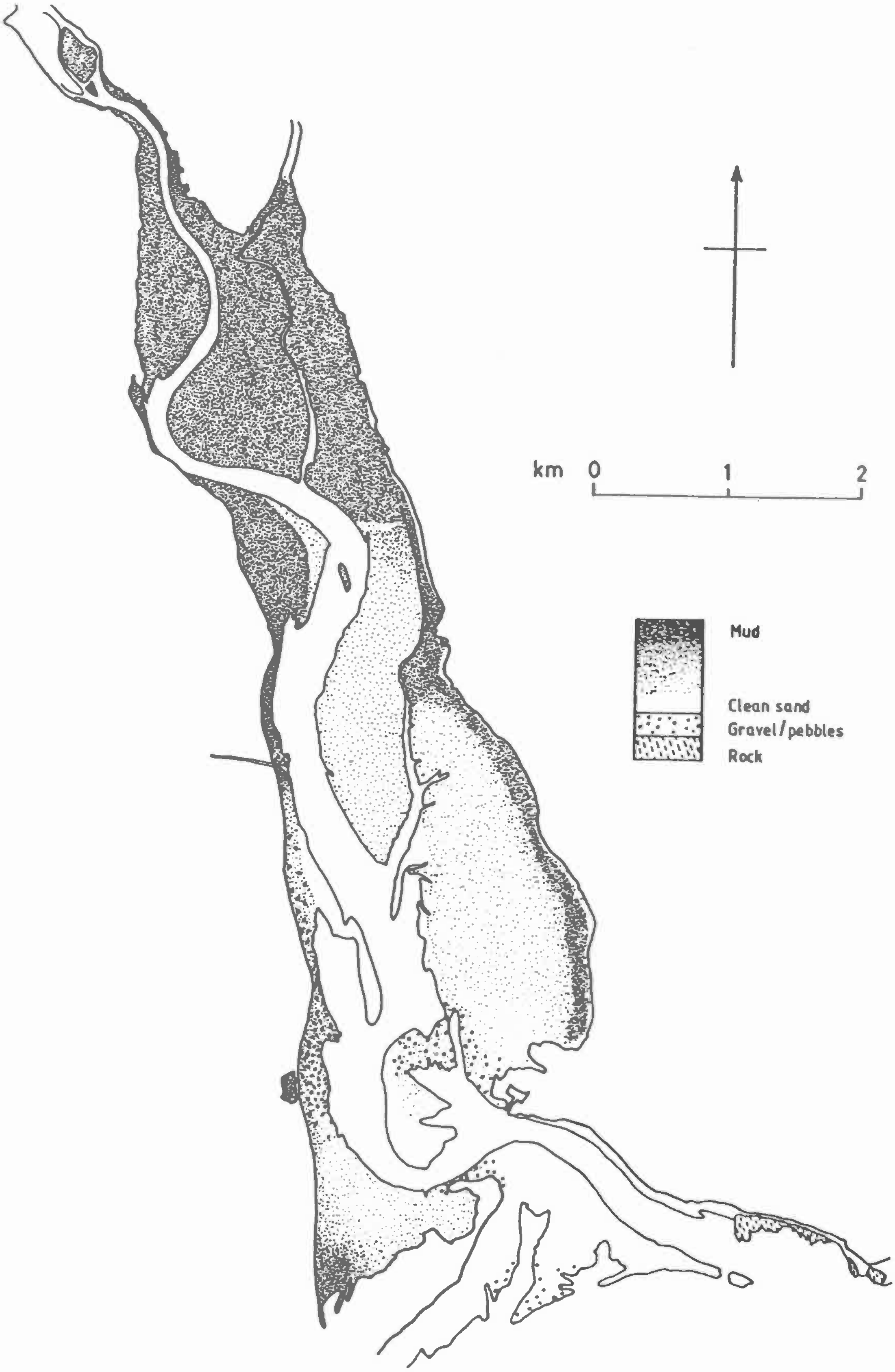

Fig. 7. Substratum types in the Exe Estuary.

2.2.6. Substratum types. the predominant substrata in the estuary are sediments, consisting of mud at the head and coarse clean sands/gravels at the mouth with intervening areas of mixed deposits (Fig. 7). Apart from the stone-faced railway embankments which line much of the upper shore on either side of the estuary, the only hard substrata to be found are small outcrops of New Red Sandstone on, or near, Orcombe Point, Exmouth beach and behind the upper shore at Lympstone.

The sediments have been derived from both marine and riverine inputs and the way in which these systems interact to give the present pattern of mud and sand-flats is discussed by Thomas (1980). Most of the mud, and some of the sand and gravel, is brought in by rivers while the sea supplies most of the sand and shell debris. Outside the estuary, the prevailing wind and waves (from the southwest or south southwest) cause a general movement of eroded material along the coast from west to east across the mouth of the estuary. This has resulted in the formation of Dawlish Warren and Pole Sand. Flood tidal streams however pick up a proportion of this sediment and transport it into the estuary. Just off Warren Point, where the estuary widens from the narrow entrance with a consequent slackening of current speed, the deposition of water borne material has formed the flood tide delta called Bull Hill. The same processes were probably responsible for building the sand spit to the west of Exmouth known as Shelly Bank.

To either side of the Bull Hill structure, finer sand with varying admixtures of mud, has been deposited to form Cockle Sand and the flats between Warren Point and Cockwood.

North of a line between Starcross and Lympstone, the intertidal sediments are predominantly mud which reflects the increasing dominance of riverine over marine influence. The mud is deposited as a result of the flocculation of riverborne suspended clay on meeting saline water. A smaller mudflat has also developed in the sheltered corner behind Dawlish Warren where Shutterton Brook (or the Salt Lake) outfalls to the estuary. The sediment of these mudflats appears to be highly reduced or anoxic below a depth of a few millimeters, with a pronounced black colour due to the predominance of reduced (as opposed to oxidised) compounds.

The channel bed, in the southern half of the estuary, consists of current-swept sand and shingle with the proportion of sand and then mud increasing northwards. North of Powderham Sand, the channel bed consists entirely of mud.

3. HUMAN INFLUENCES

3.1. Sewerage and storm drains

The basin draining into the Exe estuary, and in particular the Culm and Lower Exe catchments, incorporates one of the two most densely populated and economically active regions of the southwest. The estuary ultimately receives all the treated effluent from within this region via the Rivers Exe, Clyst and Kenn. In addition the following settlements discharge waste directly into the estuary:

Settlement	Dry weather flow (Galls per day)	Remarks
Exeter (Countess Wear)	8,500,000	Fully treated
Exminster	Storm overflow	-
Starcross	180,000	Fully treated
Topsham	Storm overflow	-
Ebford	8,000	Crude
Exton	12,500	Crude
Lympstone	68,000	Crude
Exmouth: The Point	Storm overflow	-
Maer Rocks	2,000,000	Primary treatment

At the Countess Wear works treatment involves an activated sludge process with mesophilic sludge digesters. The digested sludge is then taken by ship to be dumped at a site 12 miles offshore in Lyme Bay. At the Exmouth primary treatment plant, screened and settled effluent is discharged continually from an outfall near Maer Rocks while the sludge is discharged on ebb tides only.

The South West Water Authority monitor the estuary under the Esturial Classification System in which points are awarded for chemical quality (dissolved oxygen), biological quality (migratory and resident fish, benthic communities and toxin levels) and aesthetic quality. In 1985 the Exe was given 26 points out of a possible of 30 which merited a 'Class A, good quality' classification and description. Four points were lost due to the crude sewerage discharge at Lympstone which affects the aesthetic quality of the area but does not seriously interfere with estuary usage (B. Milford, pers. comm.).

Another potentially significant source of crude sewage and waste is from boats moored within the estuary, numbers of which have at least doubled since the late 1960's. Waste from boats can be expected to increase in the future, particularly if, as is proposed, the development of marina facilities takes place. The Water Authority has the statutory power to regulate waste disposal from boats.

The quality of the rivers supplying the estuary is classified under the River Quality Monitoring Programme, in which a target quality or 'River Quality Objective' (RQO) has been set for particular river lengths. The RQO is based on variety of chemical parameters, and annual monitoring is carried out to check that the RQO is being achieved and maintained. The RQO's and the classifications obtained over the period 1980-1984 are shown below for the Rivers Exe, Clyst and Kenn near where they outfall to the estuary:

River	Location	River Quality Classification 1980	1981	1982	1983	1984	RQO
Exe	Trews Weir, Exeter	1A	1B	1B	1B	1B	1A
Kenn	Powderham Castle	1A	1A	1A	1A	1A	1A
Clyst	Clyst St. Mary	1B	1B	1B	1B	2	2

River Classification System (National Water Council)

Classification	Description
1A	Good quality
1B	Lesser good quality
2	Fair quality
3	Poor quality
4	Bad quality

(Data from South West Water Authority, 1984)

In addition, rivers are monitored for compliance with the Council of European Communities (CEC) Freshwater Fish Directive. River lengths have been designated as being of salmonid or cyprinid quality based upon chemical characteristics and the requirements of these groups of fish. Under this directive the Exe and the Kenn were designated as salmonid rivers while the Clyst was designated as a cyprinid river. Results from river quality surveys in 1985 indicated that all three rivers complied with the Directive (South West Water Authority, 1985).

3.2. Industrial effluents and pollution

There are no industrial activities bordering the estuary producing aqueous effluents. Within the catchment of the estuary, in September 1977, 116 consents had been issued by the Water Authority for trade effluent discharges to public sewers (South West Water Authority, 1978). Of these, 95 were in Exeter and 17 in Tiverton. The general conditions of consent in the Exeter area are common to other district council areas.

Any other pollution of the estuary tends to be localised around areas of boating activity, such as harbours, sailing clubs and boat-repair yards where chronic low level inputs of oil, petroleum and anti-fouling paints occur. In the past few years there has been concern about the environmental effects of organotin anti-fouling paints and research suggests that significant ecological effects occur at very low concentrations. For example 45h LC_{50} values of 1.6 µg l^{-1} have been determined for *Crassostrea gigas* larvae; 2.3 µg l^{-1} for *Mytilus edulis* larvae and 1.5 µg l^{-1} for *Crangon crangon* larvae (Thain, 1983). Over longer periods, LC_{50} values for marine larvae occur at much lower levels and Waldock and Thain (1983) found that 0.15 µg l^{-1} tributyltin oxide was sufficient to cause shell thickening and a reduction of growth rate in larvae of *C. gigas* over 8 weeks. Also, a 15 day LC_{50} for *M. edulis* larvae in 0.1 µg l^{-1} tributyltin oxide was determined by Beaumont and Budd (1984).

The Exe Estuary was included in a survey of organotin and total tin levels in waters of Southwest England by Cleary and Stebbing (1985). Water samples were taken near the Starcross moorings in September 1984 (i.e. during the active boating season) and levels of less than 0.1 µg l^{-1} tributyltin oxide were found. This is below the detection limit of the analytical techniques used (0.1 µg l^{-1}) but the 15 day LC_{50} value for mussel larvae quoted above also borders on the current lower limits of detection. This coincidence of analytical detection limits and thresholds of biological effect creates difficulties in assessing the biological significance of limited data from the field. Also the problems of extrapolating experimental results from the laboratory to the field are well known and it is unlikely that an unequivocal cause-effect realtionship can be established without time consuming study.

3.3. Port/harbour facilities and users

The estuary has dock facilities at Exmouth, Exeter and Topsham. Ships using these facilities are limited in size by the shallowness of the estuary, and further constraints are imposed by the narrow entrance to Exmouth harbour and the dimensions of the locks on the Exeter Canal. Ships of up to 1000 tons deadweight can be accommodated at Exmouth and Topsham, and vessels of up to 350 tons use the canal. The cargoes handled at both Exeter and Exmouth include coal, timber, grain, feedstuffs, fertilizer and cement, although Exeter is nowadays comparatively little used. Exmouth dock was handling 100,000-125,000 tons of shipping annually in the early 1970's (Devon County Council, 1975) while the quay at Topsham, used by the Tuborg lager plant until recently, is no longer used commercially.

There is a small fleet of fishing boats in the area, operating mainly from Exmouth, Topsham and Lympstone. In addition, a ferry for pedestrians sails between Starcross and Exmouth during the summer months.

Several boat-building and repair businesses operate around the estuary, but in particular these occur at Exmouth, Topsham and Starcross.

Perhaps the main use of the estuary is in recreation and tourism, a survey of which took place in 1973 (Devon County Council, 1975) and twice subsequently (Devon County Council, 1977, 1978). The Exe estuary is one of the larger areas of sheltered water to be found on the Devon coast, certainly in the western half of Lyme Bay, and is a major watersports centre. Sailing, of both dinghies and cruisers, is the primary activity and there are four main sailing clubs together with smaller ones associated with local schools, youth clubs and colleges. With other motor boats and fishing vessels, there are about 2500 boats using the estuary. Moorings in part of the main channel and deep water in the lower estuary are controlled by the East Devon Council, but elsewhere about 1400 boats use public moorings which now come under the control of the Exe Mooring Owners Association.

Sea fishing is another popular local pastime both within and outside the estuary and there are at least four clubs which cater for both boat-angling and shore angling. The tourist season in particular brings a lot of visiting anglers for whom regular fishing and sightseeing boat trips are organised, mostly from Exmouth. Bait for fishing is also collected from within the estuary either by digging for polychaetes (mainly Arenicola marina, Nereis diversicolor and Nephtys spp.); by the collection of soft ('peeler') crabs from under specially laid tiles and drain-pipe sections; or by trawling for sand eels. Bait digging, is concentrated around access points, and the sandbanks behind Exmouth in particular appear to be visited frequently. The peeler crab tiles are laid out in neat rows and can cover quite extensive areas of midshore down both sides of the estuary.

In addition to sailing, fishing and cruising, other popular activities include water skiing, power boat racing, canoeing, windsurfing, diving and swimming. All these activities take place within the estuary although swimming and diving tend to be concentrated along the seaward side of Dawlish Warren, Exmouth Beach and the rocks below Orcombe Point and Straight Point. Although the whole of the estuary is used for the other watersports, there is a heavy concentration of users betrween Starcross and Dawlish Warren. During summer in particular, navigational difficulties can arise due to congestion.

The intertidal and upper shore areas around the estuary are also used for recreation purposes, including bird watching, angling, wildfowling and picnicking/sunbathing.

The Exe estuary is renowned for its winter populations of waders and wildfowl and the western half of the estuary between Warren Point and Turf is a designated wild bird sanctuary. The Devon wilfowlers Association is active in the upper part of the estuary to the east of Exeter canal, and also the marshes. Cockle Sands is also used. The season lasts from September 1st to January 31st for inland waters and until February 20th for the foreshore. The bags consist mainly of Mallard and Widgeon.

3.4. Commercial utilization of fish stocks and mariculture

Within the estuary, flatfish (predominantly plaice) mackerel, bass and mullet are taken together with eels, salmon and sea trout, and a variety of shellfish. The main fishing grounds, however, are outside the Exe estuary. In addition to fishing and collection, oysters and clams are reared and some of the mussel stocks within the estuary are managed.

The Devon Sea Fisheries Committee has overall responsibility for marine fisheries (including shellfish) with the exception of salmonids which come under the authority of the South West Water Authority. The later has responsibilities for the freshwater fisheries.

The Exe Estuary Study (Devon County Council, 1975) estimated that between 35 and 45 fishermen worked the estuary and adjacent waters professionally, and that 15 boats were based in or near to Exmouth dock. At present 19 licenses for the netting of salmon and migratory trout are held by the river Exe Helmsmen Association, and most of these work from Topsham and Lympstone. The open season for 'nets and fixed engines' commences on April 16th in the upper reaches (above Topsham) and on February 14th in the lower reaches (below Topsham) but in both areas lasts until August 16th. Since 1956, catches of both salmon and sea trout have fluctuated widely (Fig. 8).

