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Peterborough PE1 1UA

**MARINE NATURE CONSERVATION REVIEW
OCCASIONAL REPORT**

**BENTHIC MARINE ECOSYSTEMS IN
GREAT BRITAIN:
A REVIEW OF CURRENT KNOWLEDGE.**

**ORKNEY, NORTH SCOTLAND, EAST
SCOTLAND AND NORTH-EAST ENGLAND
(MNCR COASTAL SECTORS 2 TO 5).**

TERESA L BENNETT

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Reports editors

Keith Hiscock
Roger Mitchell

Editorial assistants

Mary Seaton
Joanne Ward

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PREFACE

MARINE NATURE CONSERVATION REVIEW

OCCASIONAL REPORT SERIES

BENTHIC MARINE ECOSYSTEMS IN GREAT BRITAIN: A REVIEW OF CURRENT KNOWLEDGE.

The MARINE NATURE CONSERVATION REVIEW (MNCR) is a major research programme being undertaken within the Marine Science Branch of the Nature Conservancy Council's Chief Scientist Directorate. This programme was initiated in 1987 to consolidate and complete the information already collected on British marine ecosystems, including the extensive data collected from marine survey projects commissioned by NCC since 1974. The principal objectives of the MNCR are to:-

- extend the knowledge of British marine ecosystems, particularly the distribution and extent of habitats, communities and species,
- identify sites of nature conservation importance, and
- provide the information required to promote marine nature conservation principles and counter the adverse effects of developments and pollution in the marine environment.

The MNCR is based on descriptions of habitats and the recorded abundance of conspicuous species for the whole of the coastal waters of England, Scotland and Wales from the high water mark out to the limits of British territorial seas, extending into estuaries to the limits of maritime influence. In practice, most of the survey work is logistically limited to the littoral and the sublittoral within the 50 m depth contour.

The OCCASIONAL REPORT SERIES is intended for the rapid dissemination of topics other than field survey reports, such as information reviews and accounts of methodology. As such, these reports will be of limited circulation, are open to comment and update as necessary and will provide the source material for the wider circulation 'theme report' series which will constitute the published Marine Nature Conservation Review of Great Britain.

The reports on BENTHIC MARINE ECOSYSTEMS IN GREAT BRITAIN: A REVIEW OF CURRENT KNOWLEDGE are part of a series which will form the basis of an MNCR theme report identifying key sources of information and reviewing our current knowledge of benthic marine ecosystems in Great Britain. References used in the text are listed after each coastal sector description. Additional references are held on the MNCR database covering not only further information on marine life but also water movements, water quality and pollution. This reference collection is continually being supplemented with new reports and papers.

A review of marine biological information on Shetland has already been produced. Marine ecological information is described for each of 15 review sectors shown below. The study involved searching the published and unpublished literature held by NCC, universities, marine laboratories, industrial organisations and institutions having a working interest in the coast as well as discussions with individual researchers. Much of this work was undertaken during the winters of 1987/88 and 1988/89 with a lesser amount in 1989/90 and takes account of the information available at the time of the search.

Copies of the 'occasional reports' are available on loan or may be purchased on microfiche from: The Library, Nature Conservancy Council, Northminster House, Peterborough PE1 1UA.

Roger Mitchell, Head
Marine Science Branch

Keith Hiscock, Head,
Marine Nature
Conservation Review

April 1990

Reports contributing to the MNCR theme report 'Marine ecosystems in Great Britain: a review of current knowledge'

HISCOCK, K. 1991. Benthic marine ecosystems in Great Britain: a review of current knowledge. Introduction, historical perspective, physical and chemical environment, climate, biogeography, general and offshore studies, Britain's changing marine life and benthic marine ecosystems in the north-east Atlantic. Nature Conservancy Council, CSD Report, No. 1170. (Marine Nature Conservation Review Report No. MNCR/OR/006.)

HISCOCK, K. & JOHNSTON, C.M. 1991. Review of marine biological information for Shetland. Nature Conservancy Council, CSD Report, No. 1000. (Marine Nature Conservation Review Report No. MNCR/OR/001.)

BENNETT, T.L. 1991. Benthic marine ecosystems in Great Britain: a review of current knowledge. Orkney, north Scotland, east Scotland and north-east England (MNCR Coastal sectors 2 to 5). Nature Conservancy Council, CSD Report, No. 1171. (Marine Nature Conservation Review Report No. MNCR/OR/007.)

COVEY, R. 1991. Benthic marine ecosystems in Great Britain: a review of current knowledge. Eastern England and eastern Channel (MNCR Coastal sectors 6 and 7). Nature Conservancy Council, CSD Report, No. 1172. (Marine Nature Conservation Review Report No. MNCR/OR/008.)

DAVIES, J. 1991. Benthic marine ecosystems in Great Britain: a review of current knowledge. Western Channel and Bristol Channel and approaches (MNCR Coastal sectors 8 and 9). Nature Conservancy Council, CSD Report, No. 1173. (Marine Nature Conservation Review Report No. MNCR/OR/009.)

MILLS, D.J.L. 1991. Benthic marine ecosystem in Great Britain: a review of current knowledge. Cardigan Bay and north Wales and Liverpool Bay and the Solway (MNCR Coastal sectors 10 and 11). Nature Conservancy Council, CSD Report, No. 1174. (Marine Nature Conservation Review Report No. MNCR/OR/010.)

CONNOR, D.W. 1991. Benthic marine ecosystems in Great Britain: a review of current knowledge. Clyde Sea, west Scotland, Outer Hebrides and north-west Scotland (MNCR Coastal sectors 12 to 15). Nature Conservancy Council, CSD Report, No. 1175. (Marine Nature Conservation Review Report No. MNCR/OR/011.)

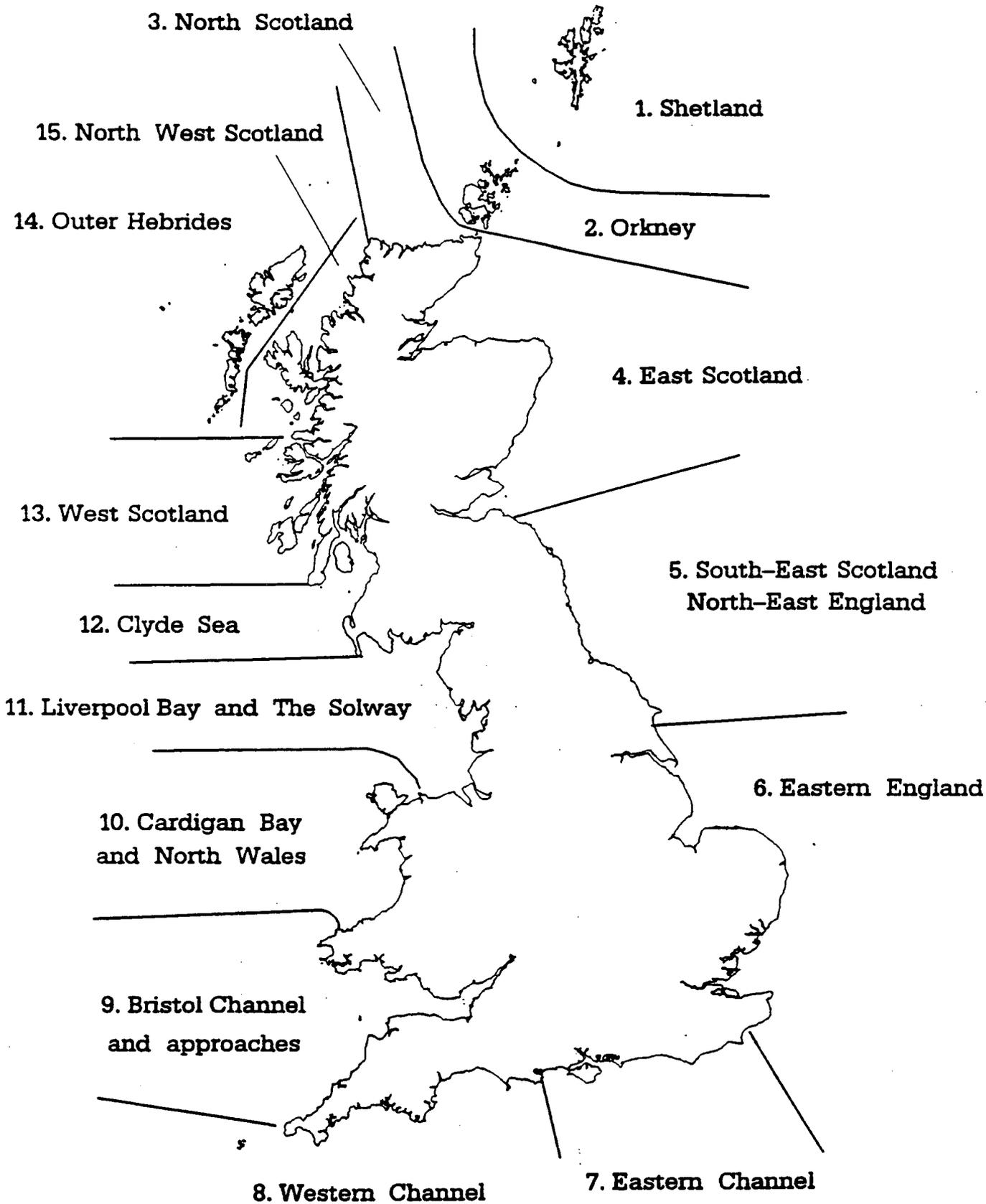


Figure 1 MNCR coastal sectors.

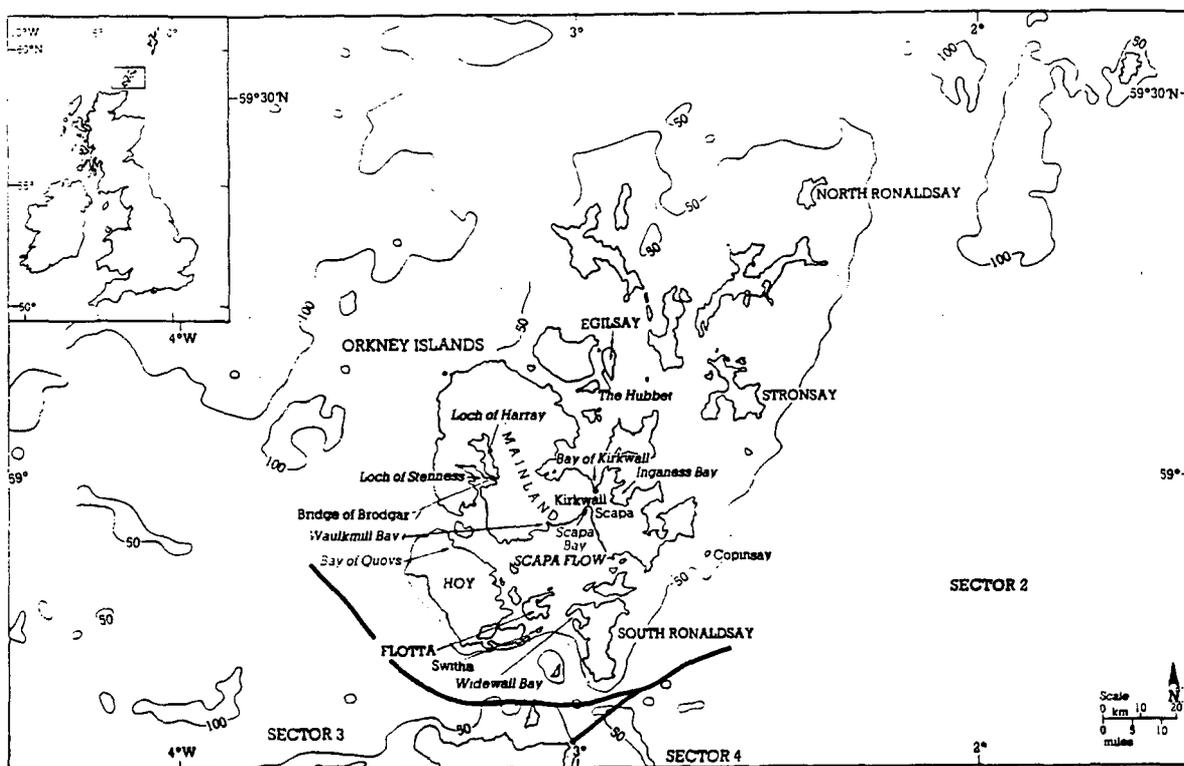
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1 ORKNEY

1.1 Introduction

Orkney comprises about 70 islands, 18 of which are inhabited (Figure 2). The islands, which have a total coastal length of about 800 km, are mainly composed of sandstone. Coastal geomorphology ranges from high cliffs and rocky shores to lowlands and sandy beaches.



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Figure 2 The location of places in the Orkney Islands named in the text.

A general description of the climate and marine environment of the Orkney Islands is provided by Jones (1975). The climate is mild but cool. Average air temperatures range from about 4 °C in winter to 13 °C in summer and sea temperatures from a minimum of 5 °C in February to a maximum of 13 °C in July. The average annual rainfall is 90 to 100 cm and humidity is the highest in the UK being 80 to 90% for most of the year. The prevailing winds are from the west to south-east. The lack of extreme temperature fluctuations and the relatively damp atmosphere allows the development of diverse littoral communities.

The Orkney Islands are influenced by the North-East Atlantic Drift which carries warm water northwards along the west coast of Britain. Tidal streams flow clockwise around the islands. The depth of water around and between the islands is less than 50 m except off the west coast of the mainland where the coast shelves steeply. The sea bed between the islands consists of rock, boulders, gravel, sand and occasional deposits of mud while the substrata of tide scoured sounds are rock, shell-gravel or sand (Jones 1975). Shores are predominantly composed of bedrock or boulders with sand in the bays. The configuration of the islands and inlets gives a range of shore exposure to wave action from very sheltered to very exposed. There are two brackish water lochs on the mainland of Orkney, Loch of Harray and Loch of Stenness.

1.2 Marine habitats, communities and species

Introduction Published observations on the marine life of Orkney extend back nearly 300 years. It is only since about 1970 that intensive work has been undertaken and then mainly in the area of Scapa Flow. The establishment of the Orkney Field Club in the 1960s and subsequent production of a quarterly bulletin generated items of general interest often relating to single species or groups. The first marine related articles appeared in 1964. Smith (1964) described grey seal research and damage to salmon fisheries in Orkney and Craigie (1964) reported that 114 species of marine fish including stranded exotics had been recorded for the Orkney Islands. Few of the marine life studies in the period up to about 1970 described the habitats and communities present around the islands.

A symposium on the natural environment of Orkney held by the Nature Conservancy Council in 1974 (Goodier 1975a) included a number of papers relevant to the marine environment. Subjects included the geomorphology of the coastline (Mather, Ritchie & Smith 1975), the hydrography, habitats and species of the marine environment (Jones 1975), seal populations (Vaughan 1975) and conservation interests (Goodier 1975b).

The Royal Society of Edinburgh symposium on the Orkney Islands brought together all environmental work at the time (Jones 1985). Most marine studies were related to commercial ventures in the area. Johnston (1985) outlined the potential for revitalizing the seaweed industry and harvesting seaweeds (predominantly *Laminaria hyperborea*). The fisheries were described by Mason et al. (1985) who reported that local vessels tended to be small and fished mainly for inshore shellfish. Seals have formed an important resource for both domestic use and export in previous centuries and the grey and common seal populations around Orkney were described by McConnell (1985). Other papers relating to the marine environment covered seabirds and otters (Reynolds 1985) and pollution (Davies 1985).

Fauna The earliest published marine biological records for the Orkney Islands were made by the Rev James Wallace in 1693 and his son Dr James Wallace in 1700. They produced descriptions of the

Orkney Islands including observations on the marine life. The nomenclature for the list of Mollusca prepared by Dr James Wallace was updated and republished by Rendall (1948). Low (1813) published a book on the fauna of Orkney which included descriptions of seals and fish. In 1830 Thomas Stewart Traill published a paper on the Orkney Islands which also contained a catalogue of marine fauna including a list of 58 molluscs. This list was again updated and republished by Rendall (1953). Since this time all records on the Mollusca of Orkney from shore surveys and dredging have been brought together by Rendall (1956).

Three salvaged warships from Scapa Flow were studied for the encrusting fauna (Forrest 1938). Although this was after much of the life had been scraped off many species were recorded indicating a rich sublittoral fauna in Scapa Flow .

Flora The earliest published records of marine algae for the Orkney Islands were made by Traill (1891, 1893, 1895) who collected 253 species. A list of algae of North Ronaldsay produced by Traill in 1894 was published by Robertson (1966).

Lyle (1929) recorded the algae from six wrecked German warships in Scapa Flow and on nearby shores for comparison. Algae were collected at different depths from the warships by dredging, scraping and diving. In total 167 species were recorded, 48 of which were common to both wrecks and shores. On the wrecks the brown algae were found to reach a depth of 12 m and at 22 m just six species of red algae remained.

Stronsay was found to have a rich algal flora possessing 225 species out of a total of 348 recorded for Orkney at the time (Sinclair 1950). Sinclair added 50 new algal records for Orkney, although many of these were microscopic epiphytes and parasites. More recently algae were noted from 11 localities of varying wave exposure and salinity in the Orkney Islands and 45 new records were produced (Wilkinson 1975).

The marine flora of Orkney was found to be typically northern with the presence of the brown algae *Fucus distichus anceps* and *Stictyosiphon tortilis* and the red algae *Odonthalia dentata* and *Lithothamnion glaciale*. The only northern species with its southern limit of distribution in Orkney was found to be the fucoid *Fucus distichus edentatus* (Maggs 1986). A southern element to the flora was found due to the North-East Atlantic Drift. Some such species that had their northern limit of

distribution in Orkney, for example the red algae *Acrosorium uncinatum*, *Ceramium echionotum*, *Cordylecladia erecta*, *Mesophyllum lichenoides* and *Rhodymenia delicatula* and the green alga *Cylindrocarpus berkeleyi*, have been found on the west coast of Scotland but not on the east. Other species which had their northern limit of distribution in Orkney were found on both the west and east coasts of Scotland. These included the red algae *Bonnemaisonia asparagoides* and *Nemalion helminthoides*, the brown alga *Sporochnus pedunculatus* and the green alga *Codium fragile tomentosum* (Maggs 1986). Algal communities on Orkney were considered to be well developed for the Northern Isles compared to the Shetland Islands (Irvine 1974).

The Orkney Islands have a history of 'kelp' making (Thompson 1983). Washed up *Laminaria* stipes and fucoids were collected from the beaches and then burnt in pits to make 'kelp' which was then used as a fertilizer. The seaweed industry, which started in 1719 for the production of soda, potash and iodine, ended in 1935 as iodine was cheaply available elsewhere (Johnston 1985). After the Second World War a factory was established at Kirkwall

for the production of fertilizers and seaweed meal for animal feedstuffs (Jones 1975). The potential for revitalizing the seaweed industry has been considered by several authors (Walker 1981; Thompson 1983; Johnston 1985). The dense laminarian beds which occurred in fairly sheltered water were considered suitable for harvesting (Walker 1947, 1950). The sublittoral fringe and upper infralittoral supported abundant kelp species including *Alaria esculenta*, *Laminaria digitata*, *Laminaria hyperborea*, *Laminaria saccharina* and *Saccorhiza polyschides*. Walker was mainly concerned with quantifying laminarians with depth to determine their productivity. The viability of harvesting kelp around the Orkney Islands was assessed by Walker (1981). It was estimated that Orkney could supply one million tonnes of raw seaweed per year with a seven year regrowth period if all areas were taken into consideration. The seaweed resource of the Orkneys has also been described by Johnston (1985). *Laminaria hyperborea* was considered to be the main seaweed of commercial use in Orkney. The shelf on which the Orkney Islands sit was thought to provide the appropriate substratum and to be of suitable depth for the growth of laminarians (Figure 3). Proposals have been put forward to redevelop the seaweed industry in Orkney (Institute of Offshore Engineering 1986).

