JOINT NATURE CONSERVATION COMMITTEE

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Benthic marine ecosystems of Great Britain and the north-east Atlantic

edited by

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Part 2

Reviews within MNCR Coastal Sectors

Chapter 4: East Scotland (Duncansby Head to Dunbar) (MNCR Sector 4)*

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Synopsis

The north part of the east coast of Scotland is broken by three major inlets, the Moray Firth (including the Dornoch, Cromarty and Inverness/Beauly Firths), the Firth of Tay and the Firth of Forth, and a few smaller inlets. The coastline is predominantly rocky with extensive intertidal sediment areas occurring mainly within the inlets. Information on the marine biology of inshore areas on the open coast is sparse but a wide range of studies describe littoral and sublittoral areas, mainly sediments, within the various inlets. Some parts of the Moray Firth, the Ythan Estuary and parts of the firth and estuary of the Forth are well studied and communities described.

4.1 Introduction and overall studies

The east Scotland sector extends from Duncansby Head in the north to Dunbar in the south, encompassing a wide range of marine habitats and including several major indentations and inlets, such as the Moray Firth (including the Dornoch, Cromarty and Inverness/Beauly Firths), the Firth of Tay/St Andrews Bay and the Firth of Forth (Figure 4.1).

A few studies have been carried out for the whole east coast of Scotland. A series of reports commissioned by the Countryside Commission for Scotland from the University of Aberdeen, Department of Geography, described the physical environment and recreational and other human pressures influencing unconsolidated (sediment and pebble) beaches and their maritime fringe around the entire Scottish coast. Relevant reports covering the east coast are: Ritchie & Mather (1970) (Caithness); Smith & Mather (1973) (East Sutherland and Easter Ross); Ritchie, Smith & Rose (1978) (Highland and Grampian Regions between Inverness and Inverbervie); Wright (1981) (Tayside); Ritchie (1979) (Fife); and Rose (1980) (Lothian and Borders Regions). Mather & Ritchie (1977) provided a summary and overview for beaches north of Inverness. Eleftheriou & Robertson (1988) surveyed 11 sandy beaches between Sinclair's Bay (Caithness) and Belhaven (East Lothian) and described their environmental conditions and faunal characteristics. Buck (1993) reviewed the conservation status and human uses of 16 estuaries in Sector 4. Smith (1984) assessed saline lagoons (in the widest sense) with respect to the Mollusca. The distribution of littoral and sublittoral Mollusca for east Scotland was reviewed and mapped by McKay & Smith (1979), who provide an important bibliography of published records. Much offshore survey work has been related to the fishing industry; although Dawson (1870) listed marine Mollusca of Aberdeenshire, Banff and Moray, it was the advent of trawling which enabled Simpson (1896) to extend this list to include offshore records. Since that time, the Marine Laboratory at Aberdeen (now part of the Scottish Office Agriculture, Environment and Fisheries Department) has carried out extensive survey work throughout the northern North Sea.

The sediments and benthic fauna of three fishing grounds off the Scottish east coast were surveyed by McIntyre (1958). Areas off Aberdeen and St Andrews had fairly uniform deposits varying from muddy to fine

* This review was completed from published sources of information on benthic habitats and communities as well as interviews with relevant workers undertaken up to 1991 and published in Bennett (1991). It has been further revised to take account of major additional studies by the second author up to the end of 1994 and up to the end of 1996 by the series editor. It does not include benthic survey information summarised for or published in the MNCR *Regional Reports* series or work now being undertaken to map biotopes in candidate Special Areas of Conservation. For information on conservation status and an analysis of rare and scarce seabed species, the reader is referred to the *Coastal Directories* series.