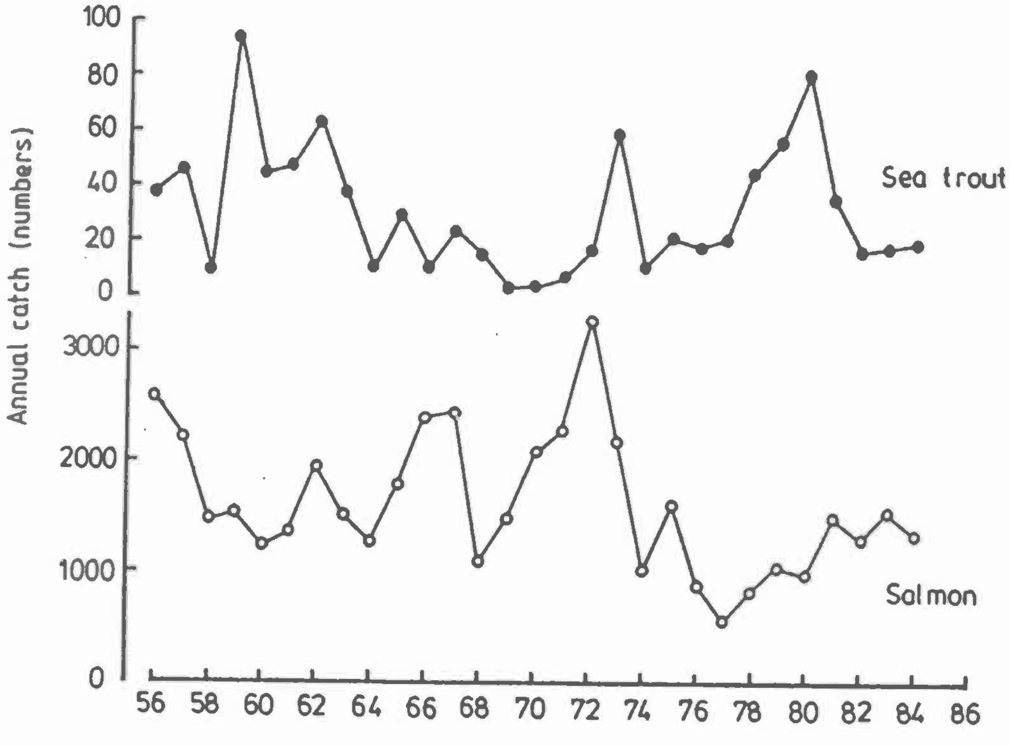

Fig. 8. Salmon and trout returns from the Exe netsmen 1956-1984.

There is a small fishery for eels (Anguilla anguilla), with yearly catches from 1980 to 1984 varying between 35 and 392 lbs (Southern Water Authority data). Oysters were once reared in Greenland Lake (a tidal lagoon on Dawlish Warren, no longer extant due to coastal erosion and the installation of groynes and gabions) and in Lympstone Lake. At present, oysters (Crassostrea gigas) are grown-on behind Dawlish Warren and up on Powderham Sand although in recent years increasing mortality at the latter site has caused that enterprise to be unsustainable (P. May, pers comm.). In addition to oyster farming a license has been granted to lay out a batch of the Manilla clam, Venerupis semidecussata, behind Dawlish Warren as an investigation into its commercial viability. This is the first known site where this alien species has been introduced to Britain, although they have since been reared experimentally in the Daucleddau estuary also.

The estuary also supports stocks of shellfish including mussels (Mytilus edulis) and winkles (Littorina littorea) which have long provided livelihoods locally. Mussel beds occur on the intertidal flats as far north as a line approximately between Powderham and Lympstone but tend to be concentrated on Bull Hill, between Starcross and Cockwood, and on Lympstone Sand. Their distribution owes much to past human intervention, with locals laying out their own mussel beds which were then tended and harvested. In addition, winkles were often actively transplanted from elsewhere onto these patches. Allen and Todd (1902) reported that winkles were collected by boys who used to sell them to the mussel-bed proprietors for the purpose of keeping the beds clear from algae. Mussels from the estuary used to be cleaned at a purification plant in Lympstone which is now no longer in use. Current commercial use of the Exe stocks is minor, although selected mussels from Bull Hill are caged and grown on.

Winkles are collected for sale and, as mentioned previously (Section 3.3) crabs and infaunal polychaetes are taken for fishing bait. The sand eel Ammodytes tobianus, which is also used as bait, is trawled from sandy areas at the mouth of the estuary, especially over Pole Sand. The old scallop fishery outside the estuary is now much reduced.

3.5. Educational

In addition to the more outward-bound orientated teaching of various youth organisations and clubs, the estuary is used by a number of local educational establishments for teaching purposes. These include schools, colleges (Exeter Technical College and St. Lukes College) and in particular, Exeter University. The whole of the estuary is used, but areas such as Dawlish Warren, Exminster marshes, the sandbanks around Bull Hill, and the sandstone outcrops on the coast are used in particular for fieldwork.

Teignbridge District Council employs a full-time warden on the Dawlish Warren Nature Reserve who gives guided walks to school parties and other visitors. Pamphlets are also published which interpret various aspects of the Warren, its natural history and ecology. There are plans to include an estuarine natural history interpretation section at Topsham Museum in the near future.

3.6. Established nature conservation importance.

The whole of the estuary, between Countess Wear bridge to the north and a line joining Langstone Rock with Orcombe Point to the south, was notified as a Site of Special Scientific Interest (SSSI) under the National Parks and Access to the Countryside Act of 1949. Points specified in the SSSI schedule included the importance of the estuary to waders and wildfowl and also to Exeter University as an area for physiographical and ecological study. Dawlish Warren and the sandstone exposures at Lympstone, Orcombe Point and Langstone Rock were also cited in the original description. The site schedule was revised in 1976 and then renotified in 1985 under the Wildlife and Countryside Act of 1981. The boundary of the SSSI was altered to include the old sludge beds and Bowling Green Marsh at Topsham. The current seaward boundary lies on the mean low water line, cutting across the entrance channel between Maer Rocks and Pole Sand. Dawlish Warren was notified separately as an SSSI in 1984.

The Exe estuary and surrounding area is included in various environmental policies drawn up as part of the Devon County Structure Plan (Devon County Council 1981, 1983). These policies give guidelines for controlling development in areas designated as Coastal Preservation Areas, Areas of Great Landscape Value, Nature Conservation Zones, and Scenic Routes. The whole of the west side of the estuary, and the east side south of Lympstone is a coastal preservation area. In addition, the west bank of the estuary falls within an Area of Great Landscape Value and the whole estuary is designated a Nature Conservation Zone. The two SSSI's are included within this latter designation which also includes Powderham Park. The course of the estuary itself, and the B 3381 from Haldon to Starcross have been declared Scenic Routes.

The estuary is of international importance for its wintering populations of waders and wildfowl such as black-tailed godwit (*Limosa limosa*), ringed plover (*Charadrius hiaticula*), avocet (*Recurvirostra avosetta*), dark-bellied brent goose (*Branta bernicla bernicla*), and wigeon (*Anas penelope*). These feed on areas of eelgrass (*Zostera* spp.), green algae (eg. *Enteromorpha* sp.) and on the macrofauna within the extensive intertidal sediments. The western side of the estuary, from Dawlish Warren to Turf, was made a Bird Sanctuary in 1934 and afforded additional protection under a Bird Sanctuary Order (S.I. no. 901) in 1951.

Reclaimed land, fringed by reed beds in the upper reaches or patchy salt marsh lower down, is used by water birds at high tide, and also provides nesting and feeding habitat for other bird species. The largest of these areas is Exminster Marshes, the subject of a conservation assessment by the Devon Trust for Nature Conservation (King, 1979).

The intertidal sediments support a typical range of estuarine and marine species but include one of only two known British populations of the polychaete, *Ophelia bicornis*. Powell *et al* (1978) gave the Exe estuary an overall marine biological grading of 3. The subsequent assessment of Bishop and Holme (1980) suggested uprating the estuary's status to grade 2 (of National Importance) due to the variety of sedimentary habitats present and its previous history of scientific and educational study. The Exe is considered to support intertidal communities representative of four distinct types, as defined in Bishop and Holme (1980). These are each named after their characteristic species, and are as follows: *TELLINA*, *ARENICOLA*, *SCROBICULARIA* and *LANICE*. In addition, populations of *OPHELIA BICORNIS* are considered to be characterisic of a variant of the CRUSTACEAN-POLYCHAETE community.

In addition to its status as an SSSI, Dawlish Warren has been a Local Nature Reserve since 1980 and is managed, through wardening, by Teignbridge District Council. It has a range of habitats, including saltmarsh, sand dunes, dune grassland, heath and freshwater marsh and also supports a variety of interesting fauna and flora, some of which are rare. A management plan for the Warren, maximising conservation rather than recreational development, was published by Teignbridge District Council (1978). Both Dawlish Warren and the Exe estuary SSSI's contain features of geological interest including the sandstone outcrops at Langstone Rock, Lympstone and Orcombe Point. Dawlish Warren itself is of interest to sedimentologists and has been much studied (e.g. Martin, 1872; Kidson, 1950, Durrance, 1969). Areas of land around Orcombe Point and Lympstone are owned by the National Trust while Dawlish Warren is part owned by Teignbridge District Council and the Devon Trust for Nature Conservation.

Between 1964 and 1985 various proposals have been put forward for the development of a marina complex in the estuary; the majority of which have been sited around Exmouth between The Point and Exmouth Harbour. Details of these, and a discussion of the potential environmental effects of such developments, have been the subject of an MSc thesis by Ling (1985). This work emphasizes the potential for conflict between many varied conservation interests and those of other users. Management of the estuary and its shoreline is divided between ten bodies; including county, district and city councils; dock, harbour and river authorities; the South West Water Authority; the Crown Estate Commissioners and the Ministry of Defence. Previous studies of recreational usage and conservation interests in the estuary have highlighted the requirement for greater co-ordination between these groups in order to achieve effective management (e.g. Devon County Council 1975, Devon Conservation Forum 1978).

4. PREVIOUS BIOLOGICAL STUDIES

4.1. Plants

Botanical records in the estuary commenced with a list of algae for Exmouth published by Lea (1927), after which there was a gap of almost 30 years before an account of the vegetation of the whole estuary was given by Gilham (1957). In this paper, the distribution and zonation of algae and saltmarsh plants is detailed in relation to salinity and substratum availability. On the basis of her own salinity records and plant lists, Gilham divided the estuary into three zones; these being the 'Freshwater' zone above Topsham; the 'Brackish' zone between Topsham and a line drawn between Starcross and Lympstone; and the 'Saltiest' zone south of this line. She concluded that substratum availability was a major limiting factor on the distribution of algae within the estuary. The distribution of *Zostera* spp. was given and it was noted that it only extended as far north as Lympstone. This contrasts with the earlier observations of Allen and Todd (1902) in their intertidal fauna survey where they stated that Greenland Bank (off the village of Exton) was 'entirely covered with *Zostera*'.

An updated account of the saltmarsh vegetation has been given by Proctor (1980) which includes details of the introduction of *Spartina anglica* to the estuary in the 1920's, 1930's and 1950's. Parkinson (1980) details the loss of saltmarsh habitat that has taken place since the 12th Century due to land reclamation, industry and embankments. Of an original estimated total of 2100 acres, only 50 acres of saltmarsh now remain and more than half of this is a *Spartina* monoculture. A detailed mapping survey of the remaining saltmarsh was carried out by the NCC in 1982 (Charman, 1982, unpublished).

With regard to specific areas within the estuary, a study of the plant ecology of Dawlish Warren was made by Wallace (1953) and a survey and conservation assessment of the Exminster marshes has been reported by King (1979).

4.2. Animals

The publication of faunal records from the Exe estuary started at the turn of this century with the shore collections, trawls and dredges made by Allen and Todd (1902). This paper also included records from Seine netting carried out earlier in 1897 by Mr. E.W.L. Holt. In addition to compiling lists of macrofauna for the sites they visited, they also noted habitat details and made preliminary observations on salinity reduction within the estuary. The occurrence of the polychaete Ophelia bicornis around the mouth of the Exe was first noted here.

At the same time, the intertidal Foraminifera were examined and listed separately by Worth (1902). From his analysis, Worth concluded that the Exe estuary was more estuarine in nature than the Salcombe inlet which had been sampled in the previous year.

Between the two World Wars, a survey of the crustacean fauna of several southwestern estuaries was carried out (Crawford, 1937). This included five brackish and freshwater sites mainly in tidal ditches and ponds around the edge of the estuary. Following on from this, a similar multi-estuary study was made by Spooner (1947, 1951) who concentrated on the taxonomy of Gammarus spp. (Amphipoda) and their distribution in relation to salinity.

The next ecological study of the intertidal flats was undertaken by Holme (1949) who made a special investigation of the effects of sediment type upon the intertidal macroinfauna near the mouth of the estuary. In most data sets from estuaries, the influences of sediment type on faunal distribution cannot be separated from those of exposure, salinity and tidal immersion because these are all normally interrelated. In Holme's study the distribution and density of animals was determined at several stations along a transect which covered a variety of sediment grades; but which were all close together at about the same tidal level. In this study, factors such as tidal immersion, salinity, pH and wave/current exposure were effectively eliminated; leaving soil grade and related factors as the main variables. Results showed that the distribution of many species could be closely correlated with sediment type and silt content, although the actual mechanisms involved in producing the observed patterns remained obscure and nowadays can still only be speculated upon.

The work of Holme in the Exe continued with a study of a population of Tellina tenuis in which it was concluded that the observed even or regular dispersal of individuals was probably related to intraspecific interaction through the foraging activity of inhalent siphons on the sediment surface (Holme, 1950)

Factors affecting the settlement and distribution of Ophelia bicornis on Bull Hill and around Salthouse Lake were the subject of much experimental study over the same period (Wilson, 1948, 1952, 1953a, 1953b, 1954 and 1955). It was established that sediment particle size and drainage were of clear importance together with the presence of particular micro-organisms as films on individual sand grains.

In 1959 and 1960, studies of the intertidal meiofauna continued with the survey of copepod crustaceans at stations throughout the Exe (Wells, 1961 and 1963). In this survey 96 species were found of which 22 were then new to the British list. This work formed part of a PhD study based at Exeter University. Other work in and around the estuary has also originated from the University which makes use of this resource for educational and research purposes. This has included the ecological and taxonomic studies of free-living nematodes by Warwick (1968 and 1971). Fourteen species new to science were described with the Exe as the type locality (Warwick, 1970). The quantitative data from this work was subsequently analysed by multivariate techniques (Field et al., 1982) which identified station groups representing four habitats each characterised by a distinct nematode fauna. The habitats represented ranged from mud to clean and well-drained sands.

Research on aspects of the meio- and macrobenthos of Cockle Sand has been carried out by the Institute for Marine Environmental Research (IMER) since the 1970's. Much of this work has been concerned with community structure and function, including the quantification of respiration and secondary production. The meiofauna of the Cockle Sand site has been used in determining the potential for use of the ratio of nematode numbers to copepod numbers as a tool in pollution monitoring. This site was considered to be unpolluted (Warwick, 1981).

These studies continue, together with those of Exeter University and the Marine Biological Association in Plymouth in particular. Synoptic studies on bioaccumulation of metals and other pollutants often include data from the Exe (e.g. Bryan and Hummerstone, 1973, Gibbs et al, 1983 and Cleary and Stebbing, 1985). A possibly new species of the polychaete genus Tharyx was collected from Dawlish Warren by Gibbs et al. (1983).

The waders and wildfowl of the Exe are well documented (National Wildfowl Counts and Birds of Estuaries Enquiry annual reports; Prater, 1981; Davies, 1983) and in addition, have been the subject of much research; particularly with respect to feeding ecology (e.g. Goss-Custard et al., 1980; Price and Davies, 1981).

In 1980 a special symposium on the Exe Estuary was held in Exmouth and the proceedings published as a special volume of the Devonshire Association for the Advancement of Science, Literature and Art (Boalch, 1980). Topics covered many aspects of the environment, and included papers on vegetation (Proctor, 1980); Foraminifera (Murray, 1980); the intertidal fauna of Bull Hill (Harris, 1980) and the ecology of oystercatchers and mussels (Goss-Custard et al., 1980). The paper by Harris concentrated on the invertebrate communities of Bull Hill and the immediately adjacent areas. He identified five distinct sedimentary habitats from this area, each with its own characteristic community.