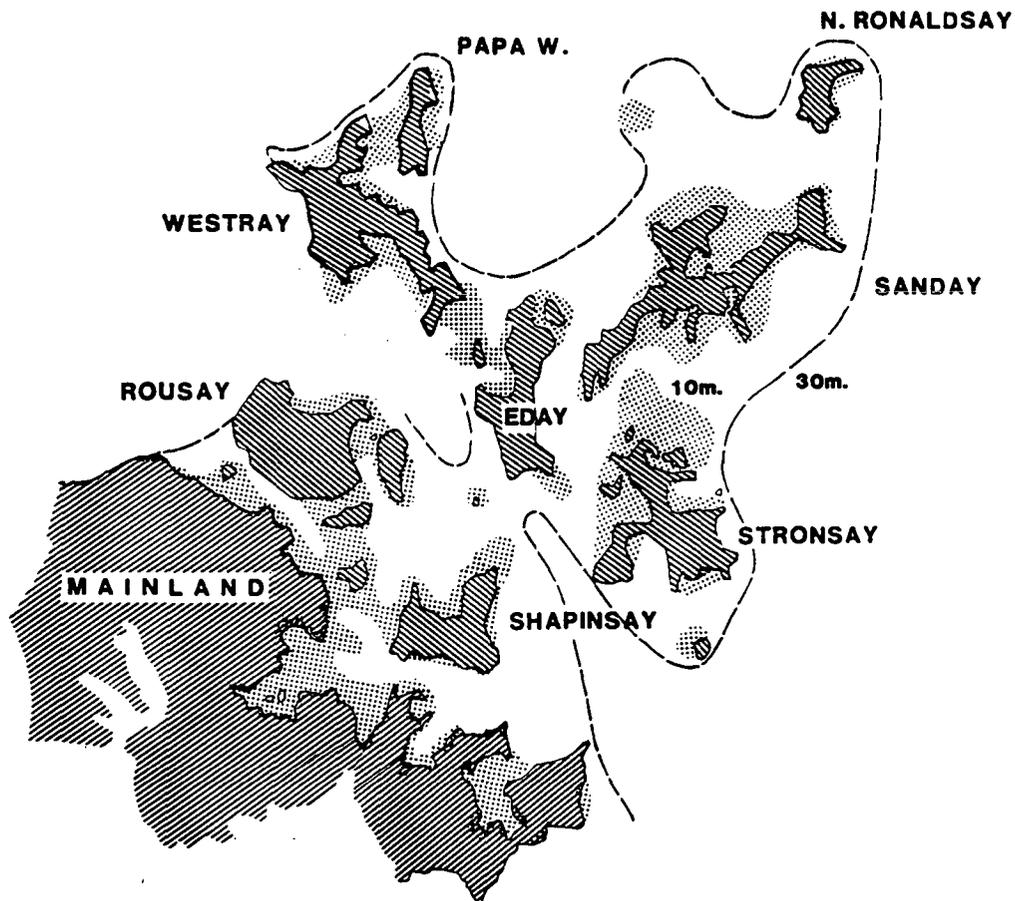


Figure 3 The northern islands of Orkney showing the platform suitable for laminarian growth with 10. and 30 m contours (reproduced by permission of the Royal Society of Edinburgh and C.S. Johnston from the Proceedings of the Royal Society of Edinburgh, volume 87B, page 7).

Littoral habitats Shores range from those exposed to extreme wave action on the west coast of Orkney to very sheltered conditions between the islands. Table 1 shows the composition of different shore types calculated for the Orkney Islands (Baxter, Jones & Simpson 1985).

Very exposed shores	14%
Barnacle dominated shores	17%
Barnacle/fucoid dominated shores	8%
Fucoid dominated shores	24%
<i>Ascophyllum</i> dominated shores	21%
Sandy shores	12%
Shingle shores	4%

Table 1 The proportion of different shore types found in Orkney (data extracted from Baxter, Jones & Simpson 1985).

Eight rocky shores of varying exposure to wave action were selected for a long term study to monitor changes in community composition mainly due to oil pollution (Baxter, Jones & Simpson 1985). Brown algae such as *Fucus vesiculosus* and *Fucus serratus* showed seasonal variation in abundance with maximum cover in summer and a minimum in late winter. Reduced cover in late winter was considered to be due to loss of fronds or whole plants through storms and frosts. The importance of the fucoids in providing damp conditions for other species at low tide was thought to be reduced on Orkney due to the mild temperatures, high humidity and the timing of low water spring tides early in the morning and late in the afternoon. Consequently some red algal species were found surviving as a 'turf' form on open rock surfaces on the lower shore.

The sandy beaches of Orkney were surveyed by Mather, Smith and Ritchie (1974). The aim of this study was to examine the physical characteristics of sediment shores with regard to their stability and the human impact on them. Each beach on each island was described in terms of topography, habitats, land use, access and recreation. The fauna of 14 sandy shores located all over the Orkney Islands (with seven in Scapa Flow) has been surveyed by Atkins, Jones and Simpson (1985). The beaches consisted of clean, fine to medium grade sand. All were dominated numerically by polychaetes and amphipods. The main species to be recorded were the polychaetes *Pygospio elegans* and *Capitella capitata* and the amphipod *Bathyporeia* spp. The Bay of Quoys, Hoy was found to be the most interesting site sampled. The shore was unique in being dominated by the polychaetes *Clymenura (Leiochone) johnstoni* and *Praxillella (Euclymene) affinis* with the occurrence of the normally sublittoral *Pseudopolydora (Polydora) antennata* and a diverse assemblage of amphipods. Scapa Bay and Waulkmill Bay have been sampled at four to eight week intervals over a four year period between 1982 and 1986 to detect seasonal fluctuations in faunal composition (Atkins, Simpson & Jones 1989).

The shores of Kirkwall Bay have been described to assess the state of the bay in relation to the disposal of untreated sewage effluent (Herbert & Jones 1978). The sediments and fauna have also been surveyed in Inganess Bay (Jones et al. 1987).

A few studies have been made on other islands including the molluscs of Copinsay (Smith 1973) and a description of the Hubbet on the west coast of Egilsay (McMillan 1972). The Hubbet is a long, almost land-locked inlet of the sea with a saltmarsh at its head and a muddy sandy beach lower down. Saltmarsh vegetation

and algae were recorded and the green alga *Codium* sp. was found to occur in profusion.

Sublittoral habitats Sublittoral surveys of the Orkney Islands by SCUBA diving took place in 1978 and 1979 by members of the Underwater Conservation Society (Dipper 1984). Sites were surveyed on the west coast of the mainland and Hoy and extensively in Scapa Flow (Figure 4). The substrata of the exposed west coast sites was predominantly bedrock. In the more

sheltered conditions of Scapa Flow there were boulder slopes leading onto sediment plains. Sites south of Scapa Flow off the islands of Flotta and Switha consisted of large boulders or bedrock subject to strong tidal flow. Kelp forests of *Laminaria hyperborea* with well developed growths of epiphytes and a red algal understorey occurred to a depth of 20 m off the west and south coasts. Dense growths of hydroids and bryozoans were characteristic of the south coast sites in the strong currents. Within Scapa Flow the kelp forest, where it occurred, only extended down to 10 m and there were few epiphytes on the stipes. The common sea-urchin *Echinus esculentus* was found to graze algal populations below the kelp forest leaving extensive areas of encrusting coralline algae. Horse mussel *Modiolus* beds with an associated faunal community were recorded in Scapa Flow. Several species were recorded for the first time on Orkney: the boring sponge *Cliona celata*, the jewel anemone *Corynactis viridis*, the Devonshire cup coral *Caryophyllia smithii*, the anemone *Actinothoe sphyrodeta* and the starfish *Stichastrella rosea*.

As part of a benthic survey of the north Scottish coast and Orkney, the Department of Agriculture and Fisheries for Scotland undertook a survey of Scapa Flow in 1975 (D. Muirison & D. Moore pers. comm.). Samples of the benthos were taken from 22 stations, trawls were made across Scapa Flow and video recordings were taken of the seabed. The sampling procedure was repeated by the University of Dundee in 1986 (Jones et al. 1988) and the sediment characteristics and fauna described. For most of the seabed the sediments were found to be variable with an uneven distribution of species. However, the north-eastern area of Scapa Flow was characterised by fine sediment supporting fewer species and individuals compared to other parts of the basin. In the east the sediments were very coarse and had the highest species richness. Abundant populations of the mollusc *Chaetoderma nitidulum* and several new species for Orkney were found.

Lagoons The flora and fauna of the brackish water Lochs of Harray and Stenness have been described by Dunn (1937) and Nicol (1938). Both lochs were shallow with an average depth of about 2 m, had flat, muddy bottoms and shores of fragmented flagstone. Loch of Harray had a very low salinity; the water was nearly fresh at the northern end and was brackish at the Bridge of Brodgar where it flowed into the Loch of Stenness. Marine species, such as the furoid alga *Fucus ceranoides*, were found to be restricted to this brackish area in Loch of Harray. Loch of Stenness with its comparatively higher salinity supported more marine species, for example, the polychaete *Hediste* (*Nereis*) *diversicolor*, a small thin form of the sand-gaper *Mya arenaria* and the furoid alga *Fucus serratus*. A further investigation on the distribution of bottom-dwelling invertebrates with salinity in the two lochs was undertaken by Heppleston and Trowbridge (1979). A comparative survey of the flora, fauna and salinity of the two lochs was carried out between 1979 and 1980 (Palmer 1980) when it was found that Loch of Stenness had a distinct halocline.

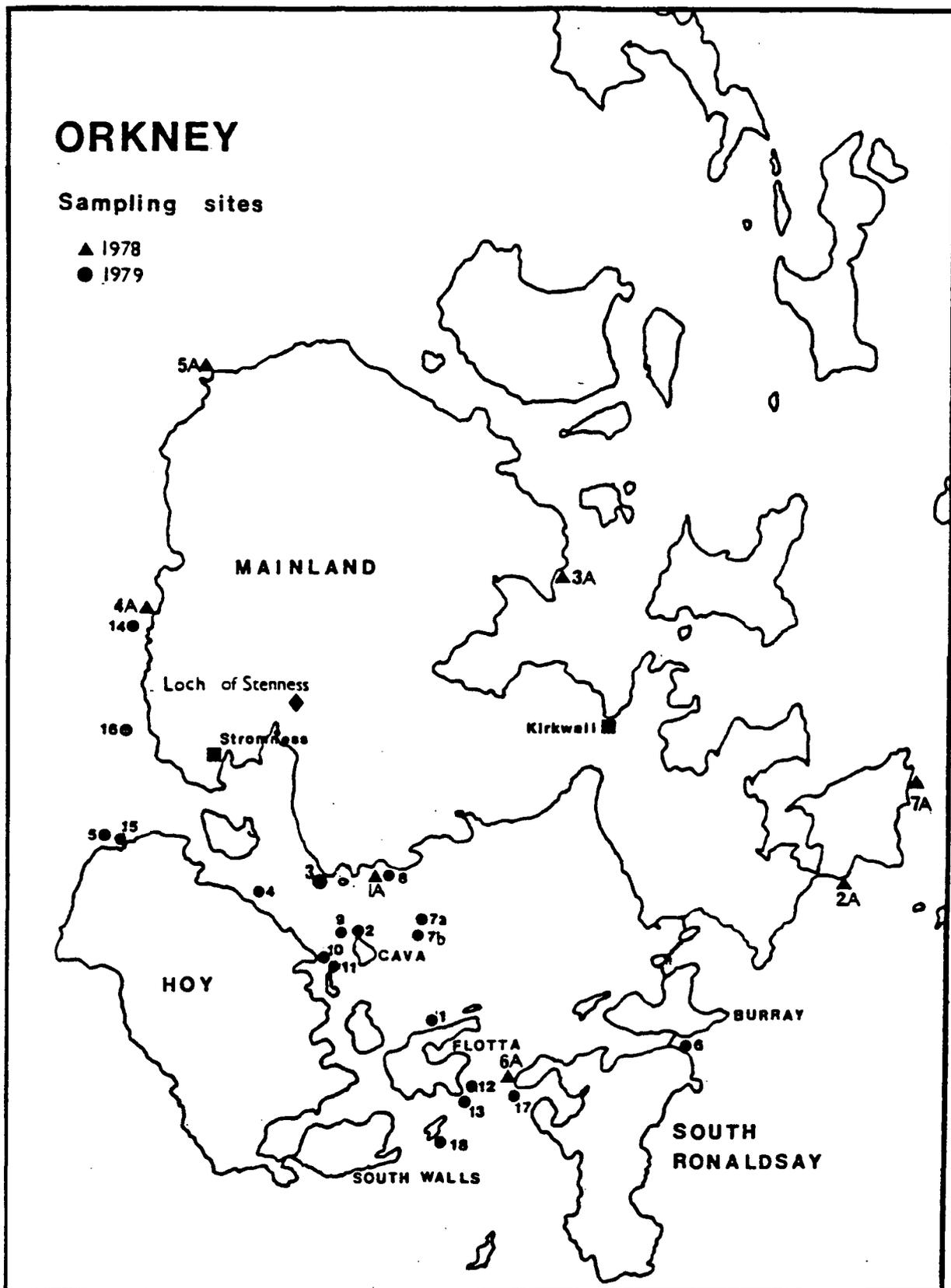


Figure 4 Location of sublittoral sites surveyed in 1978 and 1979 by the Underwater Conservation Society (from Dipper 1984).

Nine saline lagoons, which include the Lochs of Harray and Stenness, have been described for the Orkney Islands with particular reference to the molluscs (Smith 1984). Of these lagoons Lochs of Harray and Stenness were considered to be of the most marine conservation interest and the most threatened. The main pressure to Orkney lagoons was noted to be over enrichment from agricultural run-off.

Impact studies With the proposal for an oil terminal to be established in Scapa Flow an environmental assessment of the littoral fauna and flora and benthic sediments and fauna was undertaken (Jones & Stewart 1974). Following this, the Orkney Islands Council commissioned the University of Dundee to initiate an independent monitoring programme of Scapa Flow and its approaches in order to detect any deterioration in the marine environment due to industrial development, particularly from the oil industry. As a result the Orkney Marine Biology Unit was established in 1974 at Scapa. Monitoring work has involved studying transects on both rocky and sedimentary shores to record the distribution and abundance of species, as well as single species investigations. Communities on rocky shores were found to be stable. However, faunal population changes were detected in sediment shores (Jones et al. 1982).

An environmental impact assessment in relation to the development of the oil industry on Flotta was undertaken by Cairns & Associates (1973, 1975). They considered the physical marine environment, marine life and conservation importance of Scapa Flow. A monitoring programme was also undertaken between 1975 and 1977 (Johnston 1977) to assess the marine environment of Scapa Flow prior to the operation of the terminal. This work involved studying kelp holdfast communities, the flora and fauna of Widewell Bay, South Ronaldsay and chemical studies of the sediments. Comparison of the population structure of kelp holdfasts with those from other sites around Great Britain revealed that the Orkney holdfasts supported a rich and diverse fauna characteristic of clean, unpolluted waters.

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2 NORTH SCOTLAND

2.1 Introduction

The north coast of Scotland, extending from Cape Wrath in the west to Duncansby Head in the east, is approximately 200 km in length (Figure 5). The coastline consists of predominantly rocky shores backed by cliffs interrupted by the occasional sandy beach. Some of the highest cliffs on mainland Britain of 91 m (300') occur at Cape Wrath. Three major indentations are located in the western half of the coastline namely (from west to east) the Kyle of Durness, Loch Eriboll and the Kyle of Tongue.

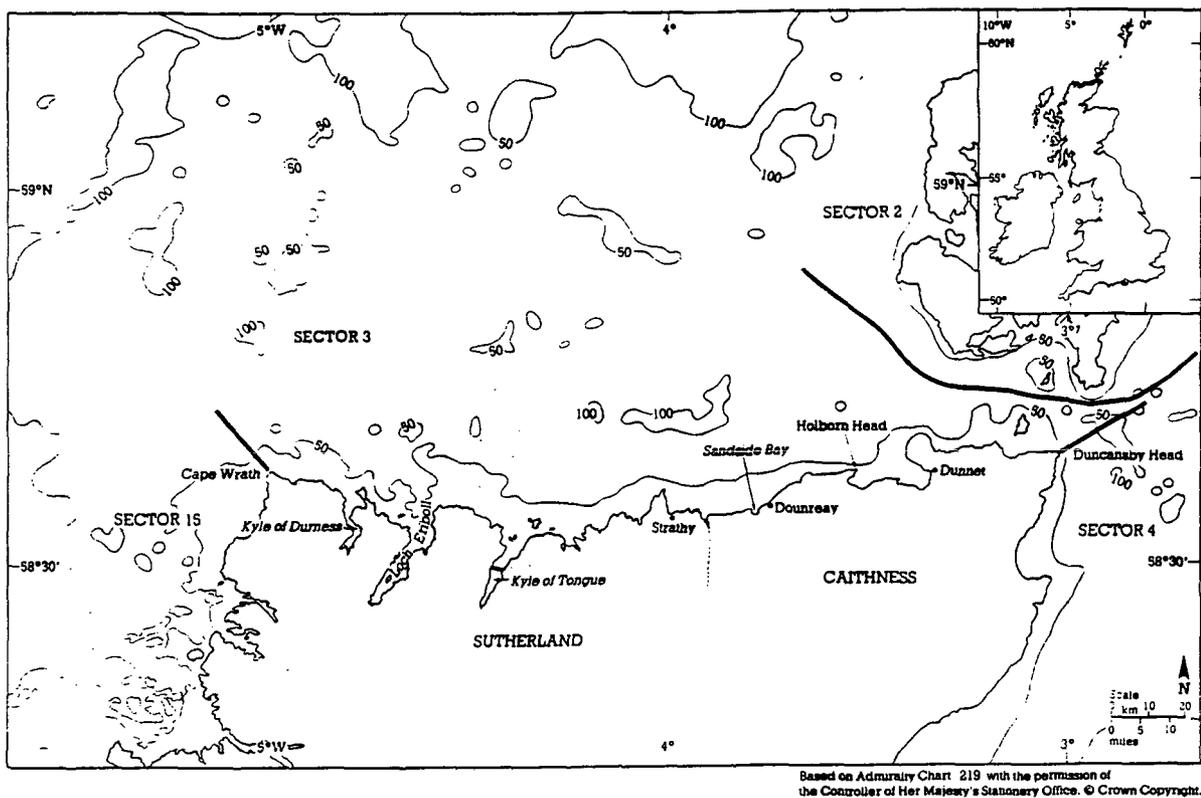


Figure 5 The location of places on the north coast of Scotland named in the text.

2.2 Marine habitats, communities and species

Open coast Rocky shores on the north coast of Sutherland have been described by Lewis (1957). Zonation of species and differences between the distribution of species on exposed and sheltered shores were described.

The exposed rocky shores of the north coast of Caithness were also studied by Lewis (1954). He described the vertical and horizontal distribution of the predominant species found and compared the data with that for other shores of the British Isles. Distinguishing features of these shores were:

- the presence of a well developed zone of blue-green algae and the red alga *Porphyra* sp. in the littoral fringe in summer
- a eulittoral zone of the common mussel *Mytilus edulis* and the limpet *Patella ulyssiponensis (aspera)* with associated red algae *Ceramium* sp. and *Callithamnion* sp. in the upper levels and *Mastocarpus (Gigartina) stellatus* and *Palmaria (Rhodymenia) palmata* lower down
- belts of the brown algae *Fucus vesiculosus* f. *linearis* and *Himantalia elongata*.

Factors affecting the exposure of these shores were the geomorphology and wave action. The strong wave action on this coast had caused an upward displacement of species and zones. The cool, less sunny weather of this area was thought to favour the development of communities higher on the shore as the effects of desiccation were reduced compared with the south of Britain. The first records of the furoid alga (as named at the time) *Fucus inflatus* f. *distichus* in Britain were from the Caithness coast from Holborn Head westwards to the border with Sutherland (Powell & Lewis 1952).

Since 1971 the rocky shores at Dounreay have been part of a monitoring programme to study the annual differences in recruitment of limpets and barnacles around Great Britain (Bowman 1978). In 1977 an oil spill from an outfall at mid tidal level occurred at Dounreay. Observations were made of the shore at the time of the spill and at intervals afterwards. Similar mortalities to those recorded at Dounreay occurred at other monitoring sites. It was therefore deduced that the mortality to shore life noted at Dounreay was due to the hot summer of 1976 rather than the oil spill.

A few studies have been carried out on the sandy shores of north Scotland. The intertidal fauna of sandy beaches at Strathy, Sandside and Dunnet have been documented (Eleftheriou & McIntyre 1976). The three beaches were classified as 'exposed'; the communities and physico-chemical characteristics of the sediments were described. Dunnet was the largest beach with a total of 10 species; Sandside supported 16 species and Strathy nine species. The human use of sandy beaches, both commercially and recreationally, has been investigated and the physical nature of beaches described for the Highlands and Islands of Scotland including the north coast (Mather & Ritchie 1977).