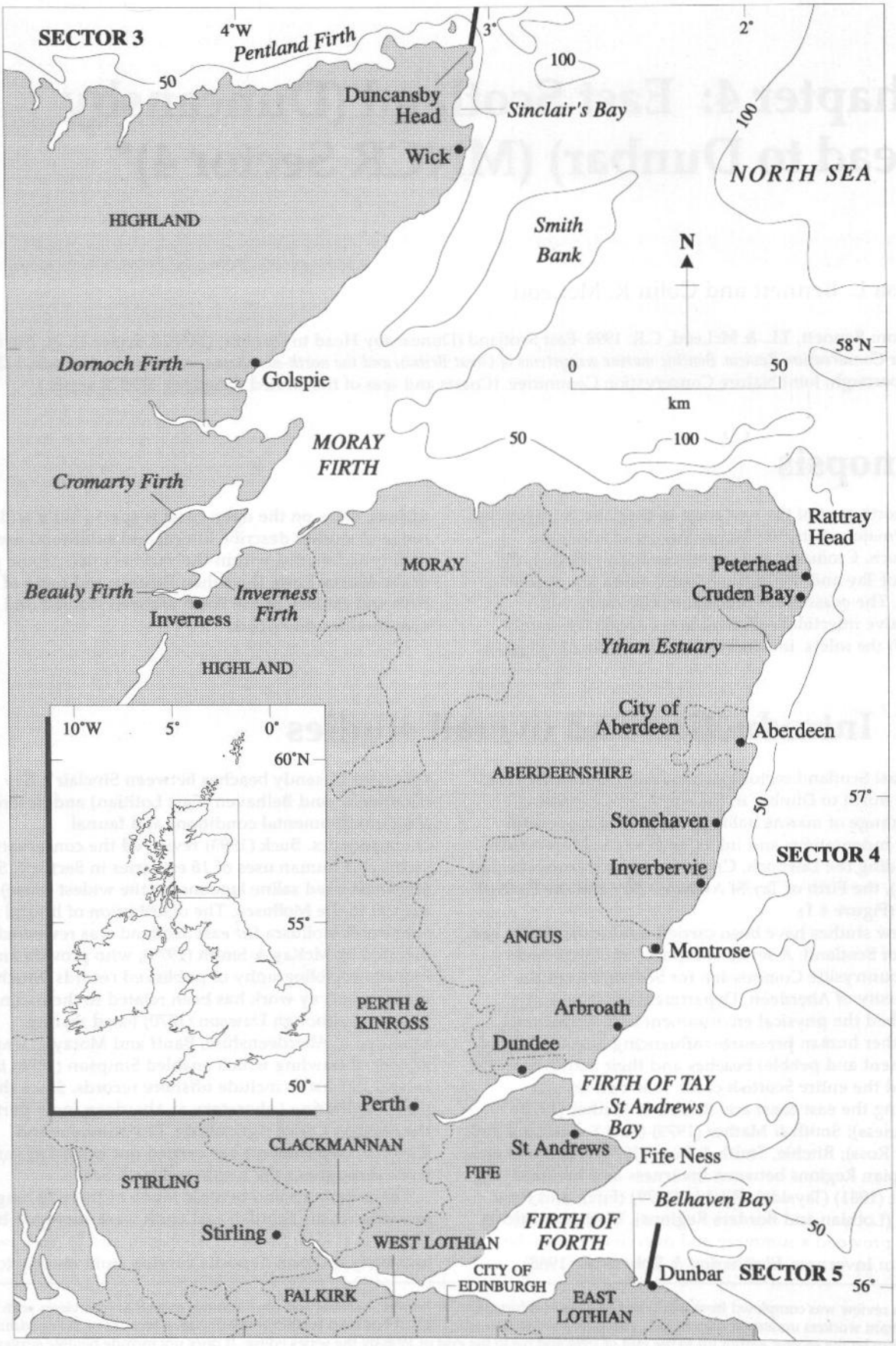

Figure 4.1. The east coast of Scotland showing location of areas mentioned in the text.

sand, with that of the Aberdeen areas being slightly coarser. The fauna in the two areas was dominated by bivalve molluscs and polychaete worms, and was found to be richer off Aberdeen. The third area sampled was the Smith Bank, in the northern part of the outer Moray Firth, 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 terms of biomass.

Major studies of the offshore benthic environment and benthos of the northern North Sea were reported by Basford & Eleftheriou (1988) and Basford, Eleftheriou & Raffaelli (1989, 1990). The abundance and distribution of epifauna was found to be determined primarily by depth and secondarily by sediment granulometry and organic content, with the 100 m depth contour being of "prime importance" as a dividing line between different epifaunal assemblages, although they were often seen to grade gradually into one another (Basford, Eleftheriou & Raffaelli 1989). Infaunal distribution was more complex and less influenced by depth, being primarily determined by sediment granulometry (Basford, Eleftheriou & Raffaelli 1990).