- Muddy shore Spartina/Scrobicularia community (Fig. 9).
- Sandy shore Arenicola/Cerastoderma community (Fig. 9).
- Well-drained sandy Ophelia community. Dominated by O. bicornis with secondary components only the surface diatoms and the meiofauna with very occasionally Nephthys spp. and Nerine cirratulus.
- Heavily scoured Ophelia community. Very mobile rippled sand with few if any macrofauna other than large numbers of O. bicornis.
- Mytillus community (Fig. 9).
- Mytillus

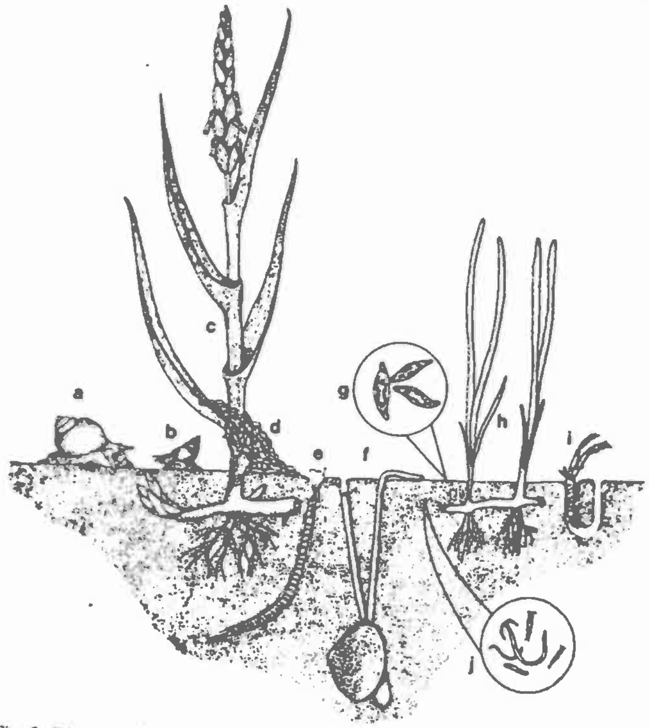

Fig. 6. Diagram of the mud-shore community of area A. a. *Littorina* sp. (see text), b. *Hydrobia ulvae*, c. *Spartina anglica*, d. *Vaucheria* sp., e. *Neanthes diversicolor*, f. *Scrobicularia plana*, g. surface diatoms, h. *Zostera hornemanniana*, i. *Corophium volutator*, j. meiofauna.

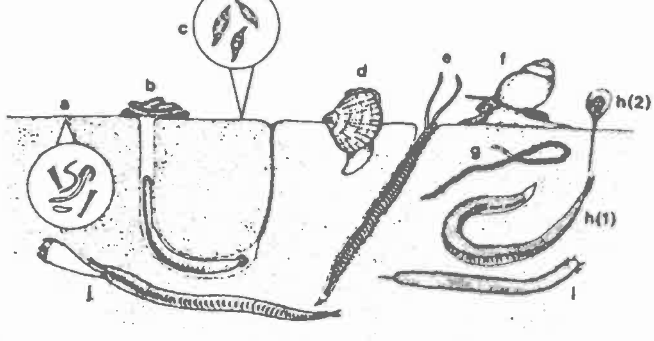

Fig. 7. Diagram of sandy-shore community of area B. a. meiofauna, b. *Arenicola marina*, c. Surface diatoms, d. *Cerastoderma edule*, e. *Nerine cirratulus*, f. *Littorina littorea*, g. *Cephalothrix rufifrons*, h. (1) *Scoloplos armiger*, h. (2). the egg-mass of *Scoloplos*, i. *Nephtys cirrosa*, j. *Glycera alba*.

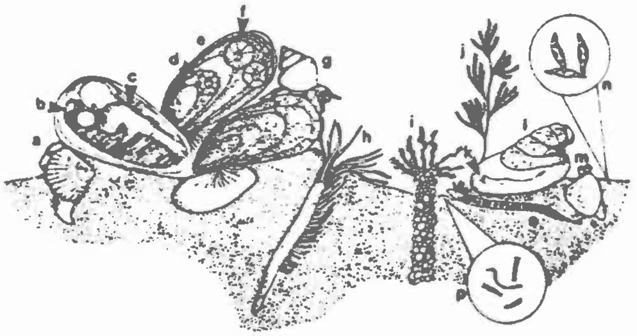

Fig. 9. Diagram of the *Mytilus* community in area E. a. *Cerastoderma edule*, b. *Pinnotheres pisum*, c. *Mytilicola intestinalis*, d. *Elminius modestus*, e. *Mytilus edulis*, f. *Semibalanus balanoides*, g. *Littorina littorea*, h. *Cirriformia tentaculata*, i. *Lanice conchilega*, j. *Dynamena argentea*, k. *Pomatoceros triqueter*, l. *Crepidula fornicata*, m. *Spisula solida*, n. surface diatoms, o. *Eumereis longissima*, p. meiofauna.

Fig. 9. Illustrations of three of the sediment communities identified by Harris (1980). Original figures and captions reproduced from Harris (1980) with permission of the Devonshire Association and T. Harris.

5. SURVEY AIMS AND METHODS

5.1. Introduction.

The aims of the field survey were:

1. To collect information on the abundance of macrofauna and flora at sites selected to include a wide range of different shore and seabed types, areas of known or likely nature conservation importance, or where rare or unusual species might be present.

2. To collect photographs of the habitats, communities and species present. During the Exe survey we also planned to sample areas which were included in the studies undertaken by Allen and Todd (1902) with the intention of comparing communities present then and now.

5.2. Fieldwork.

The combined intertidal and subtidal survey took place during the week 17th-24th August 1985 and a total of 47 sites were sampled (Fig. 10, Table 1) (Fig. 10 folds out at the end of the report in bound copies). Most of these were on intertidal sediment (Sites 1-32), and only two rocky intertidal areas fell within the survey area (Sites 33 and 34). Subtidally, Sites 35 to 44 were sampled remotely using a trawl and a pipe dredge, and divers surveyed sites 45 to 47 near the mouth of the estuary. Turbidity and currents prevented diver inspection of the seabed in the main channel north of Bull Hill.

Survey methods for both intertidal rocky shores and subtidal hard substrata were based on techniques already developed for use in NCC surveys. Techniques new to surveys being undertaken for NCC by FSC were developed for intertidal and subtidal sediment sampling. Checklists were used throughout to ensure recording to a consistent style and, for species abundance data, in a form ready for recording on computer files. Examples of recording sheets are held in Volume 3.

5.2.1. Sediment intertidal. At each site selected, the shore habitats present were recorded on the NCC Sediment Shore Recording Sheet. The abundance of species visible at the surface was noted.

The infauna was then sampled by a combination of coring ($4 \times 0.01\ m^2$ cores to a depth of 20 cm) and qualitative collection. Field notes and sketches were made to record features such as shore profile, sediment type and depth of redox discontinuity, while photographs were taken as appropriate. Core samples were sieved on a 1 mm mesh and the retained material preserved for laboratory analysis.

5.2.2. Rocky intertidal. At each site a systematic description was made of the abundance of species in the main habitats and communities present at different heights on the open shore. These normally included the lower shore (LS), lower midshore (LMS), midshore (MS), upper midshore (UMS), upper shore (US) and splash zone (Spl) as well as the other habitats. The density of each species was recorded according to the appropriate abundance scale (Appendix 1). Specimens were collected where necessary for identification. Sketches of the site location, site profile, and of any other important features were prepared and photographs taken. Data was later transferred to the NCC Rocky Shore Recording Sheet, a habitat description sheet, and plant and animal recording sheets.

5.2.3 Sampling from subtidal sediments. A 1 m Aggassiz trawl and a pipe dredge (1 m long and 25 cm in diameter) were deployed from a small fishing boat, the MV 'Margaret', in order to take qualitative samples of the epifauna and infauna respectively. Most of the fauna and flora obtained by trawling was identified and recorded in the in the field but samples from each dredged site were seived on a 1 mm mesh and preserved for laboratory analysis.

5.2.4. Epibiota on subtidal rock and sediments. High turbidity and fast currents restricted the survey of subtidal areas by divers to the mouth of the estuary. During a dive the team leader determined the separate stations from which records were to be made as they were encountered on the seabed. At each survey station, the habitat type was described and the abundance of conspicuous species was recorded according to the scales given in Appendix 2. Photographs were taken to illustrate habitats, communities and species; and specimens were collected where necessary for accurate identification. Site location information, substratum type, topographical features and other habitat details were recorded on the Sublittoral Habitat Recording Sheet. Species data were recorded on the plant and animal checklists.

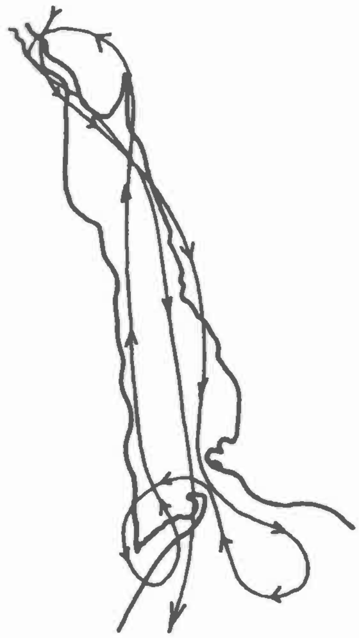

Fig. 11. Flight paths for aerial photography.

5.2.5. Aerial photography. Aerial photography was undertaken on April 5th from a Cesna 172 aircraft piloted by Mr R. Dougan from the Exeter Flying Club. The prime purpose of the flight was to survey the Salcombe inlet but photographs were also taken of the Exe, Dart and Teign. The flight path taken over the Exe estuary is shown in Fig. 11. A contiguous series of oblique photographs was taken using Olympus OM2 and OM10 cameras equipped with 50 mm lenses and a haze (ultra-violet) filter. Shutter speed was as fast as light conditions allowed but was never less than 1/250 s. Filmstock was Kodachrome 64. General views, and features of particular interest, were photographed using a Canon AV 1 equipped with a 28 to 80 mm zoom lens. Shutter speed was 1/500 or 1/1000 s and Fujichrome 100 filmstock was used which enabled processing that evening. Photographs of the Exe Estuary were taken at between 1208 and 1225 from a height of about 600'. At this time, the tide was still over the mudflats in the upper estuary.

Photographs were labelled and filed in two sets: the contiguous series and the general views. Photographs were filed in the order they were taken. The OM10 camera had malfunctioned leading to all of the photographs taken with that camera being over-exposed. However, the slides were filed where they included subjects not included in photographs taken with the OM2.

5.3. Data analysis and presentation

5.3.1. Conspicuous species. Field records of the abundance of conspicuous species in separate habitats at each site were entered into the data management program described by Hobbs (1985). Print-out from these files (Volume 2 of this report) enables a clear view of the distribution and habitat preferences of each species. The site records have been used to identify the different habitats and communities encountered during survey and to classify them.

5.3.2. Core samples. Preserved infauna samples were further washed over a 1 mm mesh seive to remove formalin and any remaining fine sediment. The samples were each spread out in a white tray, covered with water, and the biological material extracted. The fauna was identified and numbers of individuals of each species noted. Two reference collections were compiled, one being retained at the Oil Pollution Research Unit, and the other deposited with Exeter Museum.

5.3.3. Data analysis. To aid in interpretation of the infaunal data, a qualitative classification analysis was performed using Sorensen's index of similarity with a group average clustering procedure (Clifford and Stephenson, 1975). A qualitative analysis was chosen because in addition to the core sample data, qualitative field records of macrofaunal species were included. This was done in order to gain a more complete picture of the distribution of those conspicuous and more widely dispersed species which were observed in the field but not always sampled by the cores (e.g. Arenicola marina and Lanice conchilega). Finally the species list was ordinated with respect to the sequence of sites obtained from the clustering procedure. Thus in the resultant data table of species against sites, any distribution patterns reflecting environmental gradients (or habitat types) would become visually apparent.

6. RESULTS

6.1. Introduction

Intertidal habitats are described first, followed by those of the subtidal areas. In both cases habitat descriptions are ordered, where possible, from the exposed estuary mouth towards the sheltered head.

6.2. Intertidal habitats and communities

Three broad habitat types were identified. These were the rocky shores just outside the estuary; the hard substrata (stones) overlying the sediments, together with man-made walls and structures within the estuary; and the large areas of intertidal sediment within the estuary.

6.2.1. Exposed rocky shores (Sites 33 and 34). The two rocky intertidal areas surveyed were both situated on the mouth of the estuary where the constricted channel entrance opens into Lyme Bay. Both sites were therefore exposed to prevailing wave action although the tip of the Pole Sand shoals may offer a degree of protection to the western end of Maer Rocks at Site 33. The two sites were also structurally and biologically similar. Both were flat platforms of New Red Sandstone intersected by channels with overhangs, crevices and rock pools. Each site was essentially an island of rock in an otherwise sandy shore although the rock at a Orcombe Point extends into the shallow subtidal unlike Maer Rocks. The upper shore at both Maer rocks and Orcombe Point was predominantly sand with the former being backed by a road and the latter by an New Red Sandstone cliff.

At Orcombe Point the splash zone on the cliff was sparsely covered by the lichen Verrucaria maura. No fauna occurred on the south-facing cliffs, but in areas protected from direct wave action Chthamalus montagui was common together with Littorina 'saxatilis' (?rudis) and Ligia oceanica. Other species, including Semibalanus balanoides, Eliminius modestus, Anurida maritima, Patella vulgata, Littorina neritoides, L. neglecta and Mytilus edulis were less abundant. Species such as V. maura, C. montagui, L. oceanica and the upper shore/splash zone littorinids were not recorded at Maer Rocks because the habitat was not present.

From the upper shore downwards, however, both sites had a very similar range of habitats and species. Both were algal dominated, with Enteromorpha spp., Rhodochorton floridulum, and Audouinella sp. in particular covering most of the horizontal rock surfaces over the whole shore. This cover was underlain by an almost continuous turf of extremely small Modiolus sp. juveniles. Fucoid cover was extensive in places with Fucus spiralis occurring abundantly on the upper shore at Orcombe Point.

The whole midshore at Maer Rocks supported F. vesiculosus, in contrast to the corresponding level at Orcombe Point where F. serratus was recorded. A lower shore zone of F. serratus, co-dominant with Enteromorpha spp., was present at both sites. Other algal species recorded generally included Gelidium pusillum, Chondrus crispus, Porphyra umbilicalis, Gigartina stellata and Cladostephus spongiosus. Catenella caespitosa was found on the upper shore at Orcombe Point only. Species recorded on the lower shore at both sites included Palmaria palmata, Membranoptera alata, and Laminaria digitata, whilst L. saccharina and Gigartina acicularis were only recorded at Orcombe Point. The latter is a Lusitanean species with its known northern limit in Pembrokeshire.

The most diverse fauna was recorded from sheltered vertical faces, overhangs and towards the lower shore at both sites. These included the sponges; the bryozoans commonly found growing on algae; and the isopods and amphipods sheltering amongst algal fronds. The serpulid Pomatoceros triqueter/lamarcki was commonly recorded from vertical surfaces, and from within the old sewer outfall on the lower shore at Maer Rocks. Similar habitats were favoured by Balanus perforatus and Actinia equina. Patella vulgata was only found on Orcombe Point whereas P. aspera was found more generally although only infrequently. Rarely recorded animals restricted to the lower shore crevices and vertical surfaces included Sagartia troglodytes, Bugula plumosa, Archidoris pseudoargus, Rostanga rubra, Acanthochiton crinatus, Ascidia mentula, Ascidiella aspersa, Clavelina lepadiformis and Morchellium argus.

The intertidal pools at both sites were dominated by algae; mainly Enteromorpha spp. and Ceramium sp. In pools in the Fucus serratus zone on Maer Rocks, the Japanese seaweed, Sargassum muticum was occasionally recorded. No conspicuous animals were recorded from this habitat.