Kyle of Durness The Kyle of Durness is a twisting shallow inlet with vast expanses of sandy beach (Figure 6). A study of its marine environment showed the inner region of the Kyle of Durness to be dominated by well-sorted medium sand deposits with a mixture of shingle boulder and gravel shores around the periphery and bedrock at the seaward end (Jones 1975). In muddy shores at the mouths of rivers entering the Kyle of Durness the main species found were the amphipod *Corophium volutator*, and the polychaete worms *Hediste (Nereis) diversicolor* and *Nerine cirratulus*. The furoid, *Fucus ceranoides*, was also found here and in the river channels. At the entrance to the inner Kyle well developed beds of large *Mytilus edulis* were found. The

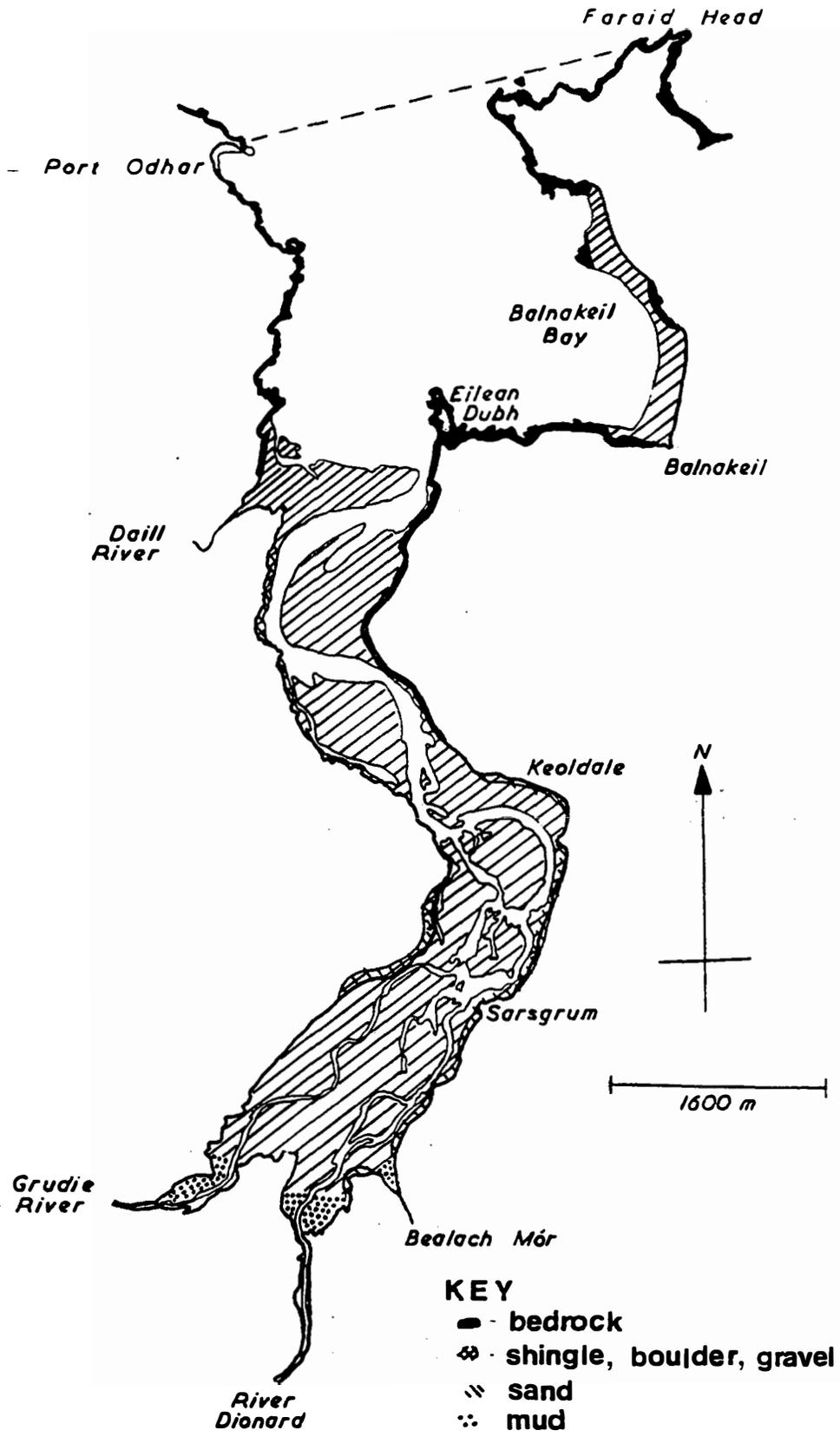


Figure 6 The distribution of littoral habitat types within the Kyle of Durness.

salinity variation within the Kyle of Durness was considered to affect the penetration of stenohaline species. The absence of the common limpet *Patella vulgata* and the dogwhelk *Nucella lapillus* and the restricted distribution of the edible periwinkle *Littorina littorea* in the inner Kyle was attributed to the reduced salinity. In general the littoral zone was considered to be poor in terms of sediment infauna; the epifauna of exposed rocky shores typical was being of high density and low diversity.

The sublittoral zone was described from eight sites where the substratum, the extent of kelp and the common fauna were recorded (Glasgow University Exploration Society 1975). Bedrock with crevices, gullies, overhangs and caves and large boulders occurred at most sites giving way to pebbles, clean sand or mud with depth. In general the bedrock extended deeper with increased exposure to wave action. At most sites laminarians extended from chart datum down to the limit of the rocks, with the deepest occurring at 23 m. The brown alga *Alaria esculenta* occurred down to about 3 m at the more exposed sites and at two of the more sheltered sites the brown alga *Saccorhiza polyschides* dominated the kelp forest. Analysis of holdfasts showed the fauna to be sparse. The most common animal recorded was dead man's fingers *Alcyonium digitatum*. The upper limit of both *Alcyonium digitatum* and the feather star *Antedon bifida* occurred deeper with increasing exposure to wave action. The most commonly recorded sea anemone was the dahlia anemone *Urticina felina* which was mainly found in crevices. The scallop *Pecten maximus* was characteristic of the clean sand.

Loch Eriboll Loch Eriboll is a deep sealoch approximately 13-14 km in length and just over 3 km wide. The marine environment has been described and communities studied in relation to habitat types (Jones 1975). The main habitats distributed along the shoreline were found to be bedrock, boulders, shingle, gravel, sand and mud (Figure 7). On the basis of habitat types Loch Eriboll was divided into two regions: an outer area dominated by bedrock shores and an inner region characterised by boulder, shingle and gravel shores. The open coast bedrock shores were dominated by barnacle and mussel communities while the more sheltered shores supported fucoid dominated communities. Rocky shores on the west coast of Loch Eriboll with its varying degrees of wave exposure supported a wider range of habitats compared to the east coast shores. Boulder, shingle and gravel shores were widely distributed in the loch and often overlaid gently sloping bedrock. These shores tended to be characterised by knotted wrack *Ascophyllum nodosum*. Boulder, shingle and gravel shores on the west coast of the loch supported a wider density and diversity of species than those on the east. Sandy shores occurred in the bays of open coast areas. Muddy shores were present in the innermost parts of small inlets in the loch and where freshwater crossed the shore. Muddy sand areas supported low densities of the common cockle *Cerastoderma edule*, the lugworm *Arenicola marina* and the crustaceans *Crangon vulgaris* and *Bathyporeia pilosa*. Areas of pure silt only contained low numbers of the crustacean *Corophium volutator*.

The range of sublittoral habitats and communities at the entrance and in the loch was found to be high (Moss 1986). Exposed bedrock slopes and cliffs occurred off islands and headlands in the outer loch, while mud and sand was typical of the inner and middle loch region. The outer loch supported kelp forest of *Laminaria hyperborea* and rich communities of sponges, ascidians, hydroids and bryozoans on vertical and steep sided bedrock. A wide variety of foliose and encrusting algae were found on cobbles and pebbles located at all exposures in the loch. Muddy sand was typical of the middle part of the loch and supported species including the anemone *Cerianthus lloydii*, the lugworm

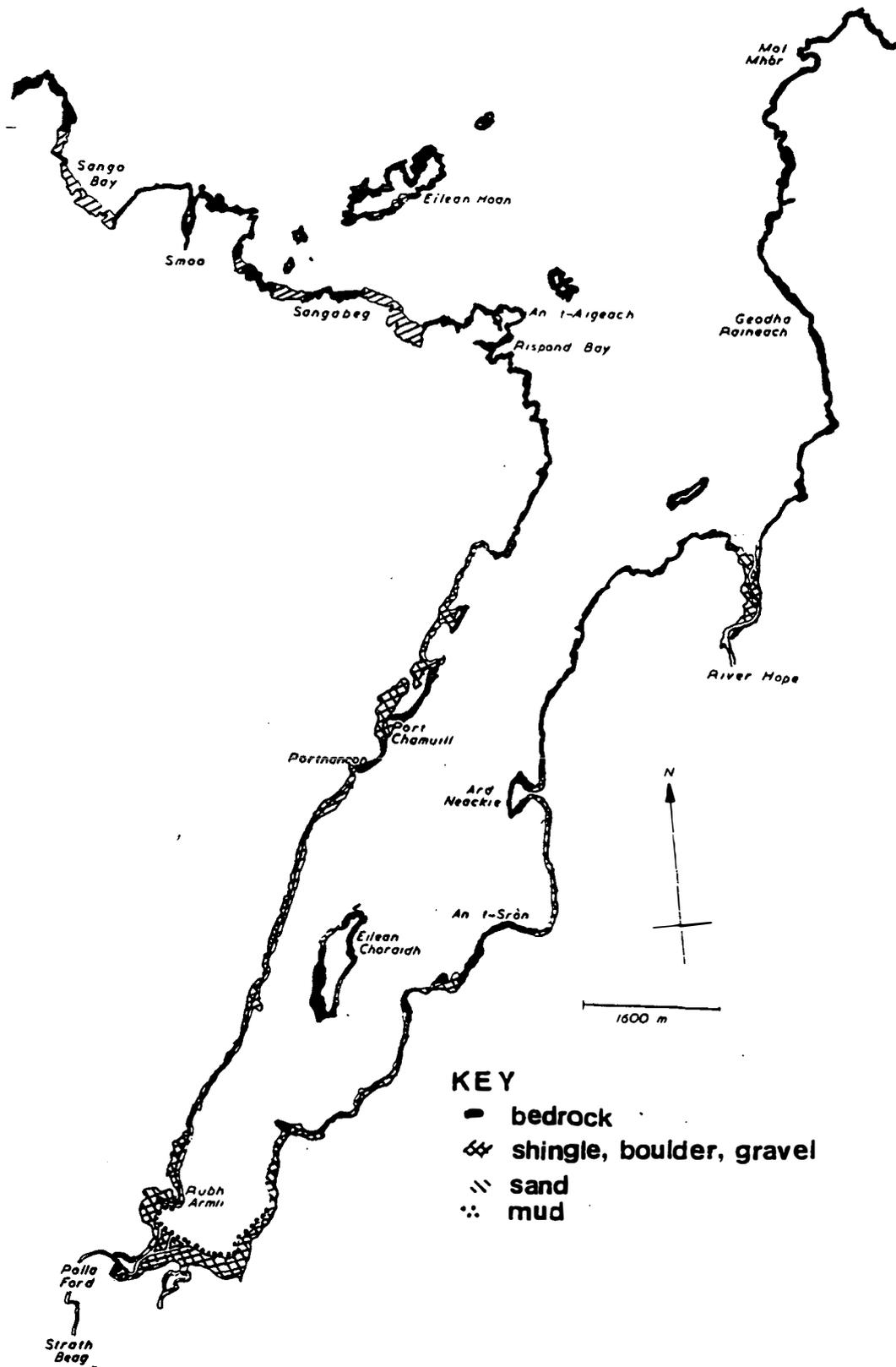


Figure 7 The distribution of littoral habitat types within Loch Eriboll.

Arenicola marina, the bivalves *Pecten maximus*, *Chlamys opercularis* and brittle star beds. Sparse patches of maerl occurred in hollows in muddy sand. Soft mud was found in deeper parts of the loch with the sea pen *Virgularia mirabilis* and the Dublin Bay Prawn *Nephrops norvegicus*.

Loch Eriboll has been selected as a Marine Consultation Area (MCA) (NCC 1990). It is the most northerly deep water sea loch in Great Britain and the only loch on the north coast of Scotland. Outcrops of limestone with vertical walls, gullies and caves add to the diversity of habitats and support rich animal communities. The northern recorded limits in Britain for the red algae *Naccaria wiggii* and *Schmitzia hiscockiana* are for Loch Eriboll.

Kyle of Tongue The Kyle of Tongue is another shallow but deeply penetrating inlet with extensive sand banks exposed at low water. No marine biological information is available for this area.

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3 EAST SCOTLAND

3.1 Introduction

The east Scotland sector extends from Duncansby Head in the north to Dunbar in the south and includes the Moray Firth, the Firth of Tay and the Firth of Forth (Figures 8, 9 and 10).

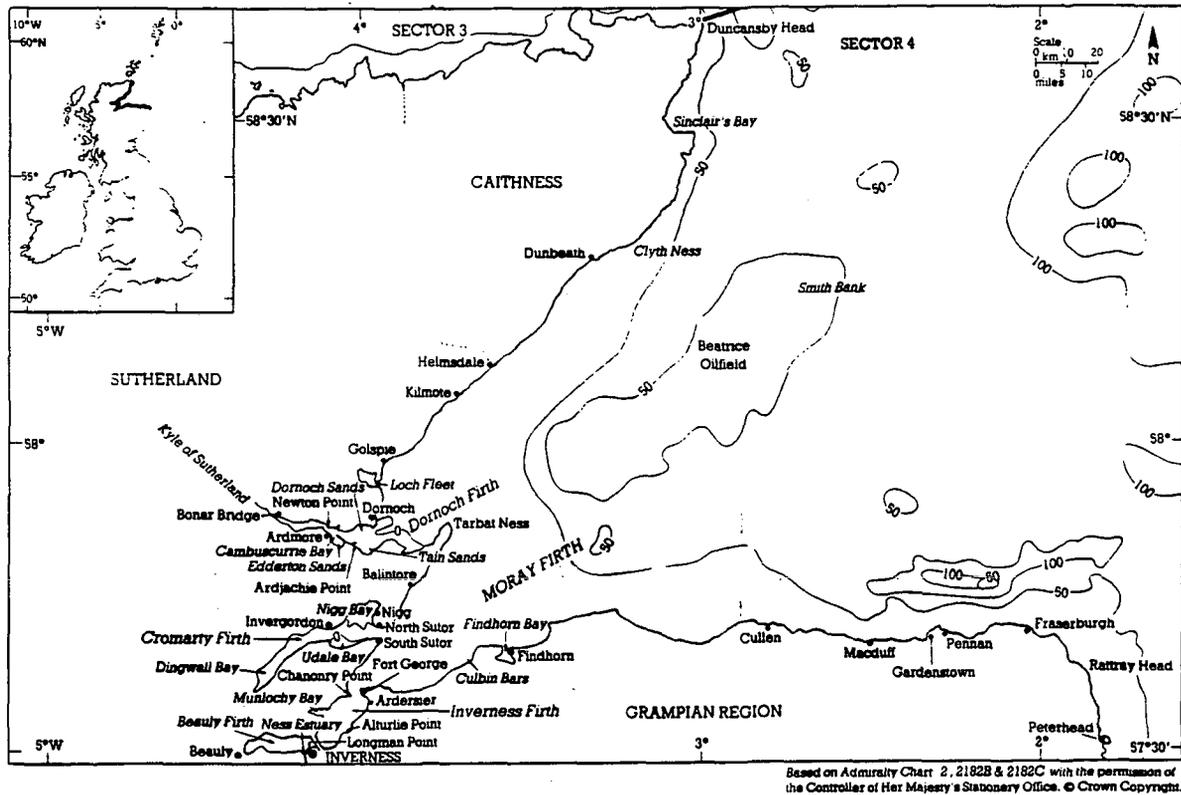
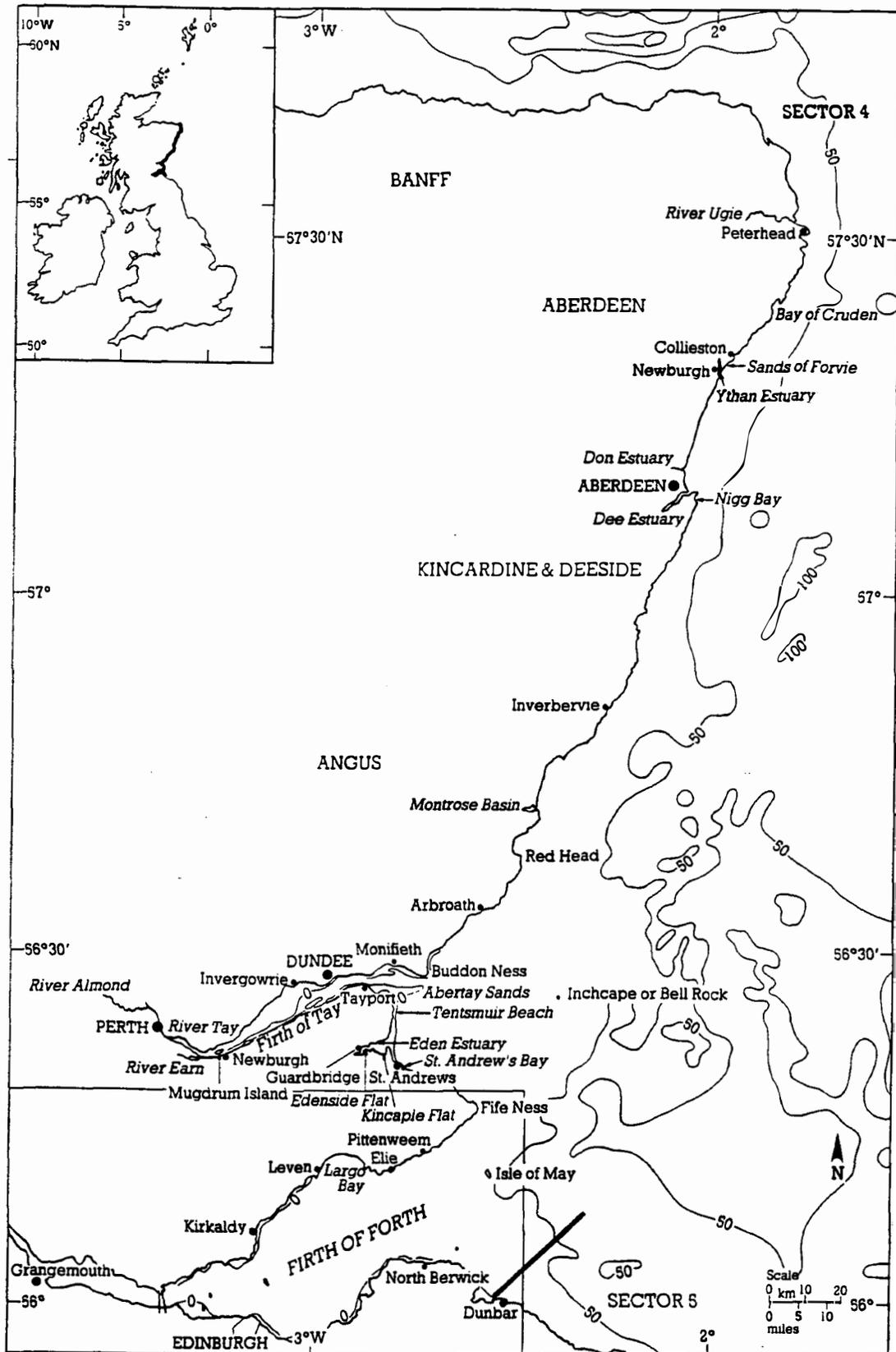


Figure 8 The location of places in the Moray Firth on the east coast of Scotland named in the text.

A few studies have been carried out for the whole coast of east Scotland. Beaches of north-east Scotland from Inverberrie to Inverberrie have been described in terms of the physical environment and recreational pressures by Ritchie, Smith and Rose (1978). Eleftheriou and Robertson (1988) have surveyed 11 sandy beaches between Sinclair's Bay and Belhaven and described the environmental conditions and faunal characteristics. The distribution of littoral and sublittoral Mollusca for east Scotland has been reviewed by McKay and Smith (1979).