The development of the North Sea oil industry since the early 1970s provided the impetus for numerous studies, both ongoing monitoring projects which frequently include many sites over a wide area, and site-specific environmental impact assessments. In the more populous southern part of this sector, many studies have been related to pollution, from both pipeline discharges and offshore sewage dumping. The results of some of these studies are reviewed below.

4.2 Moray Firth

4.2.1 Introduction

The Moray Firth is generally regarded as that area of coastline and open sea falling within the area bounded by Duncansby Head in the north, Beauly Firth in the south-west and Fraserburgh in the south-east, making it one of the largest indentations of the British coast (Figure 4.2). The coastline of the Moray Firth varies from high cliffs and rocky shores to sweeping sandy beaches and dunes, together with the sheltered inlets of Loch Fleet, the Dornoch, Cromarty, Inverness and Beauly Firths, and Findhorn Bay. Tidal streams flow in a clockwise direction around the Moray Firth on flood tides and anticlockwise on ebb tides. Inshore hydrography and plankton were investigated by Craig & Adams (1967, 1969) and Adams & Martin (1986).

In the inner Moray Firth, increasing industrialisation and population growth during the late 1960s prompted the commissioning, principally by the Highlands and Islands Development Board, of the Moray Firth Development Ecological Survey, commencing in 1969. This resulted in an important series of interim reports with the emphasis on estuarine and littoral habitats and the impact of the oil industry in particular (University of Aberdeen, Department of Geography 1970a & b, 1971, 1972, 1974, 1975, 1976, 1978, 1981a & b). Nature conservation issues and sites of nature conservation importance (coastal and inland) in this area were considered in a Nature Conservancy Council report (NCC 1978).

A summary of the available information on the oceanography, geology, topography and intertidal and coastal habitats of the Moray Firth was given by Probert & Mitchell (1980). They described the main communities characteristic of rocky and sediment shores of varying exposure to wave action and considered shores of nature conservation importance. These shores are described below. A bibliography covering the marine life, coastal environment and industrial impacts affecting the Moray Firth was 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 included coastal topography (Smith 1986), hydrography and plankton (Adams & Martin 1986), rocky and sedimentary shores (Terry & Sell 1986; Rendall & Hunter 1986), the sublittoral environment and benthos in the vicinity of the Beatrice Oilfield (Hunter & Rendall 1986; Hartley & Bishop 1986; Bishop & Hartley 1986) and pollution, especially in relation to the oil industry (e.g. MacLennan 1986). Harding-Hill (1993) provided a comprehensive bibliography and review of current knowledge for the whole of the Moray Firth, covering coastal, littoral, sublittoral and pelagic habitats and communities, together with marine mammals, the physical environment and human activities.

4.2.2 Open coast and offshore

It is convenient to consider the relatively exposed open coastline of the Moray Firth separately from the more sheltered, predominantly estuarine conditions of its smaller inlets. These firths and enclosed bays tend to contain sedimentary shores while the open coast tends to be rocky. The coast between Duncansby Head and Golspie is predominantly rocky, often backed by high cliffs, and largely unbroken, with Sinclair's Bay north of Wick being the only major indentation. Many streams and rivers, such as the Rivers Wick, Helmsdale and Brora, meet the sea along this coast, but there are no opportunities for the development of extensive estuarine conditions north of Loch Fleet. Sediment shores in east Sutherland between Kilmote in the north and Cuthill Links in the south were described by Smith & 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. Similar findings were made at eight shores in East Ross between Morrich More and Rosemarkie. The study did not investigate the fauna of the beaches.

Both sedimentary and rocky shores between Duncansby Head and Peterhead were surveyed by the Scottish Marine Biological Association/Marine Biological