6.2.2. Hard substrata within the estuary. Records of the conspicuous algal and epifaunal species are included in Table 2.

The most generally available hard substrata were the stones and small boulders which tended to overlie the sediments around the mean high water mark. In the southern half of the estuary, particularly on the western shore, stones occurred over much of the intertidal zone. In addition, beds of mussels, Mytilus edulis (which were also restricted to the southern half of the estuary but occurred on both sides) provided a habitat for small epifaunal forms. Other hard substrata were provided by the walls of the railway embankments down either side of the estuary which fell within the upper shore from around Exton and Topsham southwards. The effluent pipe from the old mussel cleaning station at Lympstone, and the earthenware tiles laid out on the sediment to attract moulting crabs, also provided isolated focal points for animal and plant settlement.

Although the diversity of algae and epifauna was in general low, it was highest in the southern half of the estuary below Lympstone where the greatest cumulative area of suitable substrata occurred, and where the salinity regime was not so rigorous.

The most widespread species were Enteromorpha spp., Ulva spp., Semibalanus balanoides, Elminius modestus and Hydrobia ulvae. These occurred over the whole intertidal range and were all found as far north as Exton, although both algae were also recorded from Site 3 at Riversmeet House. The snail, H. ulvae, was particularly abundant in the larger areas of saltmarsh developing at Sites 22 and 30.

Fucoids were widespread as a group, but vertical zonation and also zonation along the estuary was shown by individual species. Fucus spiralis occupied the highest position on the shore, either on boulders or walls, while F. vesiculosus occurred lower down over most of the midshore and lower shore where substrata were available. F. serratus was only recorded from Site 15 on the midshore. In the upper estuary between the River Kenn and Topsham, the estuarine species F. ceranoides was usually found commonly on the boulders of the upper midshore. Notable by its absence from the algal list was Pelvetia canaliculata which was reported as being present on sea walls between Dawlish Warren and Powderham by Gilham (1957) and subsequently confirmed as present by Proctor (1980). Fucoids in general provided an important refuge for crustaceans (the isopods and amphipods listed in Table 2 and Carcinus maenas (juveniles) and some molluscs including Monodonta lineata, Littorina mariae and L. obtusata which were found on the west shore south of Cockwood.

Species widespread in the southern half of the estuary but restricted in shore level incuded Gelidium spp., Anurida maritima, Patella vulgata and Littorina saxatilis agg. on the upper shore and in the splash zone. The barnacle Chthamalus montagui was also recorded from the upper shore but at Site 15 only. The mussel, Mytilus edulis occurred throughout the southern half of the estuary over the midshore range, and could occur in abundance as dense beds (e.g. Site 19, and on the top of Bull Hill Bank) or as occasional attached individuals elsewhere. The winkle Littorina littorea invariably co-occurred with mussels, together with Semibalanus balanoides and Elminius modestus. The limited range of red algae were all found on the mid to lower shores south of Lympstone where substrata were available. However, Gracilaria verrucosa occurred as far north as Exton; slightly further north than reported by Gilham (1957). The filamentous brown algae Pilayella littoralis, Giffordia sp. and Ectocarpoidea indet. were each only recorded once from the mid and lower shores at Sites 32, 30 and 15 respectively.

Animals normally typical of the lower shore were only rarely recorded in the Exe. These included Halichondria panicea, Pomatoceros lamarcki/triqueter, a chiton, the bryozoans Alcyonidium gelatinosum (A. polyoum) and Bowerbankia imbricata, the starfish Asterias rubens and the scorpion fish Cottus scorpius; all of which were found south of Starcross in the most marine influenced and stony part of the estuary. Actinia equina was found at Lympstone at mid-shore level in the mud-free shelter of the disused purification plant outfall pipe.

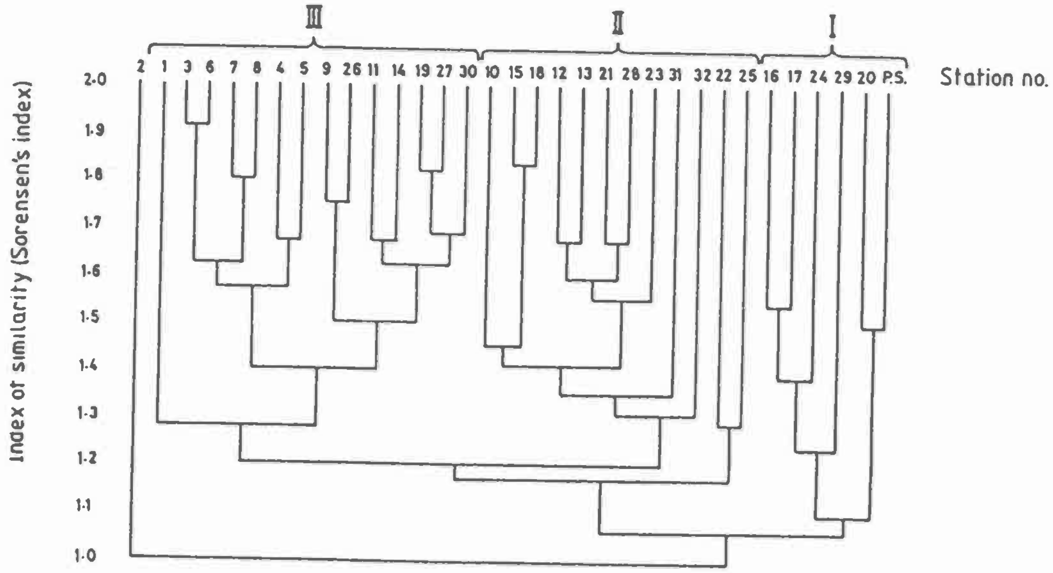

Fig. 12. Results of classification analysis of the infaunal data in dendrogram form. The three main station-clusters (I, II and III) are indicated.

6.2.3. Sedimentary shores (Sites 1-33 and Pole Sand). The quantitative data from the sediment coring study are shown in Table 3, and the results of the classification and species ordination are plotted in Fig. 12 and tabulated in Table 4. A total of 55 species (including the multispecific taxa such as Nematoda and Oligochaeta indet.) were recognised from 128 samples and the number of species recorded at each site varied from zero (at Site 2) to 17 (at Site 13).

It can be seen in Table 4 that the fauna was polychaete-dominated and that Nereis diversicolor, and the multispecific taxon, oligochaeta, were particularly abundant at a number of stations. Both are typical components of muddy estuarine fauna. Additional commonly occurring species included the spionids, Pygospio elegans and Streblospio shrubsolii, the phyllodocid Eteone longa, and the orbinid Scoloplos armiger. The majority of polychaetes however were more restricted in distribution or were only rarely found, including the sedentary forms Manajunkia aestuarina and Alkmaria romijni which can be found in high densitites in other muddy estuaries. Other notable occurrences were the opheliid Ophelia bicornis and the capitellid Capitella capitata. The former is a Mediterranean species which, until recently, had only been recorded in the U.K. from the Exe estuary. It has now also been found in intertidal sediments within Langstone Harbour (Thorpe, pers. comm.). Capitella capitata was one of the dominant animals at Site 22 (along with Oligochaeta indet.) with an estimated density of 350 per m^2. The occurrence of this species in high numbers is usually a reflection of sediment with a high organic loading resulting from either natural or industrial/domestic inputs (e.g. Pearson and Rosenberg, 1978).

Of the crustacea, the isopods Cyathura carinata and Sphaeroma rugicauda were locally numerous and were restricted to muddy and sandy sediments respectively. Amphipods were represented mainly by Bathyporeia sarsi from sandy sites. The tubicolous species Corophium volutator was not recorded as commonly or as abundantly as reported in previous accounts of the Exe macrofauna (Allen and Todd, 1902; Crawford, 1937; Harris, 1980) and C. arenarium was not found at all (c.f. Holme, 1949).

In numerical terms the small epifaunal snail Hydrobia ulvae was the overall dominant organism with densities (likely to be underestimated) of up to 13,000 per m^2. It was widespread but its distribution was centred upon the beds of Zostera noltii, along the muddy upper midshore between Exmouth station and Lympstone, and the numerous but isolated clumps of Spartina saltmarsh to be found above mean high water neaps at various points around the estuary. As Holme (1949) pointed out, its habit of floating upside down in the water from the surface film probably accounts for its widespread presence over a much wider range of substrata.

Scrobicularia plana was abundant in sediments of mud, particularly in the northern half of the estuary while the cockle, Cerastoderma edule was recorded in sandier sediments. Tellina tenuis was found in still cleaner sand towards the estuary mouth.

The distribution of the fauna was clearly related to environmental parameters chief of which were sediment type and salinity. This is clearly seen in the results of the classification analysis which, on the basis of the macrofauna, has divided the survey area into three groups of similar sites (Fig. 12). These results have been translated on to a site map in Fig. 13, and a further illustration of macrofaunal succession along the estuary is given in Table 4.

Each of the site groups identified in Figs. 12 and 13 are described below. It should be pointed out at this stage that the boundaries of these zones have been drawn subjectively and are imposed on a pattern of more gradual spatial change. Also the number of samples taken was small and therefore the full pattern of environmental and biological heterogeneity is not represented. However the results do broadly illustrate the range in sediment habitat types and species, together with the influence of changing physical conditions along the length of the estuary and up the shore.

1. Sediments composed predominantly of clean sand (Sites 16, 17, 20, 24, 29 and Pole Sand). This group of sites includes the low lying current-swept sands which fringe the main channel around the mouth of the estuary. This area is scoured by fast tidal currents and is the most marine part of the estuary, although salinity at the northernmost extent (Sites 16 and 17) can fall to below approximately 60% of full sea water on occasion (Gilham, 1957).

   The fauna in this region consisted of species generally associated with lower-shore marine-influenced sand, and was of low diversity and density. No single species was common to all sites in this group, but Bathyporeia sarsi, Urothoe brevicornis, Nephtys cirrosa and Tellina tenuis were typical of those found. All of these species, apart from

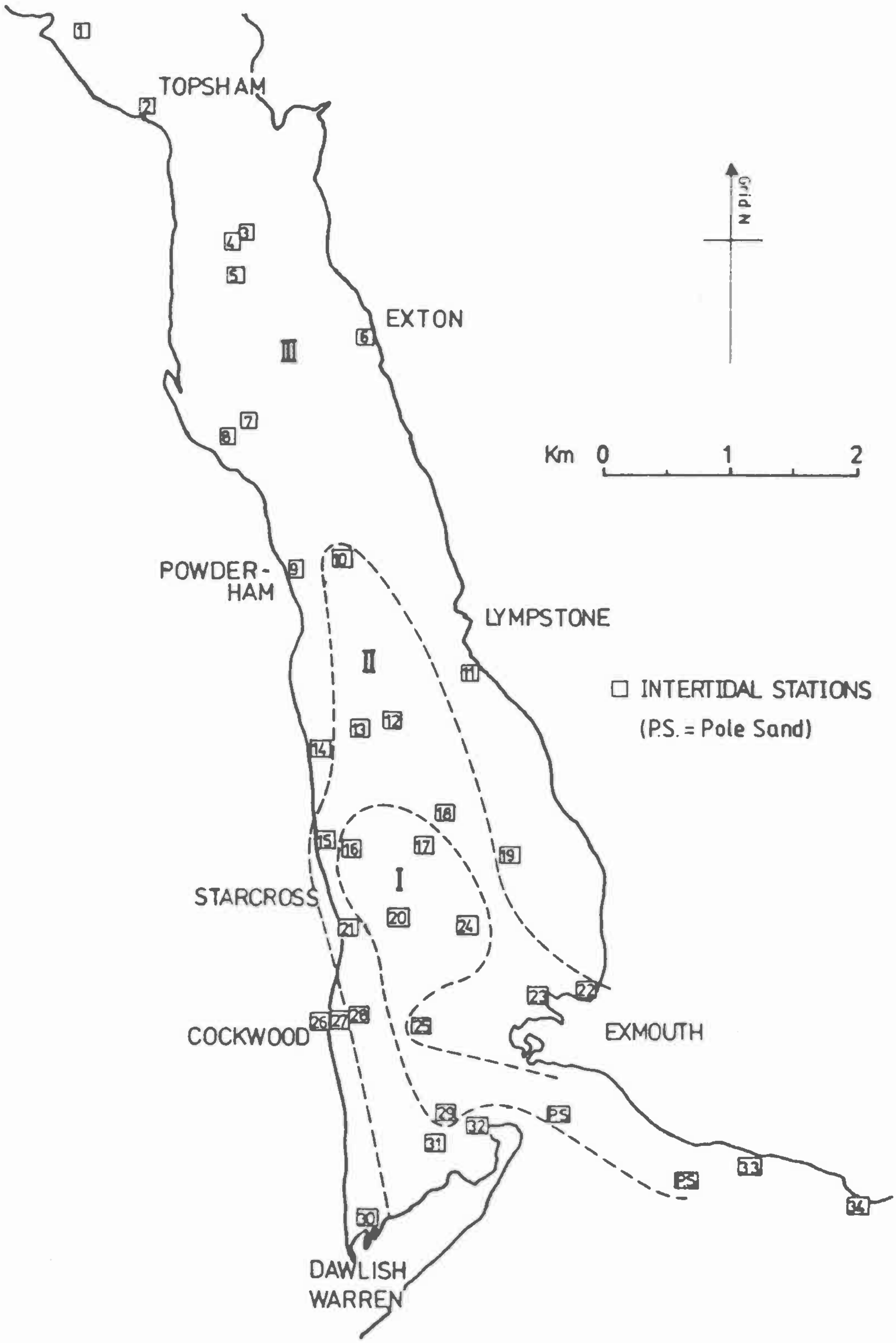

Fig. 13. The three main station-clusters (I, II and III) derived from classification analysis drawn onto a map of the survey area.

U. brevicornis, have been previously recorded from similar sediments in the Exe estuary (Allen and Todd, 1902; Holme, 1949).

Communities dominated by Ophelia bicornis were found on Shaggles Bank (Site 20) and along the northern edge of Pole Sand. These were only found in mobile, well-drained sand which corresponds to the findings of Allen and Todd (1902), Holme (1949) and Harris (1980). In addition to the factor of drainage, experiments by Wilson (1948; 1952; 1953a, b; 1954 and 1955) showed that sediment granulometry, organic matter content and the presence of micro-organisms were also important in determining the distribution and abundance of O. bicornis.

The fauna within this area corresponds closely to the CRUSTACEAN-POLYCHAETE community defined by Bishop and Holme (1980) and includes the variant community, dominated by Ophelia bicornis, as found on Shaggles Bank and on Polesand. At site 24, the fauna was very sparse and dominated (numerically) by Tellina tennuis. This lower shore area of Cockle Sand, therefore, is probably closer to the TELLINA community of Bishop and Holme (1980) and for which sites in the Exe estuary were considered regionally representative.

2. Mixed sediments of mud and sand (Sites 10, 12, 13, 15, 18, 21, 22, 23, 25, 28, 31 and 32). The area defined by these sites forms a boundary zone between the predominantly sandy sediments just described, and the muddier sediments in the more sheltered parts of the estuary. Thus sediments ranged from mud with very little sand (Sites 22 and 31) to those of coarser grades containing little or no mud (Sites 10, 12, 13, 18, 23, 25 and 32). Species diversity was highest at these sites due to this broad range of sediment particle sizes present. A large part of the fauna therefore consisted of species overlapping from the mud or clean sand habitats on either side such as Nereis diversicolor and Scrobicularia plana on the one hand; and to a greater extent, Tellina tenuis and Nephtys cirrosa on the other. In addition to the latter two species, other fauna characteristic of these mixed sediments included the polychaetes Scoloplos armiger, Pygospio elegans, Eteone longa and Arenicola marina.

Sites within this zone fall most readily into the 'sandy-shore Arenicola/Cerastoderma community' described from parts of Bull Hill and Shelly Bank by Harris (1980). Bishop and Holme (1980) defined a similar ARENICOLA community, and regarded sites within the Exe estuary as being representative of this type.