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Figure 9 The location of places on the east coast of Scotland, except the Moray Firth and Firth of Forth, named in the text.

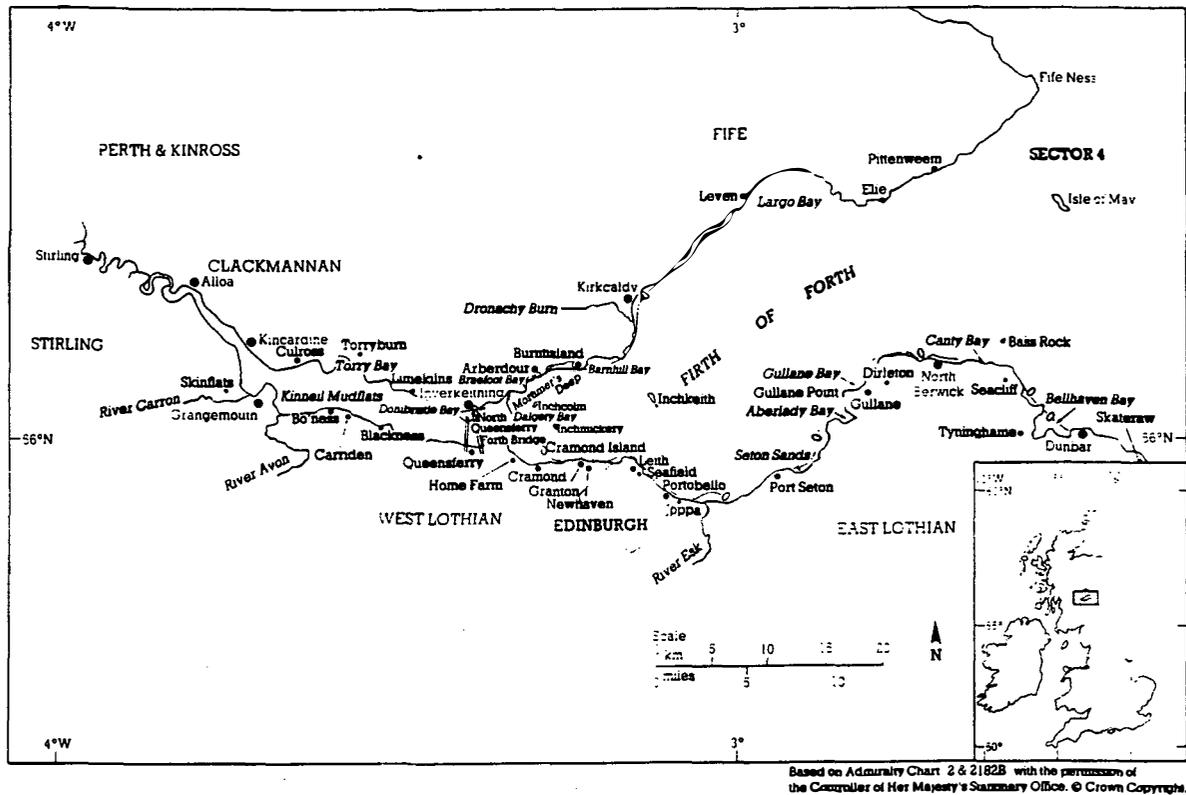


Figure 10 The location of places within the Estuary and Firth of Forth named in the text.

The sediments and fauna for three fishing grounds located off the Scottish east coast have been surveyed by McIntyre (1958). The areas at Aberdeen and St Andrew's had fairly uniform deposits varying from muddy to fine sand, with that of the Aberdeen areas being slightly coarser. The fauna in the two areas was dominated by lamellibranchs and polychaetes and was found to be richer off Aberdeen. The third area sampled was the Smith Bank where the sediments varied from sandy mud to gravel and the fauna was numerically dominated by the sea urchin *Echinocyamus pusillus* but dominated by polychaetes and molluscs in biomass.

3.2 Moray Firth

Introduction The Moray Firth is generally regarded as that area of coastline and open water falling within the area bounded by Duncansby Head in the north, Beaully Firth in the south-west and Fraserburgh in the south-east. The coastline of the Moray Firth varies from high cliffs and rocky shores to sweeping sandy beaches and dunes with the sheltered inlets of Dornoch, Cromarty, Inverness and Beaully Firths. Water flows in a clockwise

direction around the Moray Firth on flood tides and anticlockwise on ebb tides. A summary of the available information at the time on the oceanography, geology, topography and intertidal and coastal habitats of the Moray Firth is given by Probert and Mitchell (1980). The main communities characteristic of rocky and sediment shores of varying exposure to wave action are described and shores of nature conservation importance considered. These shores are described below. A bibliography covering the marine life, coastal environment and industrial impact of the Moray Firth is given by Clokie (1981). In 1985 the Royal Society of Edinburgh held a symposium on the marine environment of the Moray Firth which brought together the current knowledge at the time (Ralph 1986). Topics covered coastal topography, hydrography and plankton, rocky and sedimentary shores, the sublittoral environment in the vicinity of the Beatrice Oilfield and pollution especially in relation to the oil industry.

Open Coast Invertebrate fauna, in particular molluscs, crustaceans and echinoderms, and species of fish have been listed for the Moray Firth since the 1850s (Gordon 1852a, 1852b, 1852c, 1853a, 1853b; Palmer 1977).

The more sheltered areas within the Moray Firth are the inlets and firths which tend to contain sedimentary shores while the open coast tends to be rocky. Sediment shores between Kilmote in the north and Cuthill Links in the south have been described by Smith and Mather (1973) in relation to tourism, recreation, development and conservation value. The 11 areas studied were found to be relatively stable but all under some form of human pressure.

Both sedimentary and rocky shores between Duncansby Head and Peterhead were surveyed by the Scottish Marine Biological Association/Marine Biological Association Intertidal Survey Unit for the NCC (Bartrop et al. 1980) as part of a survey of the littoral zone of Great Britain. Shores were described and sites considered to be of marine biological importance were identified. None of the sedimentary or rocky sites chosen for their scientific interest were considered of national importance but were thought to be representative of the area. Sediment shores of note were Loch Fleet, Lower Cromarty Firth, Munloch Bay, Ardersier, Culbin Bars and Findhorn Bay. All of these sites were sheltered or very sheltered from wave action, except Culbin which rated as moderately exposed. Bartrop et al. divided the sedimentary shores into four main categories characterised by an associated community:

- a crustacean-polychaete community occurring in areas of moderate exposure to wave action and containing a low density amphipod-isopod and/or polychaete fauna;
- an *Angulus* (*Tellina*) community characteristic of clean sand and including the bivalves *Angulus tenuis* and *Donax vittatus*, the polychaete worms *Arenicola marina* and *Nephtys caeca* and the amphipod *Bathyporeia* spp.;
- an *Arenicola* community which included the polychaete worms *Arenicola marina* and *Nephtys hombergii* and the bivalves *Macoma balthica* and *Cerastoderma edule* and occurred in muddy sand;

- a muddy *Scrobicularia* community characterised by the peppery furrow shell *Scrobicularia plana*, the sand gaper *Mya arenaria* and the ragworm *Hediste (Nereis) diversicolor*.

Rocky shores considered to be of conservation interest by Bartrop et al. (1980) were Helmsdale, Tarbat Ness, Cullen, Gardenstown and Pennan. These sites were all exposed or moderately exposed to wave action (shores of extreme shelter or exposure to wave action were lacking) and were representative of rocky shores within the Moray Firth. The rare fucoid alga *Fucus distichus edentatus* was recorded at Macduff Harbour. Exposed rocky shores supported a well developed lichen zone, an abundance of the rough periwinkle *Littorina saxatilis* agg., the fucoid alga *Fucus vesiculosus* f. *linearis*, the mussel *Mytilus edulis*, the barnacle *Semibalanus balanoides*, a range of red algae including *Mastocarpus (Gigartina) stellatus* and *Ceramium shuttleworthianum* and the large brown algae *Laminaria digitata* and *Alaria esculenta*.

The upper shore regions of sheltered rocky shores were generally poor in species richness and this was considered to be due to the desiccating conditions which pervade in summer. The brown algae *Pelvetia canaliculata*, *Fucus spiralis* and *Ascophyllum nodosum* were either poorly developed or sparsely distributed on these shores. The middle and lower shore regions tended to consist of a range of habitats including boulders, cobbles, overhangs and rock pools as well bedrock at varying inclinations. Consequently these shores supported a wide variety of species such as the brown algae *Fucus vesiculosus*, *Fucus serratus*, *Halidrys siliquosa* and *Laminaria digitata*, the red algae *Laurencia pinnatifida*, *Plumaria elegans*, *Membranoptera alata*, *Odonthalia dentata* and *Ptilota plumosa*, the green algae *Enteromorpha intestinalis* and *Cladophora rupestris*, the periwinkles *Littorina saxatilis* and *Littorina littorea*, the barnacle *Semibalanus balanoides*, the limpet *Patella vulgata*, *Mytilus edulis*, the dogwhelk *Nucella lapillus*, sponges *Halichondria panicea* and *Grantia compressa* and the tube worms *Pomatoceros triqueter* and *Spirorbis* sp.

In 1981 a major rocky shore monitoring programme in the Moray Firth was initiated in order to determine whether any changes occurring on the shores were attributable to oil pollution (Sphere Environmental Consultants Ltd 1981). Transects were established on 34 shores between Duncansby Head and Fraserburgh and were selected to cover the range of predominant physiographic features in the Moray Firth. These shores were mainly rocky but also included boulder and cobble shores and covered a range of exposures to wave action. The shores selected have been described along with their associated species by Sphere Environmental Consultants Ltd in 36 separate reports. Monitoring of the shores involving analysis of species distribution within permanent quadrats and quantitative studies on barnacle, limpet and mussel populations was carried out until 1986 (Aberdeen University Marine Studies 1983, 1984a, 1985a, 1986; Terry & Sell 1986; Terry 1987). Comparisons made between the data over the years showed most observed changes to be natural.

Smith (1981) briefly described 17 shores (predominantly rocky) between Dunbeath and Ballintore with particular reference to the Mollusca. A notable find was the presence of the gastropod *Rissoella diaphana* at four sites. This species had only previously been recorded from the east of Scotland at Cruden. The shores in this area were found to be similar to those between Aberdeen and the Firth of Tay but were poorer in species compared to the shores on the south side of the Moray Firth. McKay (1977) also listed Mollusca, both littoral and sublittoral, from the

Moray Firth including the North Sea to the east of a line from Duncansby Head to Rattray Head. A survey of the distribution and abundance of littoral invertebrates in sediment shores between Alturie Point and Findhorn Bay on the south side of the Moray Firth was carried out by Wells and Boyle (1974).

Intertidal angiosperms have been surveyed in the Moray Firth. A detailed study of the environmental conditions and vegetation on saltmarshes and sand/mudflats with particular reference to the sea grasses *Zostera noltii*, *Zostera angustifolia*, and *Ruppia* sp. and glasswort *Salicornia* sp. was carried out by the Department of Geography, University of Aberdeen (1970, 1972, 1974, 1976, 1978, 1981a, 1981b). The study was initiated to consider the effects of population growth, increased tourism and industrial development on the environment of the Moray Firth.

The Beatrice oilfield lies just 12.5 nautical miles from the coast south-south-east of Clyth Ness and is located on the south-west corner of Smith Bank. Being so close to the coast there is a potential threat to marine life in shallow waters and on the coastline from oil pollution. As a result, an environmental impact analysis was made by Sphere Environmental Consultants Ltd (1977) which involved a survey of the benthic fauna in the vicinity of Beatrice oilfield and a littoral sediment survey at potential terminal sites. The sand of Smith Bank was found to support an infauna dominated by the heart urchin *Echinocyamus pusillus*, the bivalve *Moerella pygmaea* and the polychaete *Ophelia borealis*. To the north-west the deposits were fine and supported the bivalves *Angulus tenuis*, *Nuculoma tenuis* and *Thyasira flexuosa*, the scaphopod *Antalis entalis* and the sea pen *Virgularia mirabilis*. Further work on the benthic fauna in the area has been carried out by several other workers (Hartley 1978; Bishop & Hartley 1986; Hartley & Bishop 1986; Cranmer 1987). Prior to oil production the benthic communities were found to be stable (Hartley & Bishop 1986). Drilling at the Beatrice oilfield resulted in drill cuttings polluting the seabed causing a gradient of effect on the benthos. Drilling ceased in 1985 and the environmental conditions improved as hydrocarbons on the seabed continued to degrade. Comparisons of survey data collected in 1985 and 1987 showed that the benthic macrofauna had responded to the improved conditions (Cranmer 1987).

Earll (1983) has provided a review of information on the shallow sublittoral zone of the Moray Firth based on published data, interviews with local workers and species records collected by divers. The shallow sublittoral was described in terms of the physical environment, habitats, communities and conservation importance. Information on the nearshore sublittoral was found to be sparse but available data would suggest the area to be lacking in terms of habitat diversity.

Loch Fleet Loch Fleet is a small shallow loch, with predominantly sediment shores, situated between Golspie and Dornoch. A study of the distribution and abundance of littoral invertebrates in the loch has been carried out by Wells and Boyle (1975). Most of the loch consisted of muddy sand, although clean sand occurred at the mouth and on a large sandbank. Mud patches and stony scalps were also present. The most common species recorded were oligochaetes, the polychaete worms *Arenicola marina*, *Fabricia sabella*, *Nephtys* spp., *Hediste* (*Nereis*) *diversicolor*, *Pygospio elegans* and *Scoloplos armiger*, the amphipods *Bathyporeia* spp. and *Corophium volutator* and the molluscs *Hydrobia ulvae*, *Cerastoderma edule*, *Mytilus edulis*, *Macoma balthica* and tellinids.

Dornoch Firth Dornoch Firth is very scenic with wooded hills bounding the shores extending into the narrow Kyle of Sutherland

above Bonar Bridge. Wide sandy beaches occur in the large bays at the entrance to the Firth. The abundance and distribution of littoral invertebrates in sediment shores has been studied by Wells and Boyle (1973). They identified 41 species, the most common ones being similar to those found in Loch Fleet. Rendall and Hunter (1986) also studied the littoral fauna in Dornoch Firth but only from two sites; these were located in Cambuscurrie Bay and Ardjachie. The main species found were the polychaetes *Scoloplos armiger* and *Pygospio elegans*, the oligochaete worms *Tubificoides benedeni* and *Akteredrilus monospermathecus* and the Baltic tellin *Macoma balthica*. A list of the littoral algae has been compiled by Currie (1974). A survey to show the distribution and density of *Zostera angustifolia*, *Zostera noltii*, *Ruppia maritima* and *Salicornia* spp. was carried out in 1986 (Fox, Yost & Gilbert 1986). *Zostera noltii* was very abundant on Edderton Sands while *Ruppia maritima* occupied the mud and muddy sand of the Dornoch and Tain Sands. *Zostera angustifolia* was the most common of the four species recorded and *Salicornia* spp. the least common.

The sublittoral sediment fauna has been investigated by the Highland River Purification Board (Hunter & Rendall 1986) from eight stations in the Dornoch Firth. The sediments of the firth were predominantly medium sands with low organic content except at the most landward site, Newton, where estuarine silt occurred. At Newton a sparse brackish water fauna of the polychaetes *Fabricia sabella*, *Hediste (Nereis) diversicolor*, *Pygospio elegans*, tubificids and nemertean worms was recorded. More species were found at Ardmore although conditions here were still brackish. Extensive *Mytilus edulis* beds occurred in the middle of the firth. Species characteristic of coarse or sandy substrata were prominent in the samples including the polychaete worms *Nephtys cirrosa*, *Chaetozone setosa* and *Glycera capitata*, the bivalves *Angulus (Tellina) tenuis* and *Chamelea (Venus) gallina* and the amphipod *Corophium crassicornis*. At sites exposed to wave action in the outer firth, the fauna was sparse and dominated by the bivalves *Fabulina (Tellina) fabula* and *Chamelea gallina*.

Cromarty Firth The Cromarty Firth is a long natural harbour, used during the two World Wars as an anchorage for the Royal Navy. Nowadays oil platforms are to be seen in the Firth as a result of the development of a construction yard and oil terminal at Nigg. The firth is estuarine above Invergordon but seaward of here the salinity is stable and the water deep, reaching about 50 m between North and South Sutor.

Two large intertidal bays, Nigg and Udale lie within Cromarty Firth. Surveys of the abundance and distribution of littoral macrofauna in the sediment shores and the environmental factors affecting their distribution have been undertaken in the two bays (Anderson 1971). Anderson recorded 34 species only six of which were abundant. Similar studies were carried out as a baseline for a biological monitoring programme to detect any changes as a result of industrial development in Nigg Bay (Boyle & Raffaelli 1981). Work was continued in 1982, 1983 and 1985 and comparisons made between the data (Raffaelli & Boyle 1982, 1985). These studies showed an increase in the silt content of sediments in Nigg Bay from 1981 to 1983 and a decline in 1985. Changes in the infauna mirrored those of the sediments with an increase in the density of species from 1981 to 1983 and a subsequent decline in 1985. They concluded that these changes were largely natural. The intertidal macrofauna of Nigg Bay has been summarised by Raffaelli and Boyle (1986). They considered the bay to have a rich fauna and to be biologically similar to other bays within the Moray Firth. The intertidal macrofauna of Cromarty Firth has also been studied by Rendall and Hunter (1986) from three sites,

Udale Bay and the east and west sides of Nigg Bay. Samples were taken from three different levels on the shore. The upper shore stations at Udale Bay and Nigg West were dominated by a single species, *Hydrobia ulvae*, while the middle shore stations at Nigg East were characterised by *Tubificoides benedeni*. Other frequently occurring species were *Scoloplos armiger* and *Macoma balthica*.

Zostera communities of Nigg Bay have been studied and maps of their distribution produced by Sphere Environmental Consultants Ltd (1981). An intensive study of *Zostera angustifolia*, *Zostera noltii*, *Ruppia maritima* and *Salicornia* spp. in Cromarty Firth was carried out in 1986 (Fox, Yost & Gilbert 1986). *Zostera angustifolia* was the most common eelgrass in the firth although *Zostera noltii* was found to be very dense in Nigg and Udale Bays. *Salicornia* spp. was locally abundant in Dingwall Bay. The distribution of littoral algae in Cromarty Firth has been studied by Currie (1974).

Studies in relation to the industrial (oil, gas and chemical) developments in Nigg Bay have involved a description of the hydrology of the area and intertidal ecology with respect to saltmarshes, *Zostera* beds, the macrofauna and conservation interests (O'Sullivan & Kelly 1981). The rich variety of invertebrate fauna was thought to be related to the diversity of sediment types present within the bay. Other work in Nigg Bay has been in direct association with the Nigg Terminal. The fouling of the Nigg Terminal jetty pilings has been analysed by Aberdeen University Marine Studies (1984b, 1985b). Fouling has been studied by surveying the distribution of species and community composition with depth, measuring the growth of the organisms, evaluating patterns of fouling and predicting future fouling. This work has been summarised by Picken (1986). From 0 to 6 m below chart datum fouling consisted of mussel beds overgrown with seaweed and from 6 to 26 m barnacles and tubeworms were overgrown by anemones, soft corals and hydroids. Over the study period there were no significant changes in composition of fouling organisms but substantial increases in the thickness of fouling was observed. Buoys in the approaches to Cromarty Firth were completely covered by algae and mussels.

Sublittoral sediment fauna has been monitored by the Highland River Purification Board (Hunter & Rendall 1986). Six stations within the firth were studied. At Invergordon the sediment tended to be sandy with the bivalves *Fabulina fabula* and *Gari fervensis*. Further seawards the seabed consisted of stable mud with scattered clinker and a fauna characterised by the bivalve *Abra alba*. The coastline narrows where it enters the sea resulting in strong tidal currents; here the sediment consisted of firm sand. Species recorded in this area included the polychaete worms *Ophelia borealis*, *Aonides oxycephala*, *Glycera capitata*, *Prionospio cirrifera*, *Microphthalmus* sp. and *Nephtys longosetosa* and the amphipod *Atylus falcatus*. East of the entrance to the firth the sediments were finer and the diversity of species was low.