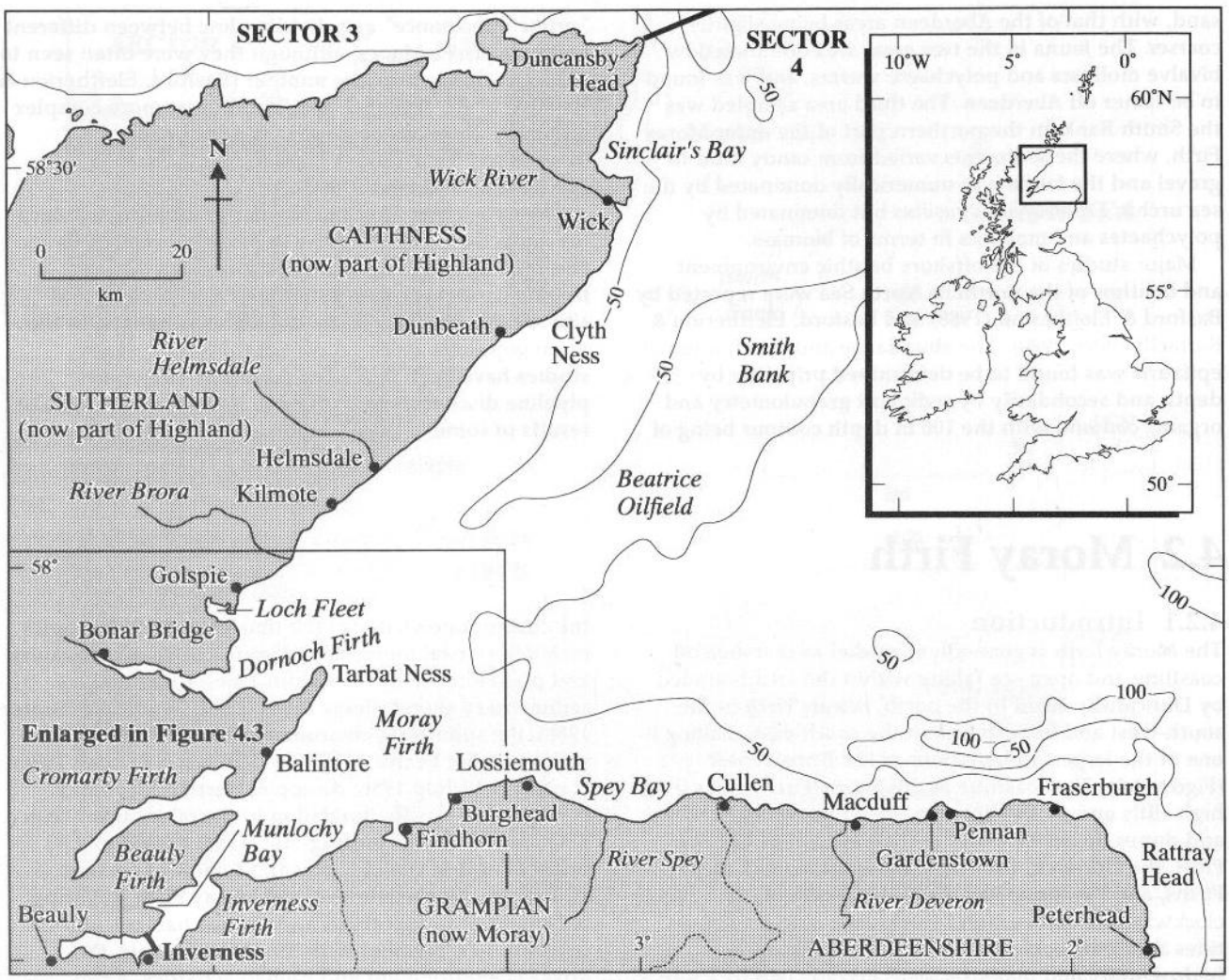

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Figure 4.2. The Moray Firth showing location of places mentioned in the text.

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 for their marine ecology, but they were considered to be representative of the area. Sediment shores of note were Loch Fleet, lower Cromarty Firth, Munlochy 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.* (1980) divided the sedimentary shores into four main categories, each 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 worm fauna;
- a *Tellina* (now *Angulus*) community characteristic of clean sand and including the bivalves *Tellina* (now *Angulus*) *tenuis* and *Donax vittatus*, the polychaetes *Arenicola marina* and *Nephtys caeca* and the amphipod *Bathyporeia* spp. ;
- an *Arenicola* community occurring in muddy sand, which included the polychaetes *Arenicola marina* and *Nephtys hombergii* and the bivalves *Macoma balthica* and *Cerastoderma edule*;
- a *Scrobicularia* community occurring in muddy sediments, characterised by the bivalves *Scrobicularia plana* and *Mya arenaria*, and the ragworm *Nereis* (now *Hediste*) *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 extreme exposure to wave action were absent) and supported a moderately rich fauna

representative of rocky shores within the Moray Firth. Exposed rocky shores supported a well developed lichen zone, an abundance of the 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 *Gigartina* (now *Mastocarpus*) *stellatus* and *Ceramium shuttleworthianum* and the kelps *Laminaria digitata* and *Alaria esculenta*. The coast south of Tarbat Ness was identified as the only continuous length of rocky shore in over 150 km of sedimentary coastline in the inner Moray Firth, with a mixture of rock types, and a very extensive kelp forest off Balnabruach. The rare subarctic fucoid alga *Fucus distichus* ssp. *edentatus* was recorded at Macduff Harbour, its only known location on the British mainland.