3. Sediments composed predominantly of mud (Sites 1-9, 11, 14, 19, 26, 27 and 30). This habitat includes all sites north of Powderham up to the M5 motorway bridge together with several higher-shore sites down both sides of the estuary towards the sheltered angles behind Dawlish Warren and Exmouth Point. The polychaete Nereis diversicolor and the bivalve Scrobicularia plana (both species typical of estuarine muds) were present at all sites in this zone with the exception of Site 2 which was afaunal. Sediment at the muddy sites in the southern half of this estuary often contained a small admixture of fine sand. Consequently the fauna included several species which are more characteristic of muddy sand such as Eteone longa, Pygospio elegans, Arenicola marina and Cerastoderma edule. North of Powderham however, the comparatively uniform mud flats supported an infauna characterised by Streblospio shrubsolii and Cyathura carinata in addition to high numbers of N. diversicolor and S. plana.

The habitat and fauna at all sites in this group correspond closely to the 'muddy-shore Spartina/Scrobicularia community', orginally described by Harris (1980) for the upper shore between Lympstone and Exmouth Station. This was also described as the SCROBICULARIA community by Bishop and Holme (1980).

6.3. Subtidal habitats and communities (Sites 35-47)

Subtidal habitats were sampled at a total of 13 sites, of which only three (Sites 45-47) were surveyed by divers. Habitats were limited in variety; being relatively shallow (above the upper circalittoral zone), basically sedimentary in nature, and confined to a long narrow channel with fast tidal currents. In addition, there was a good overlap between the dived sites and remotely sampled sites and for these reasons the two data sets have been combined. A total of four habitats were identified.

6.3.1. Tidally scoured bedrock (Site 45 only). This habitat occurred in the centre of the confined channel entrance to the Exe and fell within the lower infralittoral zone. Where the predominantly flat New Red Sandstone was not scoured clean, there was a dense turf of Modiolus sp. juveniles. Otherwise the fauna and flora was sparse. Polysiphonia elongata and Enteromorpha sp. were both Frequent whilst Laminaria saccharina, Ulva sp. and Hypoglossum woodwardii occurred Occasionally.

The remaining fauna consisted of sparse populations of encrusting species (Balanus crenatus, Verruca stroemia, Pomatoceros triqueter/lamarki), scattered Mytilus edulis, together with a few mobile forms including the starfish Asterias rubens, the hermit crab Pagurus bernhardus, and a single specimen of Buccinum undatum.

6.3.2. Infralittoral boulders (Sites 45, 46 and 47). This habitat was found in the main channel between Bull Hill bank and the open sea. At Sites 45 and 47, the boulders occurred as banks or ridges fringed on either side by pebbles or finer sediment. The boulders at Site 46 off Orcombe Point, however, were more extensive. All sites were current swept, but that of Site 47 receives some shelter from ebb flows as Bull Hill bank becomes uncovered.

This habitat was usually dominated by the sponge Halichondria panicea and by kelp; either Laminaria saccharina (Sites 47 and 45) or L. hyperborea and L. digitata (Site 46). The ascidian Clavelina lepadiformis was recorded from this habitat only. The community present on boulders at Site 45 near Conger Rocks is listed below:

Abundant species : Laminaria saccharina, Halichondria panicea.

Common species : Antithamnion plumula, Cryptopleura ramosa.

Frequent species : Hypoglossum woodwardii, Ulva sp., Polysiphonia elongata, Fucus serratus, Obelia dichotoma, Sertularia argentea, Membranipora membranacea.

Occasional species: Lomentaria clavellosa, Polysiphonia nigrescens, Pomatoceros lamarckii/triqueter, Carcinus maenas, Asterias rubens, Pagurus bernhardus, Mytilus edulis, Clavelina lepadiformis.

Rare species : Phyllophora pseudoceranoides, Brongniartella byssoides, Porphyra sp., Desmarestia ligulata, Hymeniacidon perleve, ?Microciona sp., Bugula plumosa, Enc. bryozoa indet.

Present; no record: of abundance Onchidoris bilamellata, Electra pilosa, Ophiothrix fragilis.

6.3.3. Mixed sediments continually swept by tidal currents (Sites 39-47). Sediments within this habitat ranged from rippled fine sand with stones and shells, to flat beds of cobbles and pebbles over coarse sand. The finer end of the range (fine sand, coarse sand and granules) tended to occur within the estuary north of Bull Hill (Sites 39-42 and 47) and, again, at the eastern end of the estuary entrance (Sites 43 and 46). Coarser substrata (and bedrock; Section 6.3.1.) predominated within the restricted channel between Bull Hill and Maer Rock.

Within the main estuary, at Sites 39-42, no attached algae were found, and apart from fish, the predominant epifauna were Carcinus maenas and Crangon crangon. Infauna sampled at Site 40 off Cockwood corresponded closely to that found in intertidal areas of clean sand with sparse populations of Nephtys cirrosa, Bathyporeia sarsi and Urothoe brevicornis.

Site 47 was situated between Bull Hill bank and Exmouth Dock and this area receives a certain amount of shelter from tidal currents for a large part of the ebb flow as Bull Hill becomes uncovered.

The main feature distinguishing the community found here from that of other mixed sediments was the extensive and dense population of the sand mason worm, Lanice conchilega. Elsewhere, L. conchilega was only recorded as Occasional or Frequent. Other animals found only at site 47 included Sertularia cuppressina, Urticina felina, Balanus balanus and Liocarcinus sp.

Whilst elements of the algae found on this pebbly coarse sand were similar to those found at Sites 44, 45 and 46, some additional species were also recorded including in particular, Antithamnion plumula and Chorda filum.

The complete fauna and flora recorded from this habitat at Site 47 is listed below:

Abundant/Super-abundant species : Lanice conchilega.

Common species : Antithamnion plumula, Ulva sp., Pagurus bernhardus, Asterias rubens.

Frequent species : Cryptopleura ramosa, Polysiphonia fibrata, Ectocarpoid algae, Enteromorpha sp., Balanus balanus, Carcinus maenas.

Occasional species: Hypoglossum woodwardii, Ceramium rubrum, Gracilaria verrucosa, Lomentaria clavellosa, Gelidium latifolium, Brongniartella byssoides, Polysiphonia nigrescens, Chorda filum, Cladophora sp., Sertularia cupressina, Balanus crenatus, Pomatoschistus sp.

Rare species : Halichondria panicea, Sagartia troglodytes, Urticina felina, Cancer pagurus, Liocarcinus sp., Mytilus edulis, Sygnathus sp., Agonas cataphractus, Cottus scorpius

6.3.4. Mud (Sites 35-38). This habitat includes all trawl and dredge sites in the main channel north of the River Kenn. The substratum consisted entirely of mud mixed with twigs and leaves, and with increasing amounts of gravel and pebbles to the south of the River Kenn.

Very little algae was recorded apart from Ulva sp. (probably drift), found generally, and a single specimen of Chondrus crispus at Site 38. Lack of stable substrata, as well as turbidity, salinity reduction, and fast currents, probably all have a bearing on these findings.

The mobile epifaunal crustaceans Carcinus maenas and Crangon crangon were Common or Abundant at all sites, and apart from young Pleuronectes platessa, Anguilla anguilla and Pomatoschistus minutus, very little else was found in the trawls.

The infauna at Site 36, as sampled by pipe-dredging, was very sparse; consisting only of a single ragworm (Nereis diversicolor) and a small colony of Conopeum seurati. Further downstream at Site 38, where sediment texture was wider-ranging, the infauna was comparatively varied and corresponded well with the 'muddy sand' habitat described earlier for the intertidal region. The following species were qualitatively recorded from the pipe-dredge taken at Site 38.

Campanularia flexuosa
Balanus crenatus
Elminius modestus
Oligochaeta indet.
Nereis diversicolor
Nephtys hombergii
Glycera ?tridactyla
Capitella capitata
Heteromastus filiformis
Capitomastus filiformis
Streblospio shrubsolii
Pygospio elegans
Polydora sp.
Tharyx sp.
Lanice conchilega
Bathyporeia sarsi
Melita palmata
Crangon crangon
Carcinus maenas

7. DISCUSSION

7.1. Distribution of habitats and communities.

7.1.1. Intertidal.

Substrata and habitats. Ordnance Survey maps and Admiralty Chart No. 2290 provide a synoptic view of shore types and substrata within the Exe Estuary. Descriptions have been produced by Allen and Todd (1902), Holme (1949), Thomas (1980) and Harris (1980). The present survey provides an additional description of topographical and sedimentary features of the shores sampled. Also, the aerial photographs taken during field work provide useful data although they had been lodged with the NCC by the time this section was written and so were not referred to. Physiographic and sedimentological features change with increasing distance from the coast in relation to increasing shelter and these are summarised below:

- The land surrounding the estuary was low-lying and the shores sedimentary in nature, with the exception of the New Red Sandstone cliffs at Orcombe Point and lower-lying exposures at Maer Rocks.

- On the open coast, and in the estuary entrance, sediments were of fine to medium clean sand. Admixtures of coarser sediments occurred in the region where the entrance widens into the main estuary west of Exmouth harbour. Such substrata extended northwards as a 'tongue' up the centre of the estuary, and were predominantly governed by marine influences.

- Higher up the shore on either side of the estuary, and further north, sediments contained an increasing proportion of mud and showed great heterogeneity.

- North of Powderham the sediments consisted almost entirely of mud, formed into extensive low-lying mudflats. This habitat also occurred further south in sheltered upper shore regions down both sides of the estuary as far as Dawlish Warren and Exmouth.

- The upper shore was often backed by patchy saltmarsh, and for the most part was delimited on both sides of the estuary by stone-faced railway embankments. Other hard substrata was provided by areas of cobbles and pebbles which were extensive on the Starcross and Cockwood shores, but which were restricted to the upper shore elsewhere.

Communities and Species. In addition to the environmental parameters of salinity and degree of shelter, both sediment textural changes and the increasing scarcity of stable hard substrata northwards along the estuary affected the distribution, density and diversity of the flora and fauna. These changes are summarised below.

- Floral and epifaunal diversity decreased from the mouth of the estuary towards Topsham.

- Rocky intertidal sites at Orcombe Point and Maer Rocks were algal dominated, mainly by *Enteromorpha* spp, *Rhodochorton floridulum*, *Audouinella* sp. and Fucoids. *Laminaria digitata* also occurred at both sites and *L. saccharina* was recorded at Orcombe Point. The alien alga *Sargassum muticum* was recorded from rock pools on Maer Rocks.

- Within the estuary, substrata suitable for algae was scarce and influenced by the surrounding sediments. *Enteromorpha* spp. and *Ulva* sp. were the most widespread attached algae, together with Fucoids. Of the latter group, *Fucus spiralis*, and *F. vesiculosus* predominated in the southern half of the estuary but were replaced at upper shore sites north of Powderham by *F. ceranoides*. No attached kelp plants were found within the estuary and diversity was generally reduced in comparison to the open coast rocky shore sites.

- As in the case of the algae, epifaunal diversity was low due to the scarcity of hard substrata. Diversity was further reduced with increasing distance up the estuary although no clear zonation of epifaunal species was observed due to the discontinuity of rocky or stony habitats. Widespread species included *Elminius modestus*, *Carcinus maenas* (mainly juveniles) and *Hydrobia ulvae*. However all species tended to occur more commonly in the southern half of the estuary where the greatest accumulation of hard substrata occurred.

- The range of sediment habitat types found in the estuary was reflected in the macro-infauna present.

- In the lower shore clean sands, close to the mouth of the estuary, the fauna was sparse and of low diversity, being characterised by Bathyporeia sarsi, Nephtys cirrosa, Urothroe brevicornis and Ophelia bicornis.

- The surrounding areas of muddy sand supported the most divese communities characterised by Arenicola marina, Cerastoderma edule, Scoloplos arniger, Pygospio elegans and Eteone longa.

- The mudflats north of Powderham and down either side of the estuary supported a less diverse fauna characterised by Nereis diversicolor, and Scrobicularia plana, together with Streblospio shrubsolii, Cyathura carinata and components of the muddy sand fauna.

7.1.2. Subtidal.

Substrata and habitats. Information on seabed types is available from Admiralty Chart 2290. The present survey provides a description of the seabed at sites either dredged or dived. The nature of the Exe estuary, with its narrow channel flanked by extensive sediment flats, permits the extrapolation of these results to the rest of the area. All subtidal sites fell within the upper circalittoral zone, or above, and were tidally scoured. The main features are listed below:

- Outcrops of flat New Red Sandstone occurred in the narrow channel entrance to the estuary.

- Small boulders were found in the main channel between Flat Ledge (off Orcombe Point) and Bull Hill Bank. In the constricted estuary entrance, boulders appeared to occur in low banks or ridges flanked on either side by pebbles and gravel. On flat Ledge this habitat was more extensive.

- Mixed sediments ranging from rippled sand with stones and shells to beds of pebble and cobbles over coarse sand occurred between Bull Hill and Flat Ledge. The coarser substrata in the range predominated in the narrows of the estuary entrance.

- North of the River Kenn, the main channel was very shallow (maximum depth 3 m) and consisted of mud which often contained an abundance of terrestrial plant debris such as twigs and leaves.

Species and communities. The subtidal flora and epifauna was basically estuarine in nature, sparse, and poor in species variety. As in the intertidal region, diversity tended to increase towards the coast with increasing salinity and substratum availability.

The infauna sampled by pipe dredging was very similar to that recorded intertidally, and could be described as subtidal extensions of the three sedimentary habitats distinguished by classification of the intertidal infauna.

7.2. Comparison with previous marine biological studies.

In this survey, sample sites were based, as far as possible, on the sites sampled by Allen and Todd (1902) in order to make comparison of results easier and to determine the extent of any changes that may have taken place.

In spite of differences in the sampling techniques used, the intertidal sediments and fauna appear to have remained unchanged in character since the turn of the century. The findings of Allen and Todd indicate a very similar gradation down the estuary from sheltered Nereis diversicolor/Scrobicularia plana-domianted mud, through mixed sediments with populations of Arenicola marina, Pygospio elegans, Scoloplos armiger and Cerastoderma edule, to clean tidally swept sand with populations of Tellina tenuis, Nephtys cirrosa, Bathyporeia sarsi and Ophelia bicornis.

One notable difference between the two surveys is that Allen and Todd reported Greenland mudflat to be covered with Zostera sp. They described the plants as small and stunted but growing thickly together. No Zostera was found on Greenland Bank during the present survey. The carpet shell, Venerupis decussata, was recorded as 'moderately common' from behind Dawlish Warren, on Bull Hill and Cockle Sand in 1901. Holme (1949) only found a single specimen of this species (as Paphia decussata) and in the present survey, only empty valves were observed. The ampharetid polychaete Melinna palmata previously recorded in small numbers from mud (Allen and Todd 1902, Holme 1949) was not found in the present survey. On the other hand a few specimens of Ampharete grubei and Alkmaria romijni were found in 1985. Neither was recorded by Allen and Todd, although Holme recorded A. grubei in low numbers on his Dawlish Warren transect. We also found fairly high densities (up to 400 m^{-2}) of the isopod Cyathura carinata at muddy sites north of Powderham. This species was previously recorded from mud behind Dawlish Warren by Crawford (1937) and was not reported by either Allen and Todd or Holme. These and other minor differences between the infaunal species list and those of previous workers are to be expected. They almost certainly reflect differences in sampling methods, and the precise location of sample sites in relation to marked sediment heterogeneity, quite apart from any natural biological fluctuations and changes that are taking place.

Allen and Todd also made some observations on the fauna of the rocks at Orcombe Point. They recorded more polychaete and brachyuran species than in the present survey. The main differences between the two sets of records concern the reef-building polychaete Sabellaria alveolata, the rock-boring bivalves Pholas dactylus and Barnea parvea, and the dog whelk Nucella lapillus.

Sabellaria alveolata was recorded as very common in 1901 but was not recorded at all in 1985. However, this species is known to have shown wide population fluctuations at this site over the years, with crashes due to the cold winter of 1962/63 and possibly due also to trampling pressure (Crisp et al, 1964, Cunningham et al, 1984). Having been present at Maer Rocks and Orcombe Point in the early '70's and '80's, these populations were no longer evident in 1984 (Cunningham et al, 1984).