Inverness Firth Inverness Firth extends from Inverness to Fort George. On the north side lies Munlochy Bay which has been studied for the distribution and abundance of littoral invertebrates (Boyle & Goodman 1977). Characteristic species of the area included glasswort *Salicornia* spp., the green alga *Enteromorpha* spp. and the bivalves *Mytilus edulis* and *Cerastoderma edule*. Monitoring within the firth in relation to the Inverness main drainage scheme has involved studies of the hydrography, water quality and communities (Highland River Purification Board 1985a, 1985b). Fauna of the beaches by the sewage outfall at Longman Point were found to be damaged by

pollution. Fewer species than normal occurred and large numbers of the pollution tolerant worms such as the polychaete *Capitella* sp. were found as well as *Enteromorpha* spp. Rendall and Hunter (1986) studied seven sediment sites within Inverness Firth in relation to the Inverness sewage discharge. Samples were taken from three different levels on the shore. The lower shore station located by the outfall was severely affected by the discharge having a very low species richness and diversity. The station was dominated by *Capitella capitata*. Species which commonly occurred at other sites were the polychaete *Pygospio elegans*, the oligochaete *Tubificoides benedeni*, and the molluscs *Hydrobia ulvae* and *Macoma balthica* as well as *Capitella capitata*.

The sublittoral sediment fauna has been investigated by the Highland River Purification Board (Hunter & Rendall 1986). In the inner part of the firth the seabed consisted of stones overlying clay. Alturie Deep was muddy with a community of the molluscs *Abra alba* and *Nucula* spp. and the polychaetes *Terebellides stroemi* and *Nephtys hombergii*. Further seaward the sediment became coarser and sandy with species such as the amphipod *Corophium crassicornis* and the polychaete worms *Myriochele oculata* and *Lanice conchilega*. In the narrows between Chanonry and Fort George the seabed consisted of firm sand with some coarser particles. A variety of species occurred in the strong currents including bryozoans and the polychaete worms *Aonides oxycephala*, *Glycera capitata* and *Microphthalmus similis* although some patches of sand supported very little life. Just outside the firth at Fort George the sediment was sandy and dominated by the thick trough shell *Spisula solida*.

Beaully Firth Beaully Firth lies between Beaully and Inverness. An intensive study of the distribution and density of *Zostera angustifolia*, *Zostera noltii*, *Ruppia maritima* and *Salicornia* spp. has been carried out by Fox, Yost and Gilbert (1986). The most common eelgrass within the firth was found to be *Zostera angustifolia*.

Hunter and Rendall (1986) studied the sublittoral sediment fauna at three sites towards the seaward end of Beaully Firth. The Beaully basin consisted of muddy sand with a rich fauna. In the Ness estuary the sediment was found to be black and anoxic with contamination by sewage solids. The polluted conditions were reflected in the species found which included tubificid worms, capitellids and nematodes. Towards the entrance of Beaully Firth the seabed was stony with a fauna containing the epifaunal polychaetes *Lepidonotus squamatus*, *Harmothoe* spp. and *Lepidonotus clava*, bryozoans and the hydroid *Dynamena pumila* which was colonised by the mussel *Musculus discors*.

3.3 Open coast

This section covers the coastline from Fraserburgh at the south-east entrance of the Moray Firth to Fife Ness at the northern point of the Firth of Firth. The coast is characterised by a mixture of rock and sand with several small estuaries and numerous little bays.

In 1975 the marine algae of the Grampian Region were recorded (Wilkinson 1979). From comparison with previous records, 80 new species were found for the area including the brown alga *Sorapion kjellmanii* which had not been recorded in Britain before.

The vertical and horizontal distribution of the meiofauna in the sediments at Collieston has been studied by Seaton (1975). The meiofauna showed a patchy distribution probably due to local variation in sediment structure.

Aberdeen serves as a base for the North Sea oil industry and is an important fishing port. The local sediment shore of Nigg Bay has been a site for many investigations, mainly on individual species, by students of the University of Aberdeen. The intertidal macrofauna of Aberdeen Beach was found to be dominated by the spionid *Nerine* sp. and the amphipod *Haustorius arenarius* (Hart 1971).

The algae of the district of Arbroath which is bounded by Red Head in the north and Arbroath Bay in the south have been listed by Jack (1890).

Much work has been undertaken in the vicinity of the Gatty Marine Laboratory at St Andrews. However work on the marine life in the area was started before the establishment of the laboratory with the interest of Professor W C McIntosh who produced several papers on the fauna of St Andrew's Bay (McIntosh 1865, 1875, 1893, 1926, 1927a, 1927b). Dunn (1939) recorded the algae from the shores of St Andrew's Bay and additions to the list for the area were provided by Blackler (1951, 1956). An amalgamation of all records of fauna and flora collected for St Andrews Bay was undertaken by Laverack and Blackler (1974).

The sediments and fauna at Bell Rock have been extensively studied in relation to the sludge dumping grounds in this area (various reports on behalf of Lothian Regional Council summarised by Moore & Davies 1987). The monitoring involved chemical analysis of the sediments, a quantitative analysis of the fauna and a video recording of the benthos. The sediments consisted of fine to medium grained sands. Over 300 species have been recorded from the area. Moore and Davies (1987) considered that the sediments and benthic macrofauna in the vicinity of Bell Rock had not appeared to have been adversely affected by the dumping of sewage sludge.

3.4 Small estuaries and inlets along the open coast

The distribution of furoid algae has been described for the Ugie (Peterhead), the Ythan (Newburgh), the Don (Aberdeen) and the Dee (Aberdeen) estuaries (Chatter 1927). The Ugie and the Don were similar in that they were both small estuaries supporting an abundance of the furoid alga *Fucus ceranoides*. Much of the Ythan consisted of muddy shores but where rock occurred it supported a variety of furoids. A range of furoid algae also characterised the lower part of the Dee estuary while only *Fucus ceranoides* penetrated the estuary beyond Victoria Bridge.

The Ythan Estuary, which is particularly important for its waders and wildfowl, forms part of the Sands of Forvie and Ythan Estuary National Nature Reserve. Many studies have involved investigating the distribution and feeding of various bird species in relation to the distribution and productivity of the invertebrate fauna in the mudflats (Chambers 1965; Goss-Custard 1966; Heppelston 1968; Milne & Dunnet 1972; Joffe 1978; Greenstreet 1986). The amphipod *Corophium volutator*, the gastropod *Hydrobia ulvae*, the polychaete *Hediste (Nereis) diversicolor* and the Baltic tellin *Macoma balthica* were found to be widely distributed while other species such as the common cockle *Cerastoderma edule*, the edible periwinkle *Littorina littorea*, the shore crab *Carcinus maenas* and the common mussel *Mytilus edulis* had a more restricted distribution. Other investigations covered the distribution and abundance of individual species, such as the sand goby *Pomatoschistus minutus* and the common goby *Pomatoschistus microps*, in the estuary.

The invertebrate fauna of the Dee estuary has been studied by Eleftheriou (1964). The maximum densities of marine, estuarine

and freshwater species were found at the mouth, middle and head of the estuary respectively. Analysis of faunal samples taken from intertidal stations along the Dee revealed that the Dee only supported 1/5 th to 1/10 th of the macrofauna common to long estuaries such as the Tees in Cleveland (Milne 1940).

The Montrose Basin, linked to the sea by a narrow channel, is shallow and drains completely at low water exposing approximately three square miles of mudflats important to bird life. A thorough investigation of the fauna and flora showed the Basin to have a rich estuarine fauna (McLusky & Roddie 1982). The fauna was dominated by *Hydrobia ulvae*, *Corophium volutator* and the sabellid worms *Manayunkia* sp. and *Fabricia sabella*. Based on this first study, a further quantitative survey of the invertebrate community was carried out (Milligan 1984). Population levels varied spatially depending on local conditions. Changes in abundance of certain species had occurred compared to the previous survey due to a drop in the level of organic enrichment.

The littoral zone of the Eden estuary has been studied in relation to shorebird feeding (Johnston, Cobb & Bell 1979). The sediment shores mainly fell into two areas, Edenside Flat and Kincapple Flat. Three main sediment types occurred; heavy black mud and mud cover the majority of the area and firm sand was located at the high water mark and further seaward. Only a few estuarine species, such as the rag worm *Hediste (Nereis) diversicolor* and *Corophium volutator*, which are tolerant of low salinity were found towards the head of the estuary 3 km inland from Guardbridge. High densities of *Corophium volutator* occurred at Edenside Flat while in the more saline area of Kincapple Flat *Cerastoderma edule* and *Macoma balthica* were widespread. Sea grass *Zostera marina* only occurred in limited abundance on Kincapple Flat. On the north side of the estuary the shores were dominated by fucoids. Mussel beds occurred on the banks of the river channel.

3.5 Firth of Tay

The Firth of Tay has its upper limit at Perth and lower limit at Buddon Ness on the north side and Abertay Sands on the south.

The majority of studies in the Firth of Tay have been carried out by the University of Dundee. Work has included investigations on the environment, plankton, species distribution, single species and pollution.

Cunningham (1895) provided one of the first descriptions of the physical environment of the Tay Estuary covering the dimensions, sediments, catchment area, tides and currents. The salinity of the Tay has been reported by Mill (1885). An account of the geological development of the Tay with reference to sediments in the bed of the estuary has been provided by McManus (1966, 1972). Ordinary spring tides penetrate the estuary to the junction of the Rivers Tay and Almond. The bed of the estuary in this region was found to consist of highly compacted clays over which boulders, pebbles and sand were found. Below Perth the coarse sands and fine gravels formed bars. Solid rock occurred in the channel and along the south side of the estuary between Perth and Newburgh. Coarse debris from the River Earn was found deposited as a river-mouth bar. From Mugdrum Island to Invergowrie Bay there was a wide expanse of mudflats. The channel was found to be lined with waved coarse sands.

The bathymetry, sediments and species of the Tay have been described and mapped by Buller, McManus and Williams (1971). Sediments were divided into three zonal areas; saltmarshes, upper

tidal flats, and lower tidal flats. The north shore of the estuary was composed of mud and sand flats while the south shore ranged from bedrock to mud. The macrofauna of the sediments at Invergowrie and Monifieth have been studied in relation to the Invergowrie sewage outfall (McManus et al. 1985; Jones, McManus & Herbert 1986). Only species in the immediate vicinity of the outfall appeared to be affected by the discharge. An investigation of the sediments and fauna on the southern shore of the Firth of Tay between Tayport and Tentsmuir Beach showed that the distribution of both live and dead organisms gave a good indication of sediment type and stability (Green 1975).

The distribution of fauna and flora in the littoral and sublittoral zones was surveyed during the spring and summer of 1973 (Khayrallah & Jones 1975). Salinity and substratum type were the main factors affecting the distribution of species. A study of *Bathyporeia pilosa* in the showed it to be widely distributed in the littoral sediments of the Tay (Khayrallah 1977). Much of the sublittoral had little or no infauna due to the instability of the coarse sediments present (Khayrallah & Jones 1975). The most prominent sublittoral populations were found to be *Mytilus edulis* in the middle and outer estuary (Figure 11).

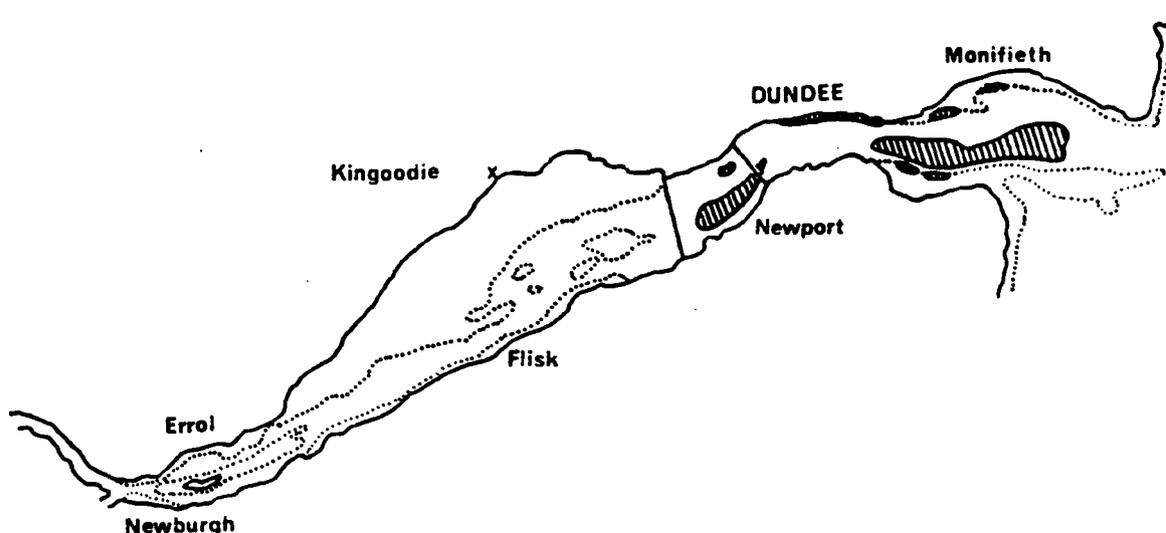


Figure 11 The distribution of major mussel *Mytilus edulis* beds in the Tay Estuary (reproduced by permission of the Royal Society of Edinburgh, N. Khayrallah and A.M. Jones from the Proceedings of the Royal Society of Edinburgh, volume 75B, page 127).

3.6 Estuary and Firth of Forth

Introduction The Estuary and Firth of Forth is defined as the area from the upper tidal limit at Stirling seaward to Fife Ness in the north and Dunbar in the south. The estuary is regarded as the area from Stirling to the Forth Bridge with the section from Stirling to Kincardine Bridge as the upper estuary and the area between Kincardine and Forth Bridges as the lower estuary. The firth consists of the area from the Forth Bridge to the seaward limits.

Much industry has developed in the Firth of Forth especially around Edinburgh and Grangemouth. The wide opening of the Firth

narrows at Queensferry but is navigable through the deep channel up to Grangemouth. The shores and sublittoral environment of the Forth Estuary are mainly sedimentary. The coastline of the Firth of Forth is an undulating series of sandy bays with rocky headlands. In general, rocky shores occur mainly in the outer parts of the firth. The sublittoral environment is predominantly sedimentary apart from the rocky islands of Inchmickery, Inchkeith, Bass Rock and the Isle of May.

Most work in the Estuary and Firth of Forth has been concentrated in the last 20 years. A symposium held in 1985 on the natural environment of the Estuary and Firth of Forth brought together all available knowledge at the time (McLusky 1987a).

The geography and geology of the Firth of Forth has been described by Browne (1987). Much work on the hydrography and water quality of various parts of the Forth has been undertaken by FRPB (1979). Many studies undertaken in the Firth of Forth have been related to pollution.

Littoral rock Intertidal rocky areas are predominantly found in the Firth of Forth as opposed to the estuary. Work has tended to be in the form of studies of individual species or groups at restricted localities.

Some algal studies concentrated on the distribution of single species but more general surveys are described here. Traill (1880, 1881, 1882, 1883, 1885) brought together records of the algae of the Firth of Forth giving the habitat and locations where each species was found. Traill also made studies of the algae at specific locations including Joppa, Elie and Dunbar (Traill 1886, 1888, 1890). Elie and Dunbar were considered to be two of the richest localities for algae in the Firth of Forth. Rattray (1886a) described the distribution of algae from shores and dredged sublittoral areas. Rattray noted that the number of species and average size of species increased from the estuary seawards. Algae on the coast of Fife have been recorded by Lowe (1935). In 1961 and 1971 the algae were surveyed at Joppa and Dunbar and comparisons made with the records of Traill (Johnston 1972). A reduction in the number of species and size of individuals was found at Joppa which was considered to be due to the discharge of untreated sewage in the area. In contrast, the 74 species selected for comparative study from Traill's work of 1890 were still present in the 1961 and 1971 surveys. The marine algae of Elie were recorded by Wilkinson and Tittley (1979) from 11 shores in the area. In comparison with the survey by Traill in 1888, no difference was found in the species richness. Comparisons were also made with other sites in the Firth of Forth. At Dunbar no change was noted in the species richness. However at Joppa a great reduction had occurred attributable to the increased level of pollution in the area. The distribution of algae on natural and artificial substrata at Pittenweem, Leven, Newhaven, Granton, North Berwick and Dunbar was investigated by Rome (1979). Habitats described included sandstone, granite, wood, steel and concrete. The distribution of algae on the rocks in the vicinity of the estuary effluent outfall at Grangemouth was studied by Collington (1986). A gradient of change was observed in the algal community to the west of the outfall. The lack of filamentous algae in the vicinity of the outfall was considered to be due to the effects of the effluent. Algae collected from a variety of shores between Canty Bay and Dunbar have been listed by Norton (1976). Observations on vertical algal distributions in the Esk, Almond, Avon and Carron estuaries showed distinct bands of algae (Wilkinson et al. 1981). The main factor influencing these zones was considered to be the salinity. Wilkinson, Scanlan & Tittley (1987) have mapped and described the algae of the Forth with

respect to changing conditions. They found algal rich shores in the outer firth and the usual gradient of species with reducing salinity into the estuary. The richest shores in the inner firth were at South Queensferry and Braefoot. Two areas, Edinburgh and Kirkcaldy, were poor in species and this could be attributed to sewage pollution and coal mining activity respectively.

Records on the abundance and distribution of invertebrate fauna and fish species in the Firth of Forth have been produced since the 1830s (Parnell 1838; Leslie & Herdman 1881; Henderson 1884a, 1884b; Scott 1894, 1896; Clarke 1895). Naturalists have also recorded species from locations such as Granton and Joppa (Allan 1886; Lindsay 1886). Oyster and clam beds within the Forth have also been described (Fullarton 1889; Fulton 1896).

The Isle of May is a small island at the seaward end of the Firth of Forth. The algae of the island have been recorded by Rattray (1886b) and Russell (1962, 1964). Species distribution in relation to habitats has been described by Bennett (1989). Shores ranged from sheltered to exposed and were found to be predominantly rocky with a few boulder areas.

A few rocky shore surveys have been carried out in relation to pollution. The shore at Burntisland has been described by FRPB (1986a) to assess the possible effects of industrial pollution. Studies at Braefoot Bay by the Institute of Offshore Engineering (IOE) included descriptions of the rocky shores in the area (Appelbee & Johnston 1977; IOE 1982). In 1975 FRPB (M. Elliot pers. comm.) surveyed four shores at Queensferry. A survey of the fauna in the vicinity of Granton harbour showed the area to be poor in species due to the movement of effluent towards the shores (Smyth 1968). The rocky shores at Leith have been studied with respect to an industrial outfall (Craig 1974) where a limited range of species was found.

The locations of the more common species of nudibranch have been listed by Evans and Evans (1917). Smith (1976, 1977, 1978) has monitored the littoral Mollusca on the shores at Port Seton, Craigielaw, Aberlady Bay, Gullane, Dirleton, Seacliff, Skateraw, Tynninghame and Dunbar. The fauna of rocky shores in the Firth of Forth with particular reference to the distribution of Mollusca, especially littorinids, has been described by Berry and Smith (1987). They found that the diversity of mollusc species decreased from the mouth of the Forth westwards. This reduction in species diversity was correlated with a decrease in the diversity of both habitats and algal species and the increased turbidity of the water.

The habitats and communities of the rocky shores in Largo Bay, Inverkeithing, North Queensferry, Gullane and North Berwick have been surveyed by IOE (pers. comm.).

Littoral sediment The sediment shores of the Firth of Forth, in particular the Forth Estuary, have been extensively studied. Much of this work has been in association with the effect of effluents on the distribution of species.

The distribution and abundance of meiofauna in intertidal sediments has been described for a number of sites in the Firth of Forth including Inverkeithing Bay, the Kinneil mudflats at Grangemouth, Seafield, Aberdour, Limekilns, Kincardine, Bo'ness, Granton, Port Seton and Dunbar (Chong 1985; Long 1985; Mulhern 1982). In the vicinity of effluent outfalls the density and species richness of meiofaunal communities was greatly reduced. Mills (1988) described the changes in species composition along a pollution gradient on Kinneil mudflats. In 1982 Moore (1987) surveyed the meiofauna on the lower shore at 21 sites in the

Forth Estuary. The main groups of meiofauna found were nematodes, copepods, polychaetes and oligochaetes (Figure 12). Distribution of species was related to salinity and three zones were distinguished in the estuary with species characteristic of poly-, meso- and oligohaline conditions. In general the number of species decreased with increasing distance from the sea although a decrease in the number of species was observed at the industrial site of Grangemouth.