The upper shore regions of sheltered rocky shores were generally poor in species diversity, attributable to the desiccating conditions that prevail 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 include a range of habitats including boulders, cobbles, overhangs and rock pools as well as 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*, mussels *Mytilus edulis*, the dogwhelk *Nucella lapillus*, the sponges *Halichondria panicea* and *Grantia compressa* and tubeworms, *Pomatoceros triqueter* and Spirorbinidae.

In 1981 a major rocky shore monitoring programme in the Moray Firth was initiated (Sphere Environmental Consultants Ltd 1981a). Thirty-four shores between Duncansby Head and Fraserburgh were selected to cover the range of predominant physiographic features in the Moray Firth and transects were established. These shores were mainly rocky but also included boulder and cobble shores and encompassed a range of exposures to wave action. The shores selected were described along with their associated species by Sphere Environmental Consultants Ltd (1981a) in 36 separate reports to the British National Oil Corporation (Britoil) (summarised by Terry & Sell (1986)). 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 Ltd. 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 (predominantly rocky) shores on the northern side of the Moray Firth between Dunbeath and Ballintore with particular reference to Mollusca. A notable find at four sites was the gastropod *Rissoella diaphana*, previously recorded for the east coast of Scotland only from Cruden, Aberdeenshire. 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 with the shores on the south side of the Moray Firth. Smith (1984) considered the fully marine Rosemarkie lagoon to be important for molluscs, it being the only known east Scottish site for *Leucophytia bidentata* and the 'west coast' limit for *Calliostoma zizyphinum* as a shore species. McKay (1977) and Palmer (1977) described mollusc recording and listed the coastal and offshore species known in the Conchological Society's marine census area S5, which includes the Moray Firth and the offshore area of the North Sea to the east of the Firth.

Intertidal angiosperms in the Moray Firth were surveyed in a series of monitoring projects by the University of Aberdeen, Department of Geography (1970a&b, 1972, 1974, 1976, 1978, 1981a & b). A detailed study was undertaken of the environmental conditions and vegetation on saltmarshes and sand/mudflats with particular reference to the seagrasses *Zostera noltii*, *Zostera angustifolia* and *Ruppia* sp., and glasswort *Salicornia* sp.

The south coast of the Moray Firth from Fort George to Fraserburgh comprises a sequence of sandy bays, more common and larger in the western part, and rocky shores, often backed by cliffs, mainly in the less sheltered east. Beaches of north-east Scotland from Inverness to Inverbervie, Kincardineshire, were described in terms of their physical environment and recreational pressures by Ritchie, Smith & Rose (1978). Major sand bars have formed off Culbin, a dynamic coastline backed by a formerly highly mobile expanse of dunes, now afforested (Comber, Hansom & Fahy 1994). Several major rivers join the sea along this coast, including the Rivers Nairn, Findhorn, Spey and Deveron. Findhorn Bay is an extensive, largely enclosed estuary, a proposed local nature reserve. Bartrop *et al.* (1980) considered the communities present to be representative of sheltered muddy sand with reduced salinity. The complex and shifting delta of the River Spey at Spey Bay is part of the largest shingle complex in Scotland. Most of the villages and small towns along this largely undeveloped coast are fishing settlements, with tourism locally important near sandy beaches, for example at Nairn, Findhorn, Spey Bay and Cullen. Pollution effects are generally limited to the vicinity of outfalls. There is an oil platform construction yard at Whiteness Head, an accreting system of saltings, sand and mudflats and saltmarsh, just outside the Inverness Firth; its environmental effects were assessed by the University of Aberdeen, Department of Geography (1974).

A survey of the distribution and abundance of littoral invertebrates in sediment shores on the south side of the Moray Firth between Alturlie Point and Findhorn Bay was carried out by Wells & Boyle (1974). This coast benefited from the work of Victorian conchologists. Gordon (1854) and Dawson (1870) described the Mollusca of this section of coast, while Macgillivray (1843) covered the whole of what was, until 1996, Grampian Region. Other papers on the Moray Firth, particularly the Burghead area, by Gordon include early accounts of crustaceans (Gordon 1852a), echinoderms (Gordon 1853) and fish (Gordon 1852b, 1852c).