The bivalves Pholas dactylus and Barnea parva were both common at Orcombe Point in 1901, but no evidence of either species (holes or valves) was observed in 1985. These omissions were most likely to have been due to patchiness of occurrence since P. dactylus was certainly present 'near Exmouth' in the early 1980's (Knight and Thorne, 1982).

The dog whelk Nucella lapillus was not present in 1985, having been 'very common' in 1901. Sharp declines in the density of this species have been noted elsewhere in southwest England (eg. Rostron, 1985, Hiscock, 1986) for reasons largely unknown although organotin compounds and dinoflagellate blooms have been suggested as causes.

Allen and Todd specifically noted the absence of Clavelina lepadiformis and Morchellium argus but both species were present on the lower shore at Maer Rocks and Orcombe Point in 1985.

Subtidally in the channel between Exmouth beach and Polesand, the paucity of the fauna found by Allen and Todd corresponded with our observations made through diving and dredging.

The algal species list obtained within the estuary was not as extensive as that discussed by Gilham (1957). Of the Phaeophyta, notable absences were Pelvetia canaliculata and Ascophyllum nodosum both of which Gilham recorded as occurring as far north as Lympstone. P. canaliculata was reported from the Exe as recently as 1980 (Proctor, 1980). In 1985, Rhodophycaeae were mainly represented by Gracilaria verrucosa, Cryptopleura ramosa, Chondrus crispus, Porphyra sp, Ceramium spp. and Polysiphonia spp. Several species were recorded only on the open rocky coast, which in Gilham's paper were recorded as far north as Exton. These included Palmaria palmata, Hypoglossum woodwardii, Catenella caespitosa and Audouinalla spp.

Shortfalls in the 1985 list of Chlorophycaee were due mainly to taxonomic difficulties.

Since Gilham's paper, no marked changes in the upstream extent of species appears to have occurred, with the exception of the Rhodophycease mentioned above.

Amongst the species of fauna and flora not previously recorded from the Exe estuary are several recent immigrants. These include the barnacles Elminius modestus, the slipper limpet Crepidula fornicata, the cultivated manilla clam, Venerupis semidecussata, and the brown algae Sargassum muticum. Most of these species, apart from E. modestus, were recorded only rarely and were not present at more than one site. The impact of E. modestus on previously existing barnacle populations, if any, is not known since previous barnacle records do not exist. The manilla clam, V. semidecussata, is at present restricted to a mesh enclosure behind Dawlish Warren. Its ability to spread by reproduction is restricted in British waters by low temperatures theoretically, but in practice this is unknown.

8. ASSESSMENT OF SCIENTIFIC INTEREST AND NATURE CONSERATION IMPORTANCE OF THE EXE ESTUARY by K. Hiscock and I. Dixon.

8.1. Introduction.

The assessment of scientific interest and nature conservation importance has been undertaken through a general evaluation which follows the criteria outlined by Ratcliffe (1977) (Section 8.2) and by ranking the conservation importance of the habitats and communities encountered and of species considered of conservation interest (Section 8.3). The conclusion of these exercises is given in Section 8.4. The criteria used here to assess conservation importance are applied in the manner outlined in the NCC 'Handbook for the Preparation of Management Plans' (1st edition, February, 1983) but defined in relation to northeast Atlantic marine ecosystems. The definitions were first used in the management plan for the Lundy marine nature reserve and have subsequently been used for the Skomer marine nature reserve management plan and to evaluate marine ecosystmes in the Isles of Scilly and the area of Bardsey and the Lleyn Peninsula. They are to be used for each area included in the Surveys of Harbours, Rias and Estuaries but are provisional until comparison of the majority of areas is possible. Where comparisons are made on a 'Regional' basis, the region is southwest Britain from north Pembrokeshire around to Portland Bill.

8.2. General Evaluation.

Size. The Exe Estuary extends 10 km from its entrance between Pole Sand and Maer Rocks to its head near the Countess Wear Road Bridge in the north. The estuary varies between 1 and 2 km in width at the high water mark but most of this area dries out at low water leaving a channel of less than 500 m width at its widest point. These are no branches to the estuary.

Diversity. The range of sediment habitats and associated communities is fairly high, ranging from clean sand and gravel near the entrance to soft mud at the head of the estuary. Several different types of hard substrata occur including subtidal bedrock in the estuary entrance, stone embankments at or near the high water mark, cobbles, and earthenware tiles laid intertidally to obtain soft crabs. These are not colonised by rich communities. The diversity of species decreases with distance northwards along the estuary.

Naturalness. The shore and seabed habitats are largely natural although land reclamation, embankments and the introduction of *Spartina anglica* have changed the nature of sections of the upper shore since the last century in particular. Most of the intertidal mussel beds originated through man's management and cultivation.

Rarity. Most of the habitats present are commonly encountered in marine inlets. However, the wide range of estuarine deposits within close proximity is notable. Certain areas of sediment around the mouth of the estuary provide a habitat for the polychaete *Ophelia bicornis* which is only known from one other location in the British Isles.

Fragility (vulnerability). Habitats and communities within the estuary appear to have been maintained without significant change over the past 85 years, demonstrating resilience to the effects of often severe climatic events such as the 1962-63 cold winter. It is likely that these features would only be changed by new or increased pollution, or by major construction works sufficient to alter current and sedimentation regimes. The nature of the fauna indicates that, to date, pollution has been localised and minor in effect. Intertidal areas are being subjected to increasing pressure from recreational and educational use.

Typicalness. Habitats and communities present are generally typical of sheltered estuarine environments. Several sediment communities are considered to be representative of their type. However, the community characterised by *Ophelia bicornis* is known to be unusual in Britain.

Recorded History. The marine biology of the Exe estuary has been studied by several workers since the turn of this century and is currently used in both research and education. Investigations have included descriptive surveys of the macrofauna, meiofauna and algae, studies of community structure and function in relation to environmental parameters, of life histories and of taxonomy. The Exe estuary is the type locality for many predominantly meiofaunal species. This history of marine biological study provides a good basis for the assessment of change.

Position in an ecological/geographical unit. The Exe estuary is of international importance for migrating waders and wildfowl. The western half of the estuary is a bird sanctuary but important feeding areas (including beds of Zostera) occur down the eastern side also. The whole of the estuary south of Countess Wear bridge, including Dawlish Warren, Polesand, and the cliffs at Langstone Rock and Orcombe Point, has been under SSSI status since 1952. Dawlish Warren has also been a Local Nature Reserve since 1980 In addition, much of the coastline around the estuary is designated under the Devon County Structure Plan for its scenic and amenity value.

Potential value. There are no areas where rehabilitation is required.

Intrinsic appeal. The estuary is attractive scenically and has a high appeal to those interested in many varieties of coastal recreation.

Research and educational value. There has been much research carried out within the estuary. There are several habitat types present and its proximity to Exeter University, the Marine Laboratories in Plymouth and to local colleges and other educational establishments make the area important for education.

8.3. Identification/confirmation of important features.

Features of littoral and sublittoral ecosystems in the area of the Exe Estuary are evaluated here in terms of their International, National, Regional or Local importance. Table 7 lists the main habitat/community types encountered and Table 8 lists species which are considered of scientific interest in their presence in the survey area. For Table 7, the separation of habitat type is according to Section 6. The rating of importance is made broadly according to the following definitions:

International. Communities which are outstandingly good examples of their type in the Northeast Atlantic. Communities recorded at only a very few locations in the Northeast Atlantic.

Species which are recorded at only a few locations in the Northeast Atlantic. Species recorded in higher abundance in the area under consideration than anywhere else in the Northeast Atlantic or where the area is one of only a very few locations where large quantities are recorded.

National. Communities which are outstandingly good examples of their type in Britain. Communities recorded in only a very few marine inlets or estuaries in Britain. Both of these definitions refer to communities which are or are likely to be widely occurring in other inlets and estuaries in the Northeast Atlantic.

Species which are recorded at only a few locations in Britain but are more widespread in other parts of the Northeast Atlantic. Species recorded in higher abundance at the inlet or estuary under consideration than in any other elsewhere in Britain or where the site is one of only a very few locations where large quantities are recorded in Britain.

Regional. Communities which are present in inlets and estuaries elsewhere in Britain but which are outstandingly good examples of their type in the inlet or estuary under consideration or are as good examples as similar communities present elsewhere in Britain. Communities recorded at only a few locations in inlets and estuaries in southwest Britain.

Species which are unrecorded or recorded at only a few locations in inlets and estuaries in southwest Britain but are widespread in other inlets and estuaries or on the open coast in other parts of Britain. Species recorded in higher abundance in the area under consideration than in any other inlet or estuary in southwest Britain or where the site is one of only a very few locations where large quantities are recorded in southwest Britain.

Local. Communities which are widespread in inlets and estuaries in southwest Britain with as good or better examples at several other locations.

The selection only of species which are of higher than Local importance precludes the use of this category in the species lists.

8.4. Conclusion

The intertidal areas of the Exe estuary are clearly important for ornithology and for aspects of the marine invertebrate fauna. The estuary is relatively unpolluted and is of considerable scenic appeal. It therefore

seems appropriate to ensure the maintenance of these features through the various designations which already exist. Subtidal areas include few special or unusual features but, as an integral part of the estuarine environment as a whole, should be included in the protection already afforded to the shores and adjacent coastline.

9. ACKNOWLEDGEMENTS

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List of Tables

Table 1.

Sites surveyed in 1985 and survey staff

Site No.	Site name	Date Surveyed	Ordnance survey Grid Ref.	Initials of Survey staff
	INTERTIDAL SITES			
1	M5 Bridge	19.08.85	SX957887	DR, MH
2	Topsham Village	19.08.85	SX963881	DR, MH
3	Riversmeet House	19.08.85	SX969872	TB, IMTD
4	Riversmeet House	18.08.85	SX968872	DR, MH
5	West Mud	18.08.85	SX969868	DR, MH
6	Exton Station	19.08.85	SX979863	TB, IMTD
7	Mid Greenland Bank	22.08.85	SX970857	TB,BB,IMTD
8	Greenland	18.08.85	SX968855	DR, MH
9	Powderham Sand Upper	18.08.85	SX974844	TB, IMTD
10	Powderham Sand Lower	18.08.85	SX978856	DR, MH
11	Lympstone Mussel Farm	19.08.85	SX990836	TB, IMTD
12	Lympstone Sand Centre	18.08.85	SX982833	DR, MH
13	Lympstone Sand	18.08.85	SX979831	DR, MH
14	River Kenn	18.08.85	SX976831	TB, IMTD
15	West Mid Shore	19.08.85	SX977826	DR, MH
16	West Lower Shore	19.08.85	SX978824	DR, MH
17	East Lower Shore	19.08.85	SX985824	DR, MH
18	East Mid Shore	19.08.85	SX986826	DR, MH
19	Mid Cockle Sand	22.08.85	SX991822	TB,BB,IMTD,DR
20	Shaggles Bank	19.08.85	SX983818	DR, MH
21	Starcross	22.08.85	SX979817	TB, IMTD
22	Exmouth Station	19.08.85	SX998812	TB, IMTD
23	The Point	19.08.85	SX995811	TB, IMTD
24	East Lower Shore	19.08.85	SX987817	DR, KH
25	Bull Hill (Nr. Buoy 17)	19.08.85	SX985807	DR, MH
26	Cockwood Harbour	18.08.85	SX976808	IMTD
27	Cockwood Upper	18.08.85	SX978808	TB, IMTD
28	Cockwood Lower	19.08.85	SX979809	DR, MH
29	Bull Hill (Nr. Buoy 13)	19.08.85	SX987802	DR, MH
30	Dawlish Warren Upper	18.08.85	SX981793	TB, IMTD
31	Dawlish Warren Lower	19.08.85	SX985800	DR, MH
32	Dawlish Warren Point	19.08.85	SX990802	DR, MH
33	Maer Rock	23.08.85	SY013797	TB, DR
34	Orcombe Rocks	20.08.85	SX022794	TB, DR
	Pole Sand - Mid *	23.08.85	SY004798	IMTD, MH
	Pole Sand - Tip *	23.08.85	SY004793	IMTD, MH

* No cores taken

Table 1. (cont.)

Site No.	Site name	Date Surveyed	Ordnance survey Grid Ref. (Distances down stream from the start are given where grid refs. were not used).	Initials of Survey staff
	SUBTIDAL SITES			
Dredge sites:				
35	Riversmeet House	20.08.85	SX968871 (ca. 250 m)	IMTD,BB,KL
36	Post No. 5	20.08.85	SX968854-976852	IMTD,BB,KL
37	Buoy 29-27	20.08.85	SX980848-978843	IMTD,BB,KL
38	Off River Kenn	20.08.85	SX977832 300 m	IMTD,BB,KL
39	Shaggles Buoy Main Channel	20.08.85	SX983821 (ca. 400 m)	IMTD,BB,KL
40	Spit Buoy (West Channel)	20.08.85	SX982815 (ca. 300 m)	IMTD,BB,KL
41	Buoy 17	20.08.85	SX983809-985803	IMTD,BB,KL
42	Buoy 13	20.08.85	SX989803-988802	IMTD,BB,KL
43	Buoy 9-8, Conger Rock	20.08.85	SY010795-009796	IMTD,BB,KL
44	Nr. Slipway	20.08.85	SY997805-994805	IMTD,BB,KL
Dived sites:				
45	No. 9 Buoy - Conger Rock	21.08.85	SY010795-010797	BB,TB
46	No. 3 Buoy - Flat Ledge	21.08.85	SY017792-018793	IMTD,DR
47	Inside Bull Hill	21.08.85	SX989807-991807	BB,TB

Table 2.