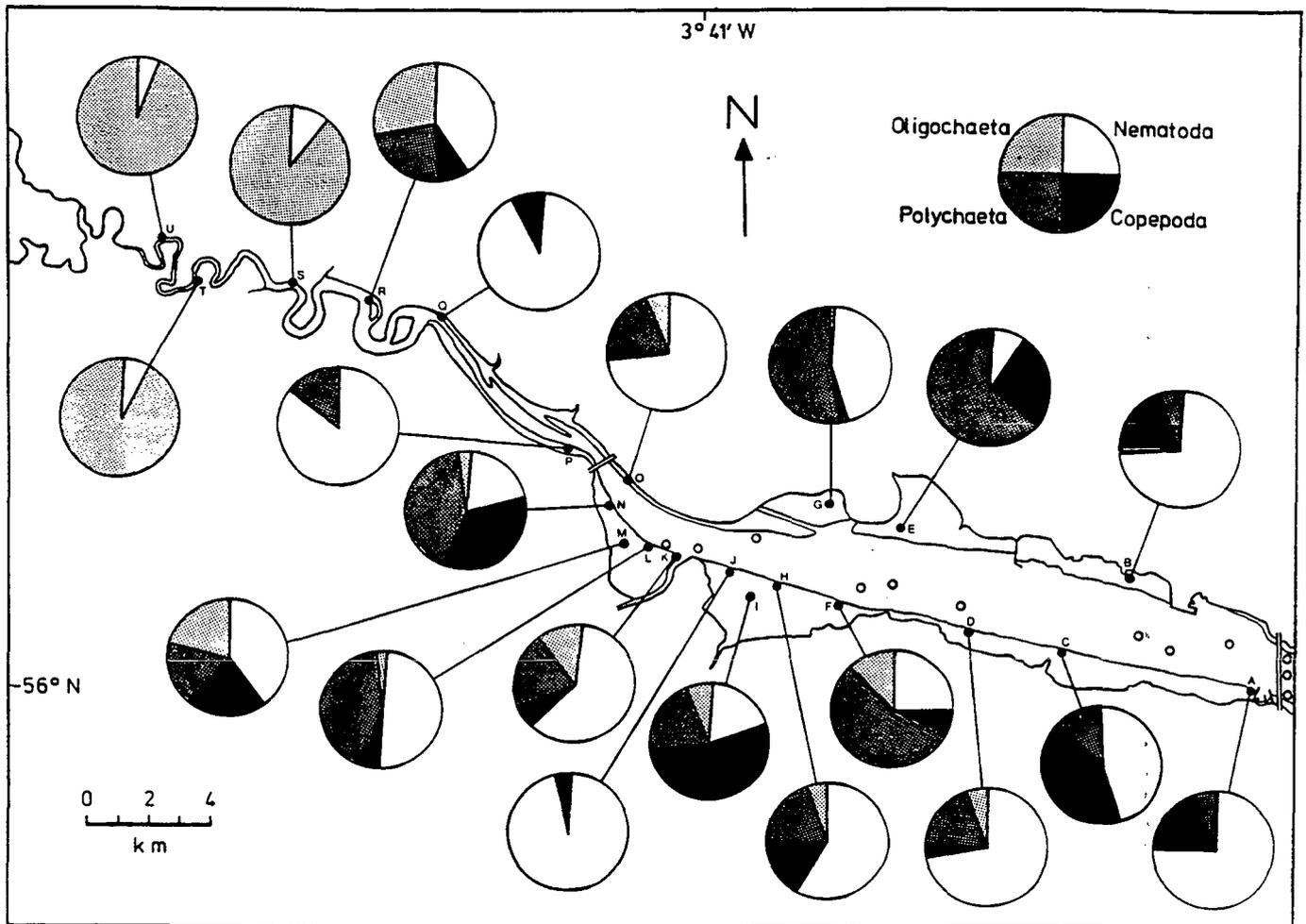


Figure 12 Composition of intertidal meiofauna by dry weight along the Forth Estuary in summer 1982; open circles indicate sublittoral survey sites (reproduced by permission of the Royal Society of Edinburgh and C.G. Moore from the Proceedings of the Royal Society of Edinburgh, volume 93B, page 417).

The sediment shores and macrofauna in the Forth Estuary have been described by McLusky (1987b). Intertidal sediments predominantly consisted of fine-grained muds and covered an area of 23.3 km², the majority occurring at Skinflats, Kinneil and Torry Bay. The salinity within the estuary ranged between 0 and 32‰. In the upper estuary the shores were narrow and organically enriched which favoured the abundance of oligochaetes. The middle estuary was the most productive area in terms of biomass of macrofauna while the lower estuary had the greatest diversity of species although a much lower biomass. The production/biomass ratio for several species in the Forth Estuary was lower compared to other estuaries which might have been due to the level of pollutants in the area.

The sediment shores of the Firth have been described and summarised by Read (1977, 1987). Shores tended to be poor in fauna which, in some areas, was due to sewage effluent. Four sediment shores, Cramond, Seafield, Portobello and Seton Sands, have been studied in detail in relation to the Edinburgh Sewage Scheme (Anderson et al. 1981). Before the introduction of the sewage treatment scheme the beaches exhibited a pollution gradient from Seafield which was grossly polluted through Portobello and Cramond to Seton Sands which was relatively unpolluted. A well developed tellinid community was present at Seton Sands and sandy parts of Cramond beach. In the muddy areas of Cramond beach with reduced salinity a Baltic tellin *Macoma balthica* community occurred. A tellinid community with reduced species diversity was found at Portobello and Seafield. The most polluted part of Seafield was dominated by the opportunistic polychaetes *Malacoceros (Scolelepis) fuliginosus* and *Capitella capitata*. After sewage treatment these two species declined and eventually disappeared. Moderate changes were noted elsewhere at Seafield and at Portobello while little change in the communities was observed at Seton Sands and Cramond. Shores west of Granton Harbour were also found to be poor in fauna due to the onshore movement of sewage from the Caroline Park and Granton Gas Works which occurred before the introduction of sewage treatment (Smyth 1968).

Many studies have been carried out to determine the influence of pollution or the effect of a new sewage scheme on the distribution of species. The distribution and abundance of macrofauna has been studied at Braefoot Bay, Dronachy Burn, Barnhill Bay, Dalgety Bay and Donibristle Bay (Appelbee & Johnston 1977; IOE 1982). Shores were found to have a relatively rich and diverse flora and fauna and were only mildly polluted. At Inverkeithing Bay the community changed with increasing distance from the origin of organic pollution with opportunistic species occurring near the point of discharge (Barne 1981). The fauna of the shores at Leith Sands have been studied in relation to effluent containing cadmium and inert particulate matter (Cleator 1986). Few species were found adjacent to the discharge but further away conditions favoured the colonisation by opportunistic species such as the polychaete *Mediomastus fragilis* and the oligochaete *Tubificoides benedeni*. Similar studies in relation to outfalls have also been carried out at Dunbar (FRPB 1981a), South Queensferry (FRPB 1981b), Inverkeithing Bay (FRPB 1984a), Burntisland (FRPB 1986a) and Gullane and Belhaven Bay (Read 1987).

The fauna of the Kinneil mudflats situated between Grangemouth and Bo'ness have been monitored in relation to oil refinery and chemical effluent by Stirling University since 1975 (summarised by McLusky 1987c). The distribution of the species on the mudflats has been described and comparisons made between data from different years. Data on the Kinneil mudflat fauna for the period 1976-1986 showed that faunal changes could be related to changes in the effluent discharge (McCrorry 1987; McLusky 1987c; McLusky & McCrorry 1987). In 1979 the old British Petroleum chemicals pipe closed and the pattern of effluent discharge was changed with a subsequent dominance by the polychaete *Manayunkia* sp. Within the ten year period there was an increase in species diversity and abundance in response to the improved environmental conditions.

The fauna of the mudflats has been studied at Skinflats, Carriden, Torryburn, Torry Bay, Culross and Blackness (McLusky & Brown 1974; McLusky 1978; McLusky & Bryant 1979). The mudflats between Carriden and Blackness were dominated by *Macoma balthica* and *Cerastoderma edule* (Teare 1975) while those at Skinflats, Kinneil and Torry Bay were characterised by *Manayunkia*

aestuarina.

A study of the distribution and population recovery of *Arenicola marina*, *Hydrobia ulvae* and *Macoma balthica* after bait digging has been investigated at Blackness (McLusky, Anderson & Wolfe-Murphy 1983). *Arenicola marina* rapidly recolonised holes created by digging but areas covered by mounds were not fully repopulated until they had been eroded. In contrast *Hydrobia ulvae* and *Macoma balthica* showed enhanced populations on the mounds.

The Forth Estuary as a whole has been considered in relation to pollution (McLusky, Elliot & Warnes 1978). They reported that the fauna upstream of Alloa, where an oxygen sag occurred, was dominated by oligochaetes and below Kincardine Bridge mudflat populations were characterised by *Hydrobia ulvae*, *Hediste (Nereis) diversicolor*, *Macoma balthica* and *Cerastoderma edule*.

In the lower estuary the distribution of *Hydrobia ulvae*, *Macoma balthica*, *Hediste (Nereis) diversicolor*, *Nephtys hombergii*, *Cerastoderma edule*, *Mytilus edulis* and *Mya* sp. has been described with reference to bird predators (McLusky et al. 1976).

The seasonal distribution and abundance of oligochaetes and small polychaetes in the estuary has been described (Phizacklea 1978; Bagheri & McLusky 1982). The most abundant species were the oligochaetes *Tubificoides benedeni*, *Amphichaeta sannio* and *Paranais litoralis* and the polychaete *Manayunkia aestuarina*. Breeding cycles and the availability of phytoplankton food influenced seasonal abundance. In the most polluted parts of the estuary oligochaetes were the only inhabitants of the mudflats whereas in the least polluted parts the numbers of oligochaetes decreased as the number and diversity of macrofauna increased (McLusky, Teare & Phizacklea 1980).

Sublittoral habitat The sublittoral habitats of the Estuary and Firth of Forth consist predominantly of sediment. The only areas of sublittoral rock are situated in the immediate area of the islands and in the shallow area off the coast of North Berwick. Most sublittoral benthic work relates to the sediments.

Various studies have been made on sublittoral sediments in the Firth of Forth. Small surveys have been carried out in relation to industrial and sewage outfalls. In 1972 the fauna in sediments between Cramond Island and Gullane Point were surveyed and the effects of sewage and industrial effluent described (Lowson 1972). Mortimer's Deep was found to be relatively rich in species (although dominated by just a few) and similar in community diversity to the surrounding area (Appelbee & Johnston 1977; IOE 1982). Sampling of benthic fauna took place at North Berwick (FRPB 1980), Kirkcaldy (FRPB 1981c) and Burntisland (FRPB 1983a) in relation to the siting of new sewage outfalls. A horse mussel *Modiolus modiolus* bed at Inchmickery, north-east of Cramond Island, has been studied in relation to heavy metal pollution (Barr 1982). Fewer numbers of species were found at Inchmickery compared to other *Modiolus* beds. A further study has been undertaken by Anderson (1986) on the meiofaunal communities in response to organic enrichment in the Firth of Forth. It was found that the diversity of meiofauna was greatly reduced in the area of pollution. In Largo Bay the meiofauna and macrofauna were recorded and a gradient of organic enrichment was found running south-west from the sewage outfall (Ellis 1986). The area of organic enrichment produced by the Leven Valley sewer was found to be elliptical with an inner grossly polluted zone characterised by large populations of opportunistic polychaetes and nematodes (FRPB 1987a). The sediments and fauna in the vicinity of the production water discharge diffuser off Kinneil,

which began discharging in 1982, have been monitored by FRPB since 1979 (FRPB 1982, 1983b, 1984b, 1985, 1986b, 1987b). With the installation of the diffuser and discharge of treated production water the sediments and fauna of the area changed. The species richness of the area increased and the community changed and eventually stabilised to that typical for this part of an estuary. Meiofauna still showed effects of disturbance in 1986 (FRPB 1987b).

FRPB have thoroughly surveyed the sediments and benthic fauna in the Forth Estuary (Elliot, Taylor & Davis 1981; Elliot 1983). Sediments consisted of sands and muds with shells, clinker, fly-ash and other debris. A decrease in the species diversity was found with decreasing salinity and from deep to shallow water. In general, polychaetes dominated the lower estuary and oligochaetes the upper estuary although certain groups such as tellinids and spionids dominated isolated patches of the sea bed. A depletion of benthic fauna occurred in areas around a sublittoral discharge point. Four species associations have been recognised by classification analysis in the Forth Estuary (Elliot & Kingston 1987). These were:

- a supra-estuarine association characterised by the polychaetes *Dodecaceria concharum* and *Neoamphitrite figulus* and *Abra alba* which occurred in the central and southern part of the estuary east of Bo'ness and into the main channel east to Inchcolm and westwards off Culross and Torry Bay;
- a similar but impoverished, in terms of species richness and abundance, supra-estuarine association which occurred along the northern and central part of the estuary east of Bo'ness;
- a stressed transition region off Kinneil Bay characterised by the polychaetes *Nephtys hombergii* and *Eteone longa*;
- a *Polydora*-oligochaete association characterised by the polychaetes *Polydora ligni*, *Polydora ciliata*, *Marenzelleria wireni* and tubificid oligochaetes which was recognised at the freshwater/brackish interface.

A detailed study of the distribution of benthic fauna in the Firth of Forth was undertaken by Heriot-Watt University in collaboration with FRPB (Kingston 1977). This work has been summarised by Elliot and Kingston (1987). The majority of the sediments were mud or muddy sand with most of the mud occurring off Edinburgh and between Inchkeith and Aberlady Bay. From Seton to Dunbar and Kirkcaldy to Fife Ness clean sands were found in the nearshore sublittoral. Muddy gravel accumulated in the deeper areas such as Mortimer's Deep while glacial clays were exposed by fast currents beneath the bridges. Four species associations have been identified by classification analysis in the Firth of Forth:

- an *Abra* community characterised mainly by the bivalve *Abra nitida* which covered the majority of the firth and which was split into two sub-groups, one a species poor *Abra* community and the other a variation of the *Abra* community dominated by the bivalve *Corbula gibba* and large numbers of

oligochaetes, and which occurred in the eastern part of the firth off Edinburgh;

- an *Echinocardium-filiformis* community which was found from Inchkeith curving north-west into Largo Bay and was dominated by the polychaete *Pholoe inornata* and characterised by the burrowing urchin *Echinocardium cordatum*;
- a *Venus* community which was found in two bands, one off Largo Bay and the other off Aberlady Bay;
- a *Crenella* association which was characterised by the bivalves *Crenella decussata* and *Timoclea (Venus) ovata* and the amphipod *Metaphoxus fultoni* and occurred as two isolated patches in the north and south parts of the mouth of the firth.

A *Modiolus* association was also recognised as occurring in the central part of the firth off Cramond. The distribution of these communities in the Estuary and Firth of Forth is shown in Figure 13.

The only sublittoral diving surveys reported within the Firth have been undertaken on the Isle of May where the habitats and communities were described (Conolly, Carey & Cobb 1979; Bennett 1989). On the north, east and south sides of the island gradually to steeply sloping bedrock gave way to a narrow band of boulders at 19 m leading onto a cobble or pebble shell gravel plain at 25 m (Figure 14). On the west side of the island vertical cliffs extended down to 3 m leading onto a steep boulder slope with a cobble and muddy shell gravel plain at about 14 m (Figure 15). Communities included kelp forests of *Laminaria hyperborea*, *Laminaria saccharina* and *Saccorhiza polyschides*, dead man's fingers *Alcyonium digitatum* dominated bedrock and boulders, communities characterised by the hydroid *Abietinaria abietina* and brittle star beds with *Ophiothrix fragilis* and *Ophiocomina nigra*. Two uncommon anemones, *Bolocera tuediae* and *Stomphia coccinea* occurred.

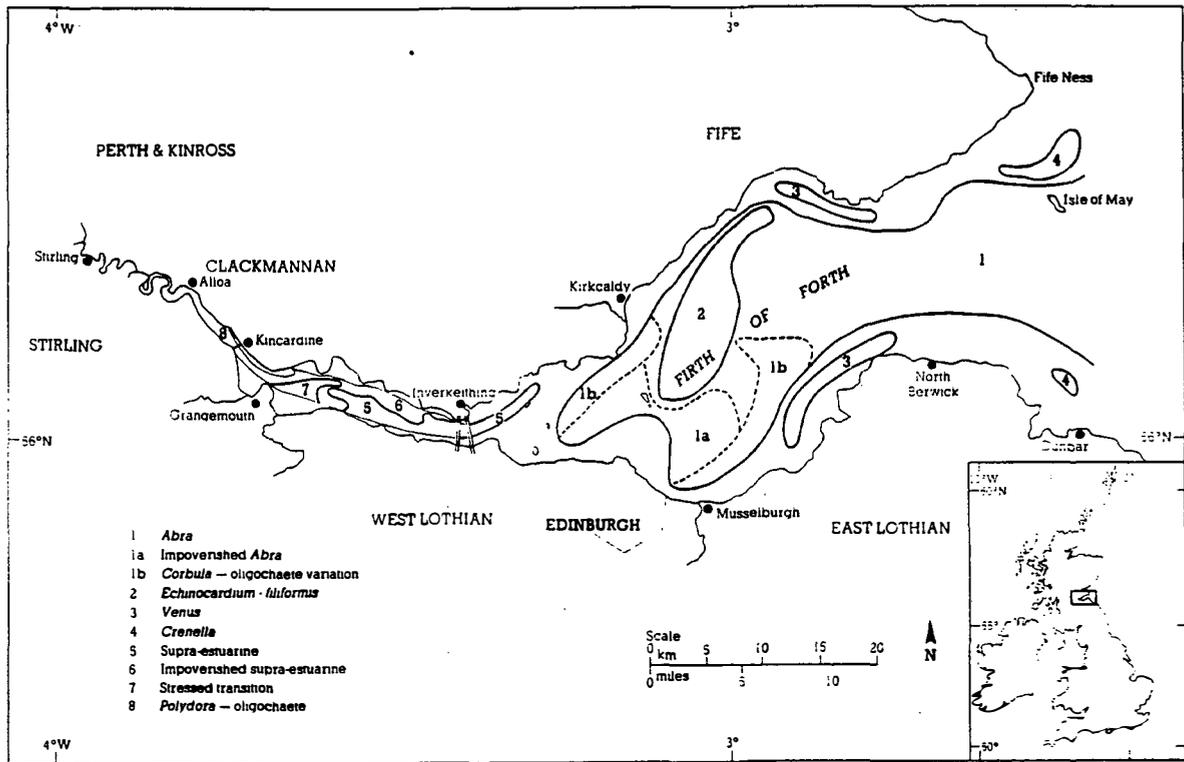
Plankton fish and seals The zooplankton of the Forth estuary has been studied by Taylor (1983, 1987) over an 18 month period to determine its composition and variability. The zooplankton was found to be dominated by a few genera of calanoid copepods. The estuary of the Forth was considered rare among British estuaries in that it supported a truly pelagic self-maintaining assemblage of zooplankton species.

The lower Forth Estuary was found to have a lower diversity of fish than other less polluted estuarine areas (Elliot and Taylor 1983, 1986; FRPB 1984c). Studies showed that the estuary was important as a nursery ground for flatfish and gadoids and an overwintering ground for clupeids. Poxton (1987) summarised the work on fish studies in both the Estuary and Firth of Forth. A total of 50 species were recorded, 36 of which occurred in the estuary and 39 in the firth.

The largest colony of seals in the Firth of Forth was found to occur on the Isle of May (Harwood and Wylie 1987). Many of these seals originally came from the Farne Islands.

Lagoons A study of lagoons in the vicinity of the Firth of Forth has been conducted by Wilkinson (pers. comm.). The brackish water pond at Home Farm, Bothkennar was studied by McLeod (1975).

Few species were found but two brackish water species, *Hediste (Nereis) diversicolor* and *Corophium volutator*, were identified.



Based on Admiralty Chart 2 & 2182B with the permission of the Controller of Her Majesty's Stationery Office. © Crown Copyright.