The Beatrice oilfield is located on the south-west corner of Smith Bank just 23 km from the coast south-south-east of Clyth Ness. Being so close to the coast there is a potential threat to marine life in shallow waters and on the coast from oil pollution. In consequence, an environmental impact analysis was carried out by Sphere Environmental Consultants Ltd (1977), involving 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 sediments 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 with distance from the platform. 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) provided a review of information on the shallow sublittoral zone of the Moray Firth based on published data, interviews with local marine researchers 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 sparse, but available data suggested the area to be lacking in terms of habitat diversity.

The Moray Firth is notable as the home range of one of only a handful of resident populations of bottlenose dolphins *Tursiops truncatus* in British waters, and probably the only resident population in the North Sea. Since 1989, a research programme on this population has been carried out by the University of Aberdeen, Department of Zoology, in collaboration with the Sea Mammal Research Unit, St Andrews. Hammond & Thompson (1991) gave a minimum estimate of population size, and current studies are enabling more accurate counts and also investigating the dolphins' health and diet (e.g. Thompson & Hammond 1992; Curran, Wilson & Thompson 1996). Similar studies are being carried out on common and grey seals in the Moray Firth (e.g. Pierce *et al.* 1991).

4.2.3 Marine inlets

The inner part of the Moray Firth includes three major inlets, the Dornoch, Cromarty and Inverness/Beauly Firths, and two other important estuaries, Loch Fleet and Findhorn Bay. All are of considerable nature conservation importance, primarily for their ornithological significance (Ratcliffe 1977; NCC 1978; Davidson *et al.* 1991).

4.2.3.1 *Loch Fleet*

Loch Fleet, situated between Golspie and Dornoch, forms the estuary of the River Fleet, and is a small shallow loch with predominantly sediment shores. A study of the distribution and abundance of littoral invertebrates in the loch was carried out by Wells & Boyle (1975). Most of the sediments 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 polychaetes *Arenicola marina*, *Fabricia sabella*, *Nephtys* spp., *Nereis* (now *Hediste*) *diversicolor*, *Pygospio elegans* and *Scoloplos armiger*, the amphipods *Bathyporeia* spp. and *Corophium volutator*, the snail *Hydrobia ulvae*, and the bivalves *Cerastoderma edule*, *Mytilus edulis*, *Macoma balthica* and other tellinids. Smith (1984) considered the molluscan fauna to be interesting, including the opisthobranch *Akera bullata*, not recorded elsewhere in east Scotland. Construction of the present A9 road embankment in 1816 sealed off an expanse of the upper estuary, which developed into a mixture of alder carr woodland and open fen, with saline lagoons supporting saltmarsh vegetation grading into freshwater swamp (NCC 1978). This wetland is now part of Mound Alderwoods National Nature Reserve. Loch Fleet and adjacent woodlands are a Scottish Wildlife Trust nature reserve.

4.2.3.2 *Dornoch Firth*

Dornoch Firth consists of a series of generally shallow basins and narrows extending into the narrow Kyle of Sutherland above Bonar Bridge, with the promontory of Tarbat Ness marking its seaward limit. The Firth is largely unspoilt, with wide sandy beaches in the large bays at the entrance to the Firth. Large sections are notified SSSIs. The abundance and distribution of littoral invertebrates in sediment shores was studied by Wells & Boyle (1973). They identified 41 species, the most common ones being similar to those found in Loch Fleet. Rendall & Hunter (1986) studied the littoral fauna at two sites in Dornoch Firth, in Cambuscurrie Bay and Ardjachie. The principal species found were the polychaetes *Scoloplos armiger* and *Pygospio elegans*, the oligochaetes *Tubificoides benedeni* and *Aktedrilus monospermathecus* and the tellin *Macoma balthica*. A list of the littoral algae was compiled by Currie (1974a). A survey of the distribution and density of the angiosperms *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* occurred on 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 at eight stations in the Dornoch Firth was investigated by Highland River Purification Board (Hunter & Rendall 1986). 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*, *Nereis* (now *Hediste*) *diversicolor*, *Pygospio elegans*, tubificids and nemertean