Qualitative data for conspicuous intertidal species.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	PS+
ALGAE *																																	
RHODOPHYTA																																	
Gelidium pusillum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F	-	-	-	-	-	-
Gelidium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	p	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chondrus crispus	-	-	-	-	-	-	-	-	-	-	O	-	-	-	-	-	-	-	-	-	F	-	-	-	p	-	F	F	-	-	-	p	-
Gracilaria verrucosa	-	-	-	-	-	F	-	-	-	-	-	-	p	-	-	-	-	-	-	-	O	-	-	-	-	-	O	-	-	O	-	p	-
Ceramium rubrum	-	-	-	-	-	-	-	-	-	-	-	-	p	-	-	-	-	-	-	-	p	-	-	-	-	-	O	O	-	O	-	p	-
Polysiphonia brodiaei	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	p	-	-	-	-	-	-	-	-	-	-	-	-
Polysiphonia denudata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	-	-	-	-	-	-
Polysiphonia elongata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F	-	-	-	-	-	O	-	-	-	-	p	-
Polysiphonia nigrescens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	p	-	-	-	-	-	-	-	-	-	-	p	-
Polysiphonia sp.	-	-	-	-	-	-	-	-	-	-	-	-	p	-	-	-	-	-	-	-	p	-	-	-	-	-	-	-	-	-	-	-	-
Porphyra sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	p	-	-	-	-	-	-	-	-
PHAEOPHYTA																																	
Ectocarpoidea indet.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	p	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Griffordia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	-	-	-
Pilayella littoralis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	p	-
Fucus ceranoides	-	-	F/C	-	-	C	-	-	-	-	-	-	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fucus serratus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	p	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fucus spiralis	-	-	-	-	-	-	-	-	p	-	-	-	-	-	p	-	-	-	-	-	-	p	-	-	-	-	A	-	-	F	-	-	-
Fucus vesiculosus	-	-	-	-	-	-	-	-	-	-	F/A	-	-	F	p	-	-	-	-	-	F	-	-	-	-	-	C/A	F	-	-	-	p	-
Fucus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	p	-	-	-
CHLOROPHYTA																																	
Enteromorpha spp.	-	-	F/A	-	-	O/A	p	-	-	-	A	-	A	-	p	-	-	-	-	-	C	F/A	C/A	p	p	-	F/C	-	-	A	p	p	-
Ulva spp.	-	-	F	-	-	F	-	-	-	-	O	-	p	-	p	-	-	-	-	-	F	C	-	-	-	-	O	F	-	C	-	p	-
Cladophora sp.	-	-	-	-	-	-	-	-	-	-	-	-	p	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	p	-
LICHENS																																	
Caloplaca thallincola	-	-	-	-	-	-	-	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Caloplaca sp.	-	-	-	-	-	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lecanora sp.	-	-	-	-	-	-	-	-	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Verrucaria maura	-	-	-	-	-	-	-	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Xanthoria parietina	-	-	-	-	-	C	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ANGIOSPERMAE																																	
Aster tripolium	-	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Atriplex hastata	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Plantago maritima	-	-	O	-	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Puccinellia maritima	-	-	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Salicornia sp.	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spartina sp.	-	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-	-	-	C	-	-	-	E	-	-	-
Spergularia sp.	-	-	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Suaeda maritima	-	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Triglochin maritima	-	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zostera noltii	-	-	-	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	F	-	-	-
Halimione portulacoides	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-	-	-
ANIMALS																																	
PORIFERA																																	
Demospongia																																	
Halichondria panicea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	p	-
COELENTERATA																																	
Anthozoa																																	
Actinia equina	-	-	-	-	-	-	-	-	-	-	p	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ANNELIDA																																	
Polychaeta																																	
Nereis diversicolor	-	-	p	-	p	p	p	p	-	-	p	-	-	p	-	-	-	-	-	-	-	-	-	-	-	O	-	-	-	-	-	-	-
Nephtys sp.	-	-	-	-	-	-	-	-	p	-	-	-	-	p	-	-	p	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scoloplos armiger	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	p	-	-	-	-	-	-	-	-	-	-
Pygospio elegans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	p	-	p	-	-	-	-	-	-	-	-	-	-	-	-
Ophelia bicornis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	p	-	-	-	-	-	-	-	-	-	-	-	-	F
Arenicola marina	-	-	-	-	-	-	-	-	-	-	-	p	p	-	p	p	-	O	C	-	C	C	F	-	-	-	F/C	C	-	C	-	-	-
Lanice conchilega	-	-	-	-	-	-	-	-	-	-	-	-	p	-	-	-	-	-	-	-	C	-	R	-	p	-	F	p	-	-	-	p	-
Pomatoceros lamarcki/ triquater	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	p	-	-	-	-	-
CRUSTACEA																																	
Cirripedia																																	
Chthamalus montagui	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Semibalanus balanoides	-	-	-	-	-	-	-	-	-	-	C	-	-	F	p	-	-	-	-	-	O	p	-	-	-	-	F/A	-	-	p	-	-	-
Elminius modestus	-	-	-	-	-	R	-	-	-	-	C	-	-	F	C	-	-	-	-	-	O	p	-	-	p	-	O/F	F	-	p	-	-	-

* Attached algae only +PS = Pole Sand

Continued .... /

Table 2 (cont.)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	PS
Isopoda																																	
Idotea granulosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-	-	-
Ligia oceanica	-	-	-	-	-	C	-	-	-	-	-	-	-	-	P	-	-	-	-	-	-	-	-	-	-	-	C	-	-	-	-	-	-
Amphipoda																																	
Hyale nilssoni	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-
Gammarus locusta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-	-	-
Chaetogammarus marinus	-	-	P	-	-	P	-	-	-	-	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
?Eulimnogammarus obtusatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-	-	-
Melita palmata	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Decapoda																																	
Carcinus maenas	-	-	P	-	-	P	P	-	-	-	C	-	-	-	P	-	-	-	-	-	-	-	-	-	O	O	F	P	-	O	-	-	-
INSECTA																																	
Anurida maritima	-	-	-	-	-	-	-	-	P	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-	C	-	-	-	-	-	-
MOLLUSCA																																	
Polyplacophora																																	
Polyplacophora indet.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-
Prosobranchia																																	
Patella vulgata	-	-	-	-	-	-	-	-	-	-	O	-	-	-	O	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-
Crepidula fornicata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-	-
Gibbula umbilicalis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-
Monodonta lineata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	-	-	O	-	-	-
Littorina littorea	-	-	-	-	-	-	-	-	-	-	A	-	-	-	P	-	-	-	A	-	P	P	O	-	-	-	A	C	-	A	R	-	-
Littorina saxatilis agg.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-	-	-	P	-	-	-	-	C	-	-	-	-	-	-
Littorina obtusata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-
Littorina mariae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F	-	-	-
Hydrobia ulvae	-	-	-	-	-	P	-	-	-	-	F	-	-	-	-	-	-	-	-	-	-	A/E	-	-	-	C	O	-	-	A	-	-	-
Bivalvia																																	
Modiolus sp. (juv.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-
Mytilus edulis	-	-	-	-	-	-	-	-	-	-	F/A	-	-	-	-	-	-	-	A	-	O	-	-	-	P	-	F/A	P	-	A	-	P	-
Cerastoderma edule	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-	-	-	-	P	-	-	-	-	P	P	-	P	P	P	-
Tellina tenuis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Macoma baltica	-	-	P	-	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scrobicularia plana	-	-	P	-	-	P	P	P	-	-	P	-	-	-	-	-	-	-	P	-	-	-	-	-	-	O	-	-	-	-	-	-	-
BRYOZOA																																	
Ctenostomata																																	
Alcyonidium gelatinosum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-
Bowerbankia imbricata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-	-
ECHINODERMATA																																	
Stelleroidea																																	
Asterias rubens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	P	-	-	-	-	-
CHORDATA																																	
Pisces																																	
Cottus scorpius	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-

Table 3.

Quantitative infaunal data from intertidal sediments.

Nos. of individuals in 4 x $0.01m^2$ cores

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
NEMERTEA																																
Nemertean indet.	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
NEMATODA																																
Nematoda indet.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	21
ANNELIDA																																
Polychaeta																																
Anaitides mucosa	-	-	-	-	-	-	-	1	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Eumida sanguinea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
Eteone longa	-	-	-	-	1	-	2	-	-	1	1	4	1	2	-	-	-	-	2	-	-	3	2	-	-	5	1	1	-	-	-	-
Syllidia armata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Syllis gracilis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Proceraea picta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nereis diversicolor	48	-	89	58	79	26	35	18	89	-	37	-	2	16	-	-	-	-	3	-	1	-	2	-	-	78	9	3	-	-	3	-
Nephtys cirrosa	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	1	-	-	-	-	-	1	1	-	-	-	-	-	-	-	1
Nephtys hombergii	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	1	-
Glycera tridactyla	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-
Glycera sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Protodorvillea kefersteini	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Scoloplos armiger	-	-	-	-	-	-	-	-	-	2	-	16	2	-	3	-	-	2	-	-	11	-	16	-	1	-	1	8	-	-	-	1
Aricidea minuta	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spio filicornis	-	-	-	-	-	-	-	-	-	-	-	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polydora sp.	-	-	-	-	-	-	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pygospio elegans	-	-	-	-	-	-	20	24	-	2	-	7	48	9	3	-	-	5	14	-	12	-	-	-	-	-	4	11	-	1	1	-
Malacoceros fuliginosus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	11	-	-	-	1	-	-	-
Malacoceros sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Streblospio shrubsolii	-	-	12	3	8	2	10	9	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Tharyx sp.	-	-	-	-	-	-	-	-	1	-	2	1	5	43	-	-	-	-	5	-	-	-	-	-	-	1	-	1	-	4	-	-
Ophelia bicornis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	-	-	-	-	2	-	-	-	-	-	-	-
Capitella capitata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	14	-	-	1	-	-	1	-	-	-	-
Capitomastus minimus	-	-	-	-	-	-	-	-	-	-	-	1	10	1	-	1	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	3
Heteromastus filiformis	-	-	-	-	-	-	-	-	-	-	5	-	-	3	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	3	-	3
Ampharete grubei	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	1	-	-	-	-	-
Alkmaria romijni	-	-	-	-	-	-	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ampharetidae indet. (fragmented)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Lanice conchilega	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	7	-	-	31
Manayunkia aestuarina	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clitellata																																
Oligochaeta indet.	50	-	24	59	115	9	110	126	221	2	52	-	153	45	1	-	-	1	51	-	8	58	1	2	1	202	2	5	-	38	3	-
SIPUNCULA																																
Golfingia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9
CRUSTACEA																																
Cirripedia																																
Elminius modestus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-
Isopoda																																
Cyathura carinata	-	-	4	-	-	15	10	13	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sphaeroma rugicauda	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	12	-	-	-	-	1	-	-	-	-	-	-	-
Amphipoda																																
Melita palmata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	2
Bathyporeia sarsi	-	-	-	-	-	-	-	-	-	-	-	2	-	-	9	6	20	8	-	1	-	-	-	-	-	-	-	-	2	-	-	-
Urothoe brevicornis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Urothoe poseidonis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Corophium volutator	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-
Euphausiacea																																
Euphausiidae indet.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Decapoda																																
Crangon crangon	-	-	-	-	-	-	-	-	2	-	-	-	-	1	-	-	-	-	-	-	-	-	2	-	-	-	2	1	-	-	-	-
Carcinus maenas	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	1
MOLLUSCA																																
Polyplacophora																																
Polyplacophora indet.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Gastropoda																																
Hydrobia ulvae	-	-	-	-	-	-	103	8	44	-	31	12	1	1	32	-	-	-	2	-	-	518	-	-	-	248	2	-	-	256	1	-
Littorina saxatilis agg.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-
Bivalvia																																
Modiolus sp. (juv.)	-	-	-	-	-	-	1	1	-	-	1	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	-	1	-
Mysella bidentata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-
Cerastoderma edule	-	-	-	-	-	-	-	-	-	-	1	-	1	2	-	-	-	-	4	-	-	-	1	-	3	-	14	-	-	11	1	2
Cardiacea (juv.)	-	-	-	-	-	-	-	-	-	-	8	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tellina ?tenuis	-	-	-	-	-	-	-	-	-	-	-	2	-	-	1	1	-	1	-	-	-	-	-	8	-	-	-	2	-	-	1	1
Macoma baltica	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scrobicularia plana	-	-	18	7	27	33	41	21	23	-	6	-	2	1	-	-	-	-	4	-	-	1	-	-	-	51	2	-	-	8	-	-
Tellinidae indet.	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total number of species	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 4.

The distribution of intertidal macrofauna along the Exe Estuary. The site order was that obtained from classification analysis (Fig. 12.). Species are ranked with respect to the site order, to emphasise distribution patterns.

	2	1	3	6	7	8	4	5	9	26	11	14	30	19	27	21	28	13	12	23	10	15	18	31	32	22	25	16	17	24	29	20	PS*
Alkmaria romijni					+																												
Polydora sp.					+	+																											
Manajunkia aestuarina								+																									
Macoma baltica			+	+							+																						
Streblospio shrubsolii			+	+	+	+	+	+				+																					
Cyathura carinata			+	+	+	+						+																					
Nereis diversicolor		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+													
Scorbicularia plana			+	+	+	+	+	+	+	+	+	+	+	+	+			+								+							
Malacoceros sp.																										+							
Eteone longa					+			+		+	+	+		+	+		+	+	+	+	+					+							
Nephtys hombergii																+	+		+					+									
Tharyx sp.									+	+	+	+	+	+			+	+	+														
Urothoe poseidonis																				+													
Pygospio elegans					+	+						+	+	+	+	+	+	+	+		+	+	+	+									
Heteromastus filiformis											+	+	+	+	+										+								
Ampharete grubei														+	+																		
Mysella bidentata														+	+																		
Nephtys sp.									+			+																	+				
Arenicola marina													+	+	+	+	+	+	+	+		+	+			+		+					
Eumida sanguinea																									+								
Syllidia armata																									+								
Syllis gracilis																									+								
Golfingia sp.																									+								
Capitomastus minimus												+				+		+	+						+			+		+			
Bathyporeia sarsi																			+			+	+					+	+		+	+	
Anaitides mucosa						+												+				+			+								
Corophium volutator							+															+		+									
Cerastoderma edule											+	+	+	+	+		+	+	+	+				+	+		+						
Capitella capitata																	+									+	+	+					
Sphaeroma rugicauda				+																							+					+	
Scoloplos armiger															+	+	+	+	+	+	+	+	+		+		+						
Malacoceros fuliginosus																										+	+				+		
Tellina tenuis																	+		+			+	+	+	+			+		+			
Lanice conchilega															+	+	+	+		+					+		+						
Nephtys cirrosa																			+	+					+			+	+	+			
Spio filicornis																		+	+														
Urothoe brevicornis																													+		+		
Glycera sp.														+				+	+					+			+						
Ampharetidae indet.													+																				
Ophelia bicornis																											+					+	+
Aricidea minuta																		+															
Protodorvillea kefferateini																											+						

* Pole Sand

Table 5.

Qualitative data from trawls.

	Trawl Site No.									
	35	36	37	38	39	40	41	42	43	44
RHODOPHYTA										
Chondrus crispus	-	-	-	-	-	-	-	-	-	-
Ceramium rubrum	-	-	-	-	-	-	-	-	-	P
Hypoglossum woodwardii	-	-	-	-	-	-	-	-	-	P
Phycodrys rubens	-	-	-	-	-	-	-	-	-	P
Polyneura gmelinii	-	-	-	-	-	-	-	-	-	P
Polysiphonia elongata	-	-	-	-	-	-	-	-	-	P
Polysiphonia spp.	-	-	-	-	-	P	-	P	-	-
CHLOROPHYTA										
Ulva sp.	F	C	F	C	C	P	-	P	-	P
PORIFERA										
Desmospongia										
Halichondria panicea	-	-	-	-	-	-	-	-	-	P
COELENTERATA										
Hydrozoa										
Hydractinia echinata	-	-	-	-	-	-	-	-	P	-
Sertularia argentea	-	-	-	-	P	-	-	-	P	-
PLATYHELMINTHES										
Platyhelminthe indet.	-	-	-	-	-	-	-	-	-	P
NEMERTEA										
Nemertea indet.	-	-	-	-	-	-	-	-	P	-
POLYCHAETA										
Annelida										
Polynoidae indet. (fragemented)	-	-	-	-	-	-	-	-	-	P
Syllis gracilis	-	-	-	-	-	-	-	-	P	-
Proceraea picta	-	-	-	-	-	-	-	-	-	P
Lanice conchilega	-	-	-	-	-	-	O	O	-	-
Pomatoceros lamarcki/triqueter	-	-	-	-	-	-	P	-	P	O
CLITELLATA										
Oligochaeta indet.	-	-	-	-	-	-	-	-	-	P
CRUSTACEA										
Cirripedia										
Semibalanus balanoides	P	-	-	P	P	-	-	-	-	-
Balanus crenatus	-	-	-	-	-	-	-	-	P	P

Continued .... /

Table 5 (cont.)

	Trawl Site No.									
	35	36	37	38	39	40	41	42	43	44
CRUSTACEA (Continued)										
Amphipoda										
Gammarus locusta	-	-	-	-	O	-	C	O	-	F
Gammarus oceanicus	-	-	-	-	-	-	P	-	-	-
Melita palmata	-	-	-	-	-	-	-	-	-	-
Corophium crassicorne	-	-	-	-	-	-	-	-	P	P
Caprella acutifrons	-	-	-	-	-	-	-	-	-	F
Decapoda										
Crangon crangon	C	A	A	A	A	A	A	A	O	A
Pagurus bernhardus	-	-	-	-	P	-	P	P	P	-
Carcinus maenas	A	C	A	A	A	A	A	A	F	A
MOLLUSCA										
Gastropoda										
Crepidula fornicata	-	-	-	-	-	-	-	-	-	R
Bivalvia										
Mytilus edulis	-	-	-	P	-	-	-	-	P	O
Modiolus sp. juv.	-	-	-	-	-	-	-	-	P	P
Venus striatula	-	-	-	-	-	-	-	-	P	-
BRYOZOA										
Ctenostomata										
Bowerbankia imbricata	-	-	-	-	P	-	-	-	-	-
Cheilostomata										
Conopeum seurati	-	-	-	-	-	-	P	-	-	-
Electra pilosa	-	-	-	-	-	-	-	-	P	P
Cryptosula pallasiana	-	-	-	-	-	-	-	-	P	-
ECHINODERMATA										
Asterozoa										
Asterias rubens	-	-	-	-	-	-	C	F	P	F
CHORDATA										
Vertebrata										
Anguilla anguilla	-	P	-	-	-	-	-	-	-	-
Syngnathus acus	-	-	-	P	-	-	-	P	-	-
Ammodytes tobianus	-	-	-	-	C	P	-	-	P	-
Pomatoschistus minutus	-	P	P	-	O	-	-	O	-	-
Cottus scorpius	-	-	-	-	-	-	P	-	-	F
Scophthalmus maximus	-	-	-	-	-	-	P	-	-	-
Pleuronectes platessa	P	P	O	-	P	-	P	O	P	O

Table 6.