Figure 13 The distribution of sublittoral sediment communities in the Estuary and Firth of Forth (reproduced by permission of the Royal Society of Edinburgh, M. Elliot and P.F. Kingston from the Proceedings of the Royal Society of Edinburgh, volume 93B, page 458).



Foliose red algae



Abietinaria abietina



Encrusting Corallinaceae



Laminaria digitata



Alcyonium digitatum



Urticina felina



Laminaria hyperborea



Cerianthus lloydii



Laminaria saccharina



Lanice conchilega



Saccorhiza polyschides



Ophiothrix fragilis



Asterias rubens



Alaria esculenta



Echinus esculentus

Key to Figures 14 & 15

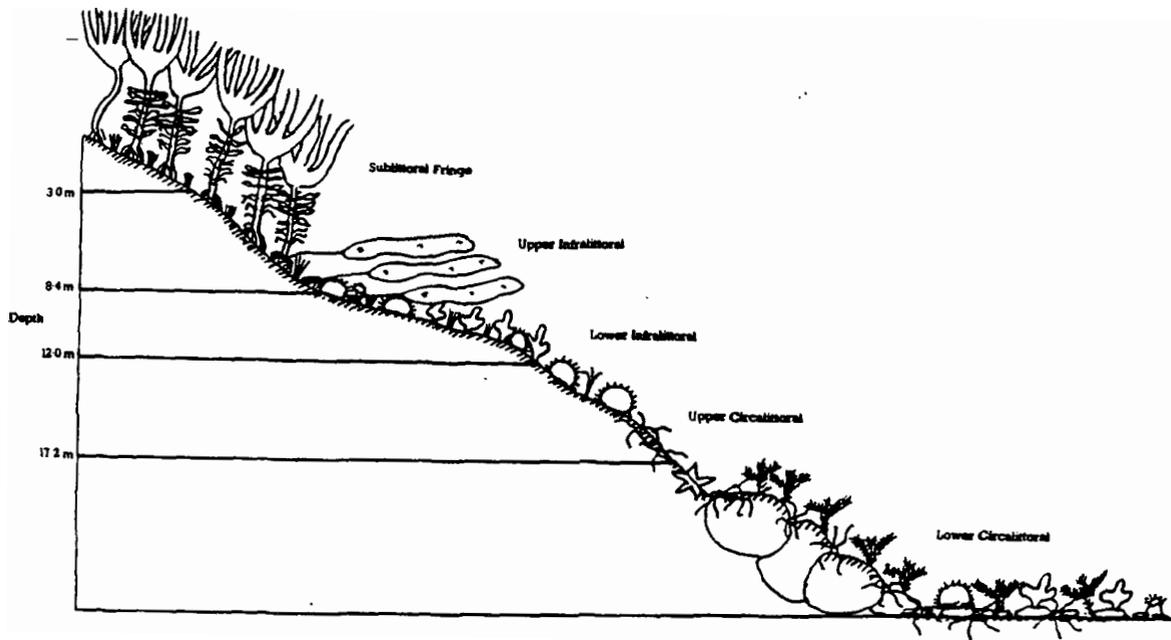


Figure 14 A generalised profile of the seabed on the east side of the Isle of May (from Bennett 1989).

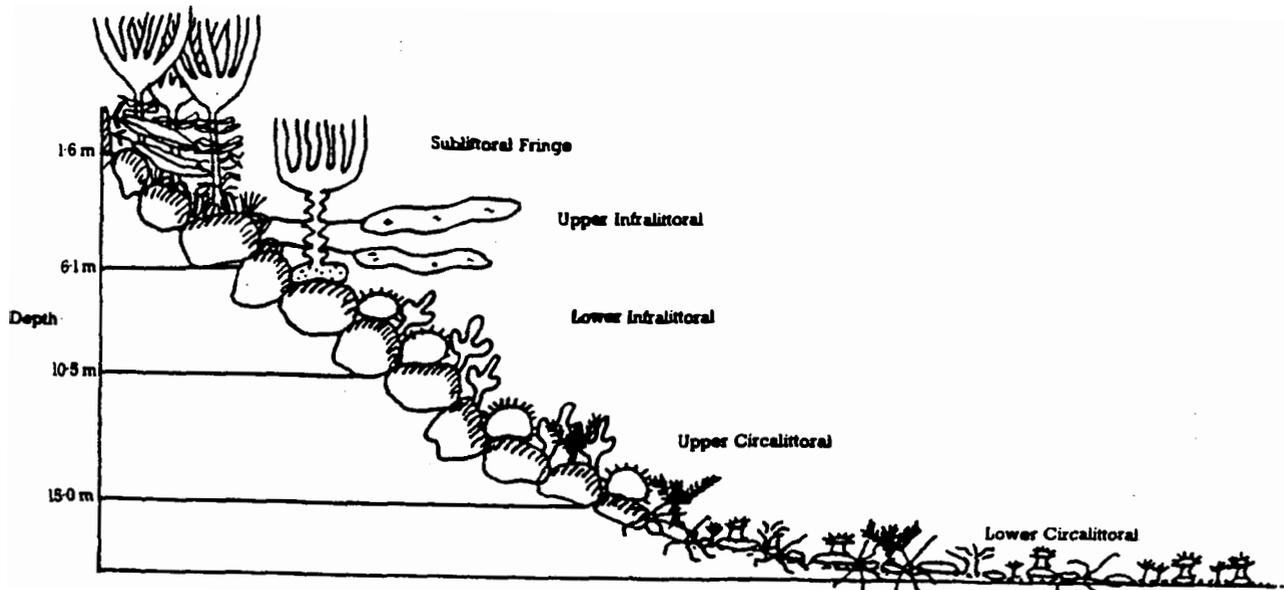


Figure 15 A generalised profile of the seabed on the west side of the Isle of May (from Bennett 1989).

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4 SOUTH-EAST SCOTLAND AND NORTH-EAST ENGLAND

4.1 Introduction

The south-east Scotland and north-east England sector extends from Dunbar in Lothian to Bridlington in Humberside (Figure 16). The coastline is relatively unbroken with only two major estuaries, the Tyne and the Tees, and several smaller ones. The only offshore islands are the Farnes situated off the Northumberland coast. Some parts of the coast are very industrialised, especially in the Newcastle, Sunderland and Middlesbrough areas, while others are important as holiday resorts, for instance Whitley Bay and Scarborough. However, there are also relatively undisturbed sections of the coastline especially in south-east Scotland, Northumberland and parts of North Yorkshire.

Much work on the Northumberland coast has been carried out from the Dove Marine Laboratory, associated with Newcastle and Durham Universities. Studies have also been undertaken in the vicinity of the Wellcome Laboratory which was located at Robin Hoods Bay and run by the University of Leeds.

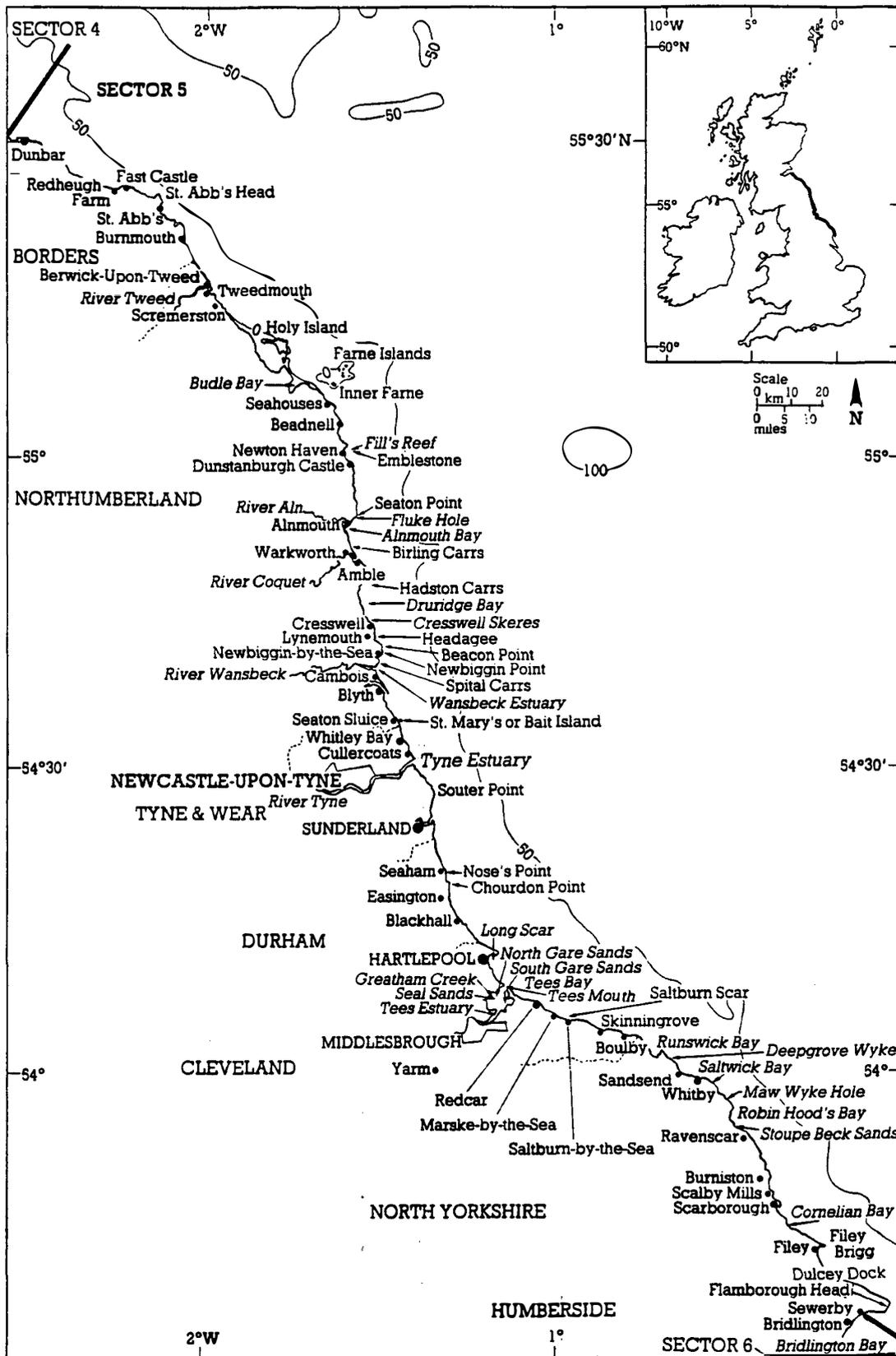
For convenience this section of the coast has been subdivided into 3 parts. However a few studies extended over the majority of this sector. Kelp holdfast fauna, in particular nematodes, bryozoans and crustaceans, has been investigated on the north-east coast of Britain between St Abbs Head and Flamborough Head (Moore 1971a, 1971b, 1972a, 1972b, 1973a, 1973b). Several studies by Jones (1969, 1970, 1971, 1972, 1973) have related the reduction in holdfast fauna to areas of increased pollution. Jones (1972) noted the existence of a pollution gradient between the Fife Ness and Flamborough Head; the Firth of Forth discharged industrial estuarine pollution, the Borders and north Northumberland coast was relatively unpolluted, south Northumberland, Tyne and Wear, Durham and Cleveland were chronically polluted and the North Yorkshire coast was turbid. However, Moore (1973c, 1973d) found a correlation between the composition of the holdfast fauna and turbidity. Correlations were also found between the composition of holdfast fauna and turbidity and heavy metal contamination by Shepherd, Bellamy & Sheppard (1980).

The environmental factors affecting the distribution of sea-thong *Himantalia elongata* along the coast between north Northumberland and Robin Hood's Bay have been investigated (Moss, Mercer & Shearer 1973). Silt was found to be a major factor inhibiting colonisation along stretches of the coast. A survey by amateur divers looked at the distribution of species between St Abbs and Souter Point (Foster-Smith 1979). A change in the composition of species occurred in this area. More species were recorded as abundant at St Mary's Island than either at St Abbs or Souter Point. A much greater seasonal variation in species was also observed at St Mary's Island compared to St Abbs.

4.2 Dunbar to Berwick

This section of coastline consists predominantly of rocky shores with a few sediment beaches and bays and a number of small estuaries. Most marine work has concentrated around the St Abbs area.

The shores in the neighbourhood of St Abbs, extending north-west to Redheugh Farm and south to Burnmouth, have been described with special reference to the Mollusca (Smith 1979; Smith 1983; Smith & Gault 1983). Much of the intertidal zone of this area consisted of rock platforms with sheltered rock pools and wave



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Figure 16 The location of places in south east Scotland and north east England named in the text.

exposed gullies and ridges. Habitats were found to be similar along this section of coast but species varied with the geology. Shores were found to be reasonably rich with those on sandstone being richest. However compared to some other sites on the east coast, for example Dunbar and St Andrew's, fewer species were recorded. This was considered to be due to the lack of variation in habitats and exposure and slightly colder water.

Algae have been recorded from the shores of the Berwickshire coast and a species list prepared (Norton 1976; Hardy 1988, 1990a, 1990b). A total of 175 algae, including sublittoral species, have been identified. As part of a sublittoral seaweed survey of the Scottish coast to find exploitable quantities of laminarians for the alginate industry, a quantitative survey was undertaken along the coast between Dunbar and Fast Castle (Walker 1952). Over 50,000 tons of *Laminaria* was found to occur in 3400 acres.

The Marine Conservation Society has been active in carrying out sublittoral surveys to describe the habitats and marine life in the St Abbs area, between Fast Castle and Burnmouth, including studies on the common sea urchin *Echinus esculentus* (Earl 1981, 1982; Pagett 1983; Hiscock 1984). Habitats were predominantly rocky with surge gullies, cliffs, rock platforms, reefs, boulders, crevices and caves. Sediments were mainly clean sand but muddy sand occurred in St Abbs Harbour and coarser sands and stones were found off St Abbs Head. The sublittoral communities were considered to be similar to those of Shetland and Orkney. Northern species such as the hydroid *Thuiaria thuja*, the sea anemone *Boilocera tuediae*, the wolf fish *Anarhichas lupus* and the algae *Callophyllis cristata*, *Odonthalia dentata*, *Phyllophora truncata*, *Ptilota plumosa* and *Rhodomela lycopodioides* were recorded. Species with a southern distribution that were noted were the algae *Schottera nicaeensis* and *Rhodymenia pseudopalmata*. Communities included rich, deep kelp forests which occurred in the clear water and dense brittle star beds. Where *Echinus esculentus* dominated a grazed zone the community was characterised by encrusting Corallinaceae, the soft coral *Alcyonium digitatum* and the tube worm *Pomatoceros* sp. There was a noticeable lack of sponges and ascidians. Epiphytes on the stipes of kelp *Laminaria hyperborea* from St Abbs have also been studied (Whittick 1983). The predominant species were the algae *Palmaria palmata*, *Ptilota plumosa*, *Membranoptera alata* and *Phycodrys rubens*. These species showed two zonation patterns, one in relation to depth and the other with position on the stipe.

The sediments and fauna off St Abbs Head have been extensively studied in relation to the sludge dumping grounds in this area (Moore & Johnston 1978, 1979; Dooley, Johnston & Moore 1979; Moore & Topping 1980; Heap 1983, 1985; Institute of Offshore Engineering 1985). The work provided chemical analyses of the sediments, quantitative analyses of the fauna and videos of the benthos. The sediments off St Abbs consisted of fine to very fine sands. Over 260 species have been recorded from the area. In general sludge dumping was not considered to have adversely affected the communities in the sediments.

The Berwickshire coast in the region of St Abbs has been selected as a Marine Consultation Area (NCC 1990). The area was considered to be of conservation interest due to the presence of deep-water rock close to the coast and the wide range of littoral and sublittoral rocky habitats and associated communities which occurred in the clear, unpolluted water. The rich fauna and flora included species representative of the Arctic and North Sea basin.

4.3 Berwick to Redcar

The length of coastline between Berwick and Redcar is referred to as the Cullercoats District. Many studies within this area have been undertaken from the Dove Marine Laboratory. A bibliography covering the literature on marine fauna for the Cullercoats District has been compiled by Foster-Smith (1984a). Distributional records of algae for Northumberland and Durham have been made since the 1860s (Brady, G S 1860, 1862, 1863, 1864; Lacey & Robertson 1953; Hardy & Aspinall 1988). The fauna has been recorded since earlier times with records dating from the 1830s (Johnston 1832; Norman 1863, 1864, 1867; Alder 1864; Brady, H B 1864; Canon, Norman & Brady 1909; Bolam 1919; Moore 1989).

The Dove Marine Laboratory has also produced a series of reports on the fauna (as well as the algae) of the Cullercoats District. Most major groups have been covered in this series which includes notes on the distribution of individual species. The groups covered are:

Seaweeds	(Hardy 1985a, 1987)
Porifera	{Bull 1963}
Anthozoa	{Bull 1939}
Coelenterata & Ctenophora	{Evans 1978}
Priapulida, Echiurida, Sipunculida	{Bull 1966a}
Entoprocta	{Eggleston & Bull 1966}
Chaetognatha	{Bull 1966b}
Polychaeta	{Garwood 1981, 1982}
Pycnogonida	{Bamber 1983}
Acari	{Bamber 1985}
Arthropoda: Crustacea; Branchiopoda	{Bossanyi 1967a}
Cirripedia	{Evans 1980}
Arthropoda: Crustacea; Copepoda	{Bossanyi & Bull 1971}
Arthropoda: Crustacea; Ostracoda	{Bossanyi 1967b}
Mysidacea	{Bamber 1986a}
Amphipoda	{Shearer 1983}
Tanaidacea	{Bamber 1986b}
Arthropoda: Crustacea; Euphausiacea	{Bossanyi 1964}
Crustacea: Decapoda	{Moore 1987}
Arthropoda: Diplopoda, Chilopoda	{Bull 1964a}
Arthropoda: Insecta; Apterygota	{Bull 1964b}
Arthropoda: Insecta; Pterygota	{Bull 1967}
Mollusca: Caudofoveata, Solenogastres, Polyplacophora, Gastropoda, Scaphopoda, Cephalopoda	{Foster-Smith 1986}
Mollusca: Bivalvia	{Kingston 1980}
Ectoprocta	{Eggleston 1975}
Echinodermata	{Buchanan 1966}
Fishes	{Davis 1983a}
Zooplankton	{Evans 1985}
Cetacea	{Stephenson & Bull 1964}.

Berwick-upon-Tweed is located on the north Northumberland coast, at the mouth of the River Tweed estuary. A small fishing port is situated at Tweedmouth. The shores at the mouth of the estuary and to the south consist of sand. North of Berwick-upon-Tweed and south around Scremerston the coastline is cliffed with rock platforms below. Offshore the seabed consists predominantly of sediment. The abundance and distribution of the algae has been studied at Berwick-upon-Tweed since the 1880s (Batters 1882, 1883, 1884, 1889; Hardy 1984).

The littoral and sublittoral between Berwick-upon-Tweed and Beadnell including the Farne Islands were surveyed by the MNCR in 1987 (Connor 1989). The Farne Islands had also been surveyed

previously by Edwards (1983). The shores from Scremerston to Beadnell were predominantly sediment while those of the offshore Farne Islands and the eastern side of Holy Island were rocky. The seabed shelved gradually from the mainland and Holy Island leading onto plains of sediment, tide-swept cobbles and boulders; around the Farne Islands the rock extended further into deeper water. This whole section of coast was found to be subject to a wide range of exposures to wave action and tidal streams. The area had a high habitat diversity and a large number of species with a northern distribution. Rocky shores were dominated by fucoids or barnacles and mussels. On vertical limestone of the lower shore rich communities were found. Of particular note was the finding of the eelgrass *Zostera* sp. in rock pools. The predominant populations for sediment shores were the lugworm *Arenicola marina* and mussels *Mytilus edulis* with the sand eel *Ammodytes tobianus* in the more mobile sands. Large, dense beds of *Zostera* sp. occurred on Fenham Flats. Sublittoral rock was found to support extensive kelp forests in the clear water around the Farne Islands. The rock beneath the kelp was extensively grazed by the sea urchin *Echinus esculentus* and covered with encrusting Corallinaceae. Vertical rock was covered by the tubeworm *Pomatoceros triqueter* and in strong tidal movement the soft coral *Alcyonium digitatum* was abundant. Rich communities of hydroids, bryozoans and crustaceans were present on areas of tide-swept cobbles. Rich sublittoral sediment communities were found off Budle Bay and supported the burrowing urchin *Echinocardium cordatum*, the razor shell *Ensis arcuatus* and the bivalve *Angulus tenuis*. Rare species for the area were the anemone *Bolocera tuediae*, the bryozoan *Tricellaria ternata* and the wolf fish *Anarhichas lupus*.

Included in this section of coast is the Lindisfarne National Nature Reserve noted for its sand dunes, *Zostera* beds and the seaducks and seabirds which feed on the rich mud and sand flats. Bait digging within the reserve at Budle Bay has been of concern as a major impact in reducing lugworm populations and the associated community. The scale of this activity in relation to damage has been assessed (Olive 1986). The Farne Islands form a major tourist attraction and visitors take boat trips from Seahouses to view the seabirds and seals. The shores of the Inner Farne Island have been studied on several occasions. Records are provided of shore descriptions and the general ecology (Sowerby 1958; Thompson et al. 1966), the habitats and algae (Moss 1959) and aquatic fauna (Gascoigne 1969). Most published papers on the Farne Islands relate to the seal populations (e.g. Coulson 1959, 1981; Coulson & Hickling 1964; Hickling 1983).

The coastline from Beadnell to Dunstanburgh Castle consists of sandy bays separated by rocky headlands. Sublittorally shallow reefs run perpendicular to the shore and either extend into extensive areas of horizontal bedrock or shelve into sand. The shores were initially described in 1983 (Hodgson 1984) when a new species to the Cullercoats District, the polychaete worm *Protodrilus chaetifer*, was recorded. A more intensive study of the shores and shallow sublittoral was undertaken in 1987 (Foster-Smith & Foster-Smith 1987) providing descriptions of the habitats and 30 assemblages of flora and fauna. The majority of habitats and species were common to the north-east coast of England but several rare habitats for the area were also described. In particular, Fills Reef and Emblestone were unusual in that they formed a protective barrier around a sandy beach allowing the colonisation by a community characterised by *Echinocardium cordatum*, *Ensis ensis* and *Ensis arcuatus*. Other rare habitats in the area included prominent headlands, single reefs and steep boulder beaches. The area was considered to have a high range of habitats and a high diversity of species with

records for over 460 species.

Newton Haven has been intensively studied. The littoral habitat types, flora and fauna were originally described in 1983 (Foster-Smith 1983). Following this a checklist of 72 plants and 346 animals with notes on their distribution and abundance was provided (Foster-Smith 1984b). A quantitative and qualitative study of the infauna revealed that the beach was unique among beaches of north-east England (Olive 1984). Newton Haven was the only beach in this area to have an intertidal population of *Echinocardium cordatum* occurring in conjunction with sparse numbers of *Echinocardium flavescens*. Offshore *Echinocardium cordatum* formed part of the *Echinocardium-filiformis* community but intertidally it formed an extension of the Venus community. The interstitial fauna of the beach was considered to be unusually rich. Most beaches in north-east England had a poor interstitial fauna due to silt derived from boulder clay which filled the interstices. The distribution of species was not uniform on the beach. The sandy shore in the south part of Newton Haven supported a high diversity of bivalves. Overall Newton Haven was considered to have a rich and diverse polychaete, mollusc, crustacean and interstitial fauna.

Alnmouth is a small holiday resort and yachting haven. The village was once an important port before the River Aln changed its course and the harbour became silted up. The area to the north of Alnmouth consists of sand dunes supporting golf courses with sandy beaches and outcrops of rocky shore. Sandy beaches backed by dunes stretch for 3 miles to the south of the village. The algae of the Alnmouth area between Seaton Point and Birling Carrs have been recorded since 1884 (Amory 1884). Past and more recent algal data has been drawn together by Hardy (1985b). Amory recorded a total of 107 species from this area while only 39 have been recorded this century. This reduction in the number of algae was considered to be due to the lack of recent investigations rather than to a mass loss of species.

Amble lies at the southern end of a three mile stretch of sandy beach to the south of Alnmouth at the entrance to the River Coquet. The mouth of the Coquet Estuary is known as Warkworth Harbour although Warkworth itself lies two miles upstream of Amble. The harbour was once a small coal port but is now used by fishing boats. The geological and ecological features from Amble to Hadston Carrs have been described and marine species recorded with a view to interpretation for visitors to the area (Foster-Smith 1987a). The coastline includes rock platforms and outcrops separated by sandy beaches and dunes.

South of Hadston Carrs lies the great expanse of sandy beaches and dunes of Druridge Bay. Four habitats within the bay have been described (Bamber & Coughlan 1989); these were the littoral rock of Hadston Carrs, the expanse of sandy beach, the sublittoral sand of the bay and the sublittoral rock or Cresswell Skeres. The first recordings of the polychaete *Baldia johnstoni* were from the northern end of the bay and also in the nearby bay of Fluke Hole. The submerged Cresswell Skeres are located offshore to the southern end of the bay. Habitats and species on the Skeres were recorded during a sublittoral survey (Foster-Smith 1987b). The species list included the first record for the east coast of Britain of the sponge *Axinella infundibuliformis*. Fish samples taken from Druridge Bay during the years 1975-1980 have resulted in a list of 44 species (Walker 1984). Fish species have also been recorded from Lynemouth (Davis & Dunn 1982a). Five rocky shores between Cresswell and Newbiggin-by-the-Sea have been described for the algae (McAllister 1973). Cresswell was found to be the richest in terms of number of species (42) and abundance due to the wide range of habitats and

distance from sources of pollution. Beacon Point, Newbiggin Point and South Spital Carrs appeared to fall along a gradient of increasing pollution (from the Tyne area) resulting in reduction in the number of algae recorded. Headagee was found to be heavily polluted by spoil from the nearby colliery.

The River Wansbeck discharges into Cambois Bay. The three miles of the Wansbeck estuary has been studied for the distribution of flora and fauna in relation to salinity and substratum (Vasisht 1965). Between the Wansbeck estuary and Blyth the two mile stretch of sand and shingle shore is speckled with coal dust. Blyth harbour is important for importing timber and exporting coal and is also used by fishing and sailing boats. Studies within the Blyth Estuary have concentrated on mussel parasites (Ellenby 1947; Bolster 1954), nematode distribution (Capstick 1959) and fish (Davis & Dunn 1982b, 1982c). Plankton has been recorded in both Cambois and Blyth Bays (Bossanyi 1957). The shore from Blyth to Seaton Sluice is a two mile stretch of sandy beach.

At Seaton Sluice the shoreline changes to becoming predominantly rocky. The rocky shores of St Mary's Island, which can be reached on foot at low water, were studied for the fauna and flora (Foster-Smith 1984c). Two species, the polychaete *Amblyosyllis formosa* and the pycnogonid *Endeis spinosa*, rarely recorded along this section of coast were found.

The presence of the Dove Marine Laboratory at Cullercoats has facilitated many marine studies. Shores in the vicinity of the laboratory have mainly been used for single species studies. The sediments off the Northumberland and Tyne and Wear coast have been described by Buchanan (1964) who noted that the area around the mouth of the River Tyne was polluted. Buchanan (1963, 1965) has also described the distribution of benthic communities in relation to sediment. Between the shore and a depth of 40 m rocks outcropped around sandy bays of clean, fine sand. A plain of fine sand, divided by a band of medium sand and gravel running parallel to the shore, occurred between 40 and 60 m. Deeper than 60 m the sediments consisted of very fine sand with varying proportions of silt. Three communities, a burrowing brittle star *Amphiura filiformis*-*Amphiura chiajei* community, an amphipod *Haploops tubicola* community and a bivalve *Chamelea gallina* community, have been identified for this area. These communities were found to be poorly correlated with sediment type. However, *Echinocardium cordatum* typically occurred with the *Amphiura filiformis* community to a depth of 60 m and in the finer sediments at 70 to 80 m the sea urchin *Brissopsis lyrifera* formed a community with *Amphiura chiajei*. Long-term monitoring of two benthic stations off Blyth has shown community stability interspersed with periods of change (Buchanan & Moore 1986a, 1986b; Buchanan et al. 1986). Using data from five monitoring stations located between Blyth and the Tyne Estuary, and two broad surveys, the spatial and temporal variability in the benthic macrofauna has been assessed for the period 1971-1976 (Buchanan, Shearer & Kingston 1978). Variation in winter temperatures appeared to cause changes in community structure and species abundance.

Plankton research off the Northumberland coast has been continuing since 1900 providing data on the community composition, distribution, density and long term variability (Meek 1928; Roff 1969; Evans 1973a, 1973b, 1977; Wilson 1981; Roff, Middlebrook & Evans 1988). Fish plankton in particular have been recorded by Harding and Nichols (1987). Northumberland fishes have been recorded and described by Davis (1983b).

A number of studies have been undertaken on the Tyne Estuary

mainly in relation to pollution. Water quality of the estuary was sampled over the period 1971-1976 (Douglas & Edwards 1976). Water quality, nutrient discharges and bacteriological conditions have also been studied (James 1972, 1973). The sediments and fauna from 17 sites along the estuary showed salinity and water quality (i.e. organic pollution loading) to have the greatest effect on the diversity and quantity of species present (Sinton 1979). The fauna predominantly consisted of capitellids, oligochaetes, nematodes and the polychaete *Polydora* sp.

Sewage sludge has been dumped off the entrance to the Tyne Estuary since 1980. The sediments and fauna at the dumping site have been studied and the effects of sludge disposal monitored by Northumbrian Water Authority (Pomfret & McHugh 1983; Rees et al. 1985; Pomfret 1988). Sludge disposal operations did not appear to have caused significant alterations to the benthic fauna or sediment chemistry, as prevailing water movements had adequately dispersed the sludge. Fauna has been recorded from benthic trawls and bacteriological sampling undertaken on the sludge dumping ground by the Northumbrian Water Authority (1987a).

The effect of dumping colliery waste, dredgings and fly ash off the coast between Lynemouth and Seaham has been investigated (Eagle et al. 1979). Dumping of fly ash and colliery waste caused severe depletion of the benthic fauna, in both species and abundance, in the areas where waste was tipped with greatest intensity. Some recovery appeared to take place on older, weathered waste deposits.

The Durham coastline is well known for the impact of the coal industry and the dumping of coal waste on the cliffs and shores. The impact of the colliery waste on the coastline between Seaham and Easington has been studied by Nelson-Smith (1988). Washery slurry was discharged at the top of the shore between Seaham Harbour and Nose's Point. The fauna and flora of dumped masonry and bedrock near Seaham Harbour, a rocky reef at Nose's Point and on rocky shores at Chourdon Point was found to be impoverished. Only 18 species were recorded at Nose's Point while 44 were found at Chourdon Point. Reduction in numbers of species was considered to be due to the turbidity, abrasive particles in the water and accumulation of fine sediments in crevices. Edwards (1975) calculated that there had been a 16.6% reduction in common algal species over the past century along the Durham coast. As this reduction in algae was comparatively low in relation to the considerable increase in industrialisation and urbanisation, it appeared that pollution was only having a minimal effect on species diversity on the open coast where there was good water circulation.

Hartlepool is located on a rocky limestone headland with sandy beaches stretching to the north and in Tees Bay to the south. With the vast amount of industry associated with the Tees Estuary most studies have been related to pollution. The sediments, water chemistry and fauna have been monitored in the Tees estuary for several years by Imperial Chemicals Industries Ltd (ICI) and described in a series of confidential reports. The distribution and abundance of fauna and flora in the Tees from Yarm to the sea has been studied by Alexander, Southgate and Bassindale (1936). Benthic meiofauna has been studied in the Tees estuary by Gray (1971). Comparisons made with 1935 data showed there to be no major reduction in species.

Studies in relation to pollution have also concentrated on Greatham Creek/Seaton Channel where cooling and wash waters from a titanium dioxide manufacturing plant were discharged. Benthic communities in the channel were studied but no significant damage

due to the discharge was found (Newell 1984). Northumbrian Water Authority (1987b) were also active in monitoring the water quality sediment and benthos in the creek.

After land claim on Seal Sands, three areas of sediment remained at Tees Mouth; North Gare Sands, South Gare Sands and the remainder of Seal Sands. These beaches were studied for their sediments and fauna (Kendall 1976). North and South Gare Sands consisted predominantly of well graded sand exposed to wave action and supported a sparse fauna. In contrast, Seal Sands consisted of soft mud with abundant but few species. Consideration was given to the macrofauna in relation to shorebird diets on Seal Sands (Evans et al. 1979). This study investigated the distribution and density of macrofauna and again found the invertebrate life on the mudflats to be limited in species composition. Kendall (1979) found the community to be highly stable and dominated by the polychaete *Manayunkia aestuarina*.

Community production and biomass analysed from grab samples taken off the coast at Blackhall, Long Scar, Saltburn and Robin Hood's Bay did not appear to show any serious effects of pollution (Rees 1983). This indicated that the coastal waters had a sufficient capacity to dilute and disperse effluents from the Tees Estuary. The dominant species in terms of biomass were the polychaetes *Spiophanes bombyx*, *Magelona* spp. and *Nephtys* spp.

The recent sludge dumping ground off Tees Bay has been monitored by Northumbrian Water Authority for possible changes in sediments and fauna (Pomfret 1986, 1988).

4.4 Redcar to Bridlington

Redcar is a popular resort with sandy beaches and outcrops of rocky shores. The environment and species of Redcar Rocks have been described in a popular guide for the visitor (Tinsley 1987). The guide was based on a survey which revealed a diversity of marine life in an area often considered as polluted. Between Redcar and Saltburn-by-the-Sea stretches a sandy shore backed by dunes, except for the interruption of Marske-by-the-Sea.

From Saltburn-by-the-Sea to Filey the shore consists predominantly of wave cut platforms backed by high, sheer cliffs with a few sand and/or pebble pocket beaches and bays. Large areas of sandy beach occur at Saltburn, Whitby and Scarborough. At Skinningrove, Boulby and Runswick Bay the sediments have been analysed and species recorded as part of a monitoring scheme for the potash industry and described in various confidential reports prepared for ICI by Tapp and others. The benthos off the coast between Sandsend and Robin Hood's Bay was studied in relation to the proposed siting of a mining effluent pipe at Maw Wyke Hole (Newton 1973). A mosaic of sediment types ranging from mud to very coarse sand occurred supporting a total of 81 species. The fauna was dominated by polychaetes, amphipods, decapods and pleuronectid fish. The most widely distributed and numerous species included the polychaetes *Nephtys cirrosa*, *Eteone longa*, *Scoloplos armiger*, *Spio filicornis*, *Spiophanes bombyx*, *Magelona mirabilis* (*papillicornis*) and *Chaetozone setosa* and the amphipod *Pontocrates arenarius*. Species richness of the area was considered poor and diversity low. Sublittoral infaunal communities were also studied off the coast at Sandsend Bay and Maw Wyke Hole by Atkins (1985). At Sandsend Bay the sediments consisted of well-sorted, fine sand with a fauna low in diversity and dominated by tubicolous (mostly spionid) and predatory (mostly nephtyid) polychaetes. At Maw Wyke, the sediments were poorly sorted ranging from muddy sand to coarse shell gravel and were dominated by the polychaete *Melinna cristata*. The coastline

between Saltburn Scar and Burniston Bay has been described in terms of habitats, fauna and flora and features of conservation importance (Foster-Smith 1988). Apart from the wave cut platforms, boulders formed an important habitat. Rocky shores varied in exposure to wave action and communities were characterised by mussels, barnacles and fucoids. Boulder beaches provided overhangs and in deeper channels between boulders where sand and silt accumulated the tube worm *Sabellaria spinulosa* was commonly found. Exposed sandy beaches supported low numbers of *Arenicola marina*. A subjective assessment of biological diversity showed Skinningrove, Deepgrove Wyke, Saltwick Bay and Ravenscar to support the greatest number of interesting communities. The seabed off the Yorkshire coast has been described, especially in relation to crab stocks (Edwards 1967). Between Redcar and Flamborough Head to approximately 2 miles offshore the bottom was found to be rugged. Beyond this, extending 3 to 6 miles offshore the seabed was sandy with outcrops of rocks and stones. South of Flamborough Head in Bridlington Bay the seabed was sandy.

Naturalists have recorded the fauna and flora at Robin Hood's Bay since the 1930s (Anon. 1933). During the time that the Welcome Marine Laboratory, run by the University of Leeds, was established at Robin Hood's Bay numerous studies were undertaken in the area. Many of these concentrated on single species and long term change (J R Lewis pers. comm.). Ecological studies have been made on *Mytilus edulis* (Seed 1967), the amphipod *Bathyporeia* spp. (McGrorty 1972), littoral nudibranchs (Todd 1977), rocky shore nematodes (Cramp 1985) and pool-dwelling serpulids and spirorbids (Hanna 1989; Grahame & Hanna 1989) while population studies have been concentrated on dogwhelks *Nucella lapillus* (Feare 1969, 1970, 1971) and the isopod *Ligia oceanica* (Willows 1984).

The fauna in the top 3 cm (approximately) of Stoupe Beck Sands was examined in 1949 and 1950 (Colman & Seagrove 1955). The fauna was found to be poor and dominated by amphipods. In a later study meiofauna and macrofauna were quantitatively described from the wave exposed Stoupe Beck Sand (Robin Hood's Bay) and compared with that of the less exposed Filey Beach (Gray & Rieger 1971). Filey was found to be richer in both numbers and species of meiofauna.

The marine algae of the coast between Scalby Mills and Cornelian Bay has been recorded by Masee (1885) and more recently the algae and rocky shores from Robin Hood's Bay to Flamborough have been described by Perkins (1953).

The intertidal area and species in the Scarborough area have been described (Lewis 1987a) in a guide to the Scarborough shoreline. In preparing the guide the harbour walls, rocky shores and sandy beaches were surveyed. A similar study was carried out in the production of a guide to Filey Brigg (Lewis 1987b).

South of Filey Brigg the shoreline is sandy until the chalk exposures of the Flamborough headland. From Dulcey Dock around the Head to Sewerby the chalk cliffs lead down to boulders and wave cut platforms. Naturalists have been active in recording the algae and fauna, in particular the molluscs, from the Flamborough area since the 1890s (Hey 1894; Pearsall & Mason 1923; Philp 1934; Norris 1973).

The chalk shores around Flamborough Head have been surveyed by the British Museum (Natural History) (George et al. 1988; Tittley 1988). The chalk outcrop at Flamborough Head is the most northerly in Britain. It is relatively hard and has been eroded to form caves, arches and stacks. The chalk cliffs of this area

are virtually unspoilt. On the north side of the headland the chalk is harder and the shores are relatively steep, rugged and exposed to wave action while on the south side the chalk is softer and the shores have broader wave cut platforms and are more sheltered. Shores of varying exposure were studied and a total of 270 invertebrates and 112 species of algae were recorded. The more sheltered sites supported more species compared to the more exposed shores. Many species found at Flamborough Head have not been recorded from other chalk shores in Britain. The red alga *Ptilota plumosa* was found to reach its southern limit at Flamborough Head. The chalk cliff algal communities were found to be richer on the north side of Flamborough Head compared to the south and were slightly different to those found elsewhere in Britain.

A sublittoral survey of Flamborough Head showed the area to be predominantly rocky, with a wide range of habitats, and rich in species (Wood 1988). On the north and east sides of the headland nearshore chalk platforms were dissected to form gullies and outcrops with vertical faces between 4 and 6 m high. These formations lead onto terraces with progressively lower steps and a bedrock plain further offshore. Along the south side of the headland there were no rock outcrops and the bedrock terraces were lower and often covered by small boulders, cobbles and pebbles. Well developed kelp forests with an undergrowth of red algae were present down to a depth of 3 to 4 m. The vertical chalk faces were mainly colonised by sessile animals and red algae. A wide range of hydroids and bryozoans were dominant in areas of strong tidal streams and sand scour along with *Alcyonium digitatum* and colonial tunicates. Species able to bore into the chalk included the sponge *Cliona celata*, the polychaete *Polydora ciliata* and the bivalve *Hiatella arctica*. There appeared to be a low population density of *Echinus esculentus* and fish. The flora and fauna included some species with a northern distribution, for example the red algae *Odonthalia dentata* and *Ptilota plumosa* and the bottle-brush hydroid *Thuiaria thuja*, and others with a southern distribution, such as the brown alga *Taonia atomaria* and the red algae *Schottera nicaeensis* and *Rhodymenia holmesii*, the sponge *Polymastia boletiformis* and the ascidian *Archidistoma aggregatum*.

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