Qualitative data from pipe-dredges.

	Site No. 36	38	40
COELENTERATA			
Hydrozoa			
Campanularia flexuosa	-	F	-
POLYCHAETA			
Annelida			
Nereis diversicolor	P	F	-
Nephtys hombergii	-	P	-
Nephtys cirrosa	-	-	O
Glycera tridactyla	-	P	-
Pygospio elegans	-	O	-
Polydora sp.	-	P	-
Streblospio shrubsoli	-	P	-
Tharyx sp.	-	O	-
Capitella capitata	-	F	-
Capitomastus minimus	-	O	-
Heteromastus filiformis	-	P	-
Lanice conchilega	-	P	-
CLITELLATA			
Oligochaeta indet.	-	C	P
CRUSTACEA			
Cirripedia			
Balanus crenatus	-	O	-
Elminius modestus	-	O	-
Amphipoda			
Melita palmata	-	O	-
Bathyporeia sarsi	-	P	P
Urothoe brevicornis	-	-	P
Decapoda			
Crangon crangon	-	P	-
Carcinus maenas	-	P	-
BRYOZOA			
Ctenostomata			
Alcyonidium mytili	-	F	-
Cheilostomata			
Conopenum seurati	P	F	-

Table 7.

Classification, description and evaluation of the conservation importance of habitats/community types present in the Exe Estuary and encountered during the survey.

Classification (based on Section 6.2 and 6.3).	Description	Provisional suggested importance
INTERTIDAL		
1. Exposed rocky shores (described in Section 6.2.1.).	Open coast habitat. Flat platform of New Red Sandstone intersected by channels with overhangs, crevices and rockpools.	Local
2. Hard Substrata within the estuary (described in Section 6.2.2.).	Stones, small boulders, mussel beds, man-made stone embankments in upper shore and earthenware tiles laid in mid shore. Low diversity biota of estuarine character.	Local
3. Sediment composed predominantly of clean sand (described in Section 6.2.3.).	Low lying current-swept sands fringing the main channel in the estuary, near the mouth. Fauna of low diversity but including *Ophelia bicornis* which is only known from one other locality in Britain. Communities at certain sites correspond to the TELLINA community for which the Exe estuary is a representative locality of regional importance. The assessment of importance relates mainly to the presence of *Ophelia bicornis*.	National
4. Mixed sediments of mud and sand (described in Section 6.2.3.).	Sediments range from mud, with very little sand to those of coarser grades containing little mud. These sediments provided the greatest within-habitat variety, and supported the most diverse infaunal communities. These are regionally representative of the ARENICOLA community type.	Regional
5. Sediments composed predominantly of mud (described in Section 6.2.3).	Infaunal communities with a low diversity characteristic of the SCROBICULARIA community type. This is representative of the community type on a regional basis.	Regional

Table 7. (Continued).

SUBTIDAL

6. Tidally scoured bed-rock (described in Section 6.3.1.).	Flat scoured outcrops of New Red Sandstone in estuary entrance, supporting sparse flora and fauna of low diversity.	Local
7. Infralittoral boulders (described in Section 6.3.2.).	Tidally scoured boulders in estuary entrance supporting a poor current-swept sponge and kelp community.	Local
8. Mixed sediments continually swept by tidal currents (described in Section 6.3.3.).	Clean sand with varying admixtures of gravel, pebbles and or cobbles. Sediments are coarsest in the estaury entrance. Biota not diverse or unusual, apart from an extensive dense bed of *Lanice concheliga*. This is the subtidal form of the intertidal LANICE community for which the Exe estuary is regionally important.	Regional/ Local
9. Mud (described in Section 6.3.4.).	Sediments of mud with small amounts of sand and gravel, becoming progressively finer towards the head of the estuary. Very little epifauna. Infauna in mixed sediments corresponds to intertidal muddy sand communities, becoming less diverse and abundant towards the head of the estuary.	Local

Table 8.

Species of high conservation interest recorded during survey work in the Exe Estuary.

Species	Notes	Suggested Importance
ANIMALS		
Ophelia bicornis	The Exe estuary is one of only two sites in Britain where this Mediterranean species is known to occur. It has been, and still is, the subject of much scientific interest and research.	National

APPENDIX 1

Abundance scales for rocky shore species.

1. Live barnacles (except B. perforatus) (record adults, spat, cyprids separately); Littorina nerotoides, Littorina neglecta

   7 Ex 500 or more per 0.01 m^2, 5+ per cm^2
   6 S 300-499 per 0.01 m^2, 3-4 per cm^2
   5 A 100-299 per 0.01 m^2, 1-2 per cm^2
   4 C 10-99 per 0.01 m^2
   3 F 1-9 per 0.01 m^2
   2 O 1-99 per m^2
   1 R Less than 1 per m^2

2. Balanus perforatus

   7 Ex 300 or more per 0.01 m^2
   6 S 100-299 per 0.01 m^2
   5 A 10-99 per 0.01 m^2
   4 C 1-9 per 0.01 m^2
   3 F 1-9 per 0.1 m^2
   2 O 1-9 per m^2
   1 R Less than 1 per m^2

3. Patella spp. 10 mm+, Littorina littorea (juv. & adults), Littorina mariae/obtusata (adults), Nucella lapillus (juv., <3 mm)

   7 Ex 20 or more per 0.1 m^2
   6 S 10-19 per 0.1 m^2
   5 A 5-9 per 0.1 m^2
   4 C 1-4 per 0.1 m^2
   3 F 5-9 per m^2
   2 O 1-4 per m^2
   1 R Less than 1 per m^2

4. Littorina 'saxatilis', Patella <10 mm, Anurida maritima, Hyale nilssoni and other amphipods, Littorina mariae/obtusata juv.

   7 Ex 50 or more per 0.1 m^2
   6 S 20-49 per 0.1 m^2
   5 A 10-19 per 0.1 m^2
   4 C 5-9 per 0.1 m^2
   3 F 1-4 per 0.1 m^2
   2 O 1-9 per m^2
   1 R Less than 1 per m^2

5. Nucella lapillus (>3 mm), Gibbula spp., Monodonta lineata, Actinea equina, Idotea granulosa, Carcinus (juv. & recent settlement), Ligia oceanica

   7 Ex 10 or more per 0.1 m^2
   6 S 5-9 per 0.1 m^2
   5 A 1-4 per 0.1 m^2
   4 C 5-9 per m^2, sometimes more
   3 F 1-4 per m^2, loc. sometimes more
   2 O Less than 1 per m^2. locally sometimes more
   1 R Always less than 1 per m^2

6. Mytilus edulis, Dendrodoa grossularia

   7 Ex 80% or more cover
   6 S 50-79% cover
   5 A 20-49% cover
   4 C 5-19% cover
   3 F Small patches, 5%, 10+ small individuals per 0.1 m^2, 1 or more large per 0.1 m^2
   2 O 1-9 small per 0.1 m^2, 1-9 large per m^2; no patches except small in crevices
   1 R Less than 1 per m^2

7. Pomatoceros lamarkii

   5 A 50 or more tubes per 0.01 m^2
   4 C 1-49 tubes per 0.1 m^2
   3 F 1-9 tubes per 0.1 m^2
   2 O 1-9 tubes per m^2
   1 R Less than 1 tube per m^2

8. Spirorbinidae

   5 A 5 or more per cm^2 on appropriate substrata; more than 100 per 0.01 m^2 generally
   4 C Patches of 5 or more per cm^2; 1-100 per 0.1 m^2 generally
   3 F Widely scattered small groups; 1-9 per 0.1 m^2 generally
   2 O Widely scattered small groups; less than 1 per 0.1 m^2 generally
   1 R Less than 1 per m^2

9. Sponges, hydroids, Bryozoa

   5 A Present on 20% or more of suitable surfaces
   4 C Present on 5-19% of suitable surfaces
   3 F Scattered patches; <5% cover
   2 O Small patch or single sprig in 0.1 m^2
   1 R Less than 1 patch over strip; 1 small patch or sprig per 0.1 m^2

10. Flowering plants, lichens, lithothamnia

   7 Ex More than 80% cover
   6 S 50-79% cover
   5 A 20-49% cover
   4 C 1-19% cover
   3 F Large scattered patches
   2 O Widely scattered patches all small
   1 R Only 1 or 2 patches

11. Algae

   7 Ex More than 90% cover
   6 S 60-89% cover
   5 A 30-59% cover
   4 C 5-29% cover
   3 F Less than 5% cover, zone still apparent
   2 O Scattered plants, zone indistinct
   1 R Only 1 or 2 plants

Other animal species: record as percentage cover or approx. numbers within 0.01, 0.1 or 1 m^2.

APPENDIX 2

Scales for the interpretation of abundance notations in subtidal surveys using diving.

ANIMALS

1. Large solitary species and colonies. For instance, solitary sponges, *Alcyonium digitatum*, hydroid clumps, large anemones, *Pentapora foliacea*, *Cellepora pumicosa*, echinoderms, large solitary tunicates.

ABUNDANT	One or more per 0.1 m^2.
COMMON	One or more per 1 m^2.
FREQUENT	Less than 1 per m^2 but more than about 20 individuals observed.
OCCASIONAL	About 3-20 observed.
RARE	One or two observed.

2. Small solitary species. For instance, *Grantia compressa*, small anemones, *Caryophyllia smithi*, *Antedon bifida*, small solitary tunicates.

ABUNDANT	One or more per 0.01 m^2.
COMMON	One or more per 0.1 m^2.
FREQUENT	One or more per m^2, scattered patches.
OCCASIONAL	Less than one per m^2, scattered small patches.
RARE	Widely scattered individuals, one or two small patches.

3. Small colonial species and crustose species. For instance, encrusting sponges, *Corynactis viridis*, small hydroids, *Polydora ciliata*, beds of *Mytilus edulis*, barnacles, bryozoa, encrusting tunicates.

ABUNDANT	Large confluent colonies with more than 50% cover. More than 100 per 0.01 m^2.
COMMON	Many small or a few large patches with 10% to 50% cover. One or more per 0.01 m^2.
FREQUENT	Scattered patches less than 10% cover overall. One or more per 0.1 m^2.
OCCASIONAL	Scattered small patches less than 1% cover overall. One or more per m^2.
RARE	Widely scattered very small patches or individuals. Less than one per m^2.

ALGAE

Kelps.

ABUNDANT	Plants mostly less than 50 cm apart. Difficult to swim between.
COMMON	Plants 50 cm to 1 m apart.
FREQUENT	Plants 1 to 2 m apart. Easy to swim between.
OCCASIONAL	Plants more than 2 m apart, zone still apparent.
RARE	Few plants present.

Foliose or filamentous undergrowth species.

ABUNDANT	More than 20% cover over most of area.
COMMON	Less than 20% cover but many plants present throughout zone.
FREQUENT	Less than 20% cover and distribution patchy or scattered plants present throughout zone.
OCCASIONAL	Scattered plants present.
RARE	Few plants seen in dive.

Kelp stipe flora.

ABUNDANT	Plants dense on most stipes.
COMMON	Plants present on most stipes but not dense.
FREQUENT	Distribution patchy, plants may be dense on some stipes, absent on others.
OCCASIONAL	Few plants on many stipes.
RARE	Only few plants seen during dive.

Crustose species.

ABUNDANT	More than 50% cover.
COMMON	More than 20% cover.
FREQUENT	More than 5% cover.
OCCASIONAL	Less than 5% cover. Few scattered large patches or many small patches.
RARE	Few patches seen.

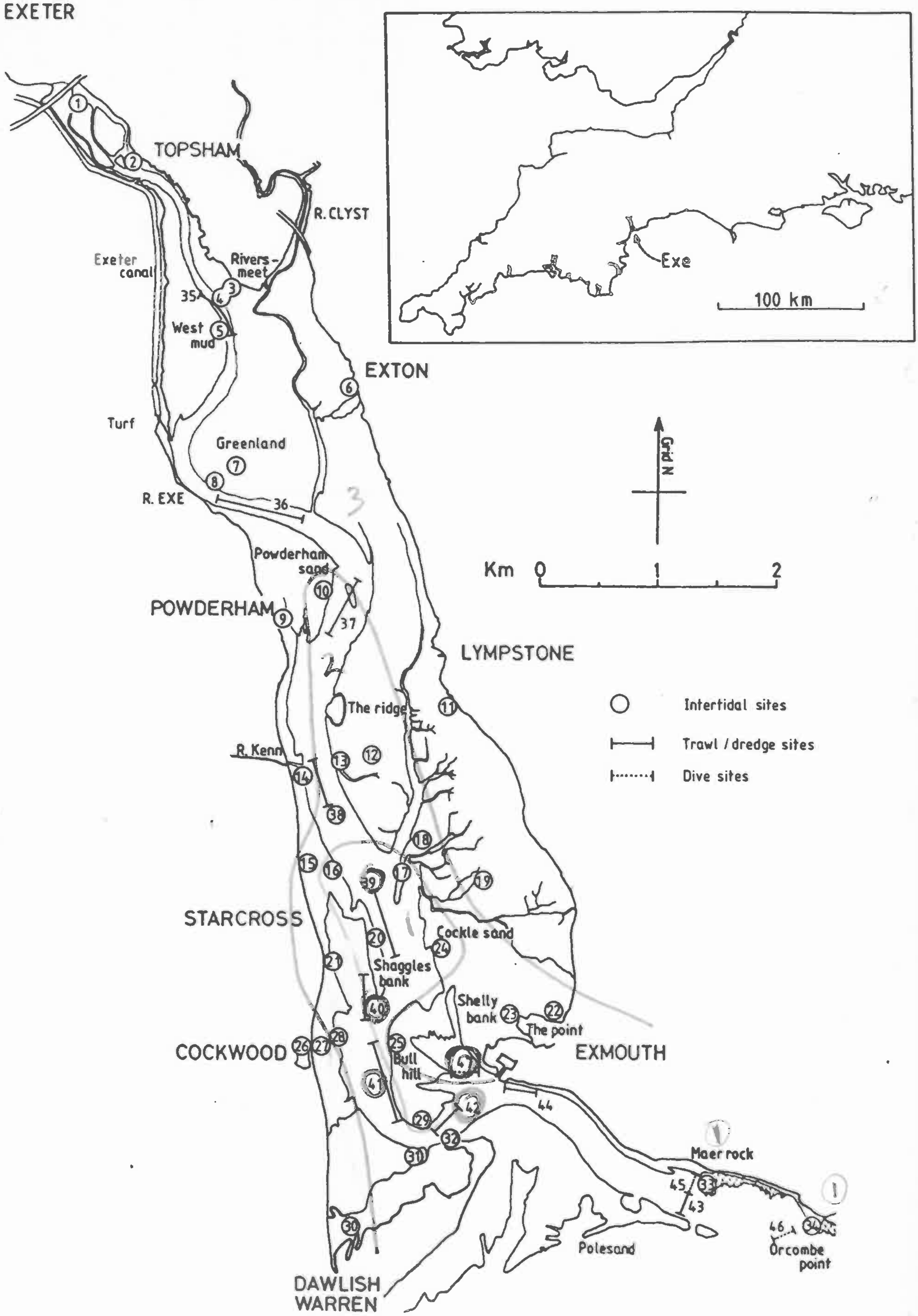

Fig. 10. The Exe Estuary: Location of sites surveyed in August 1985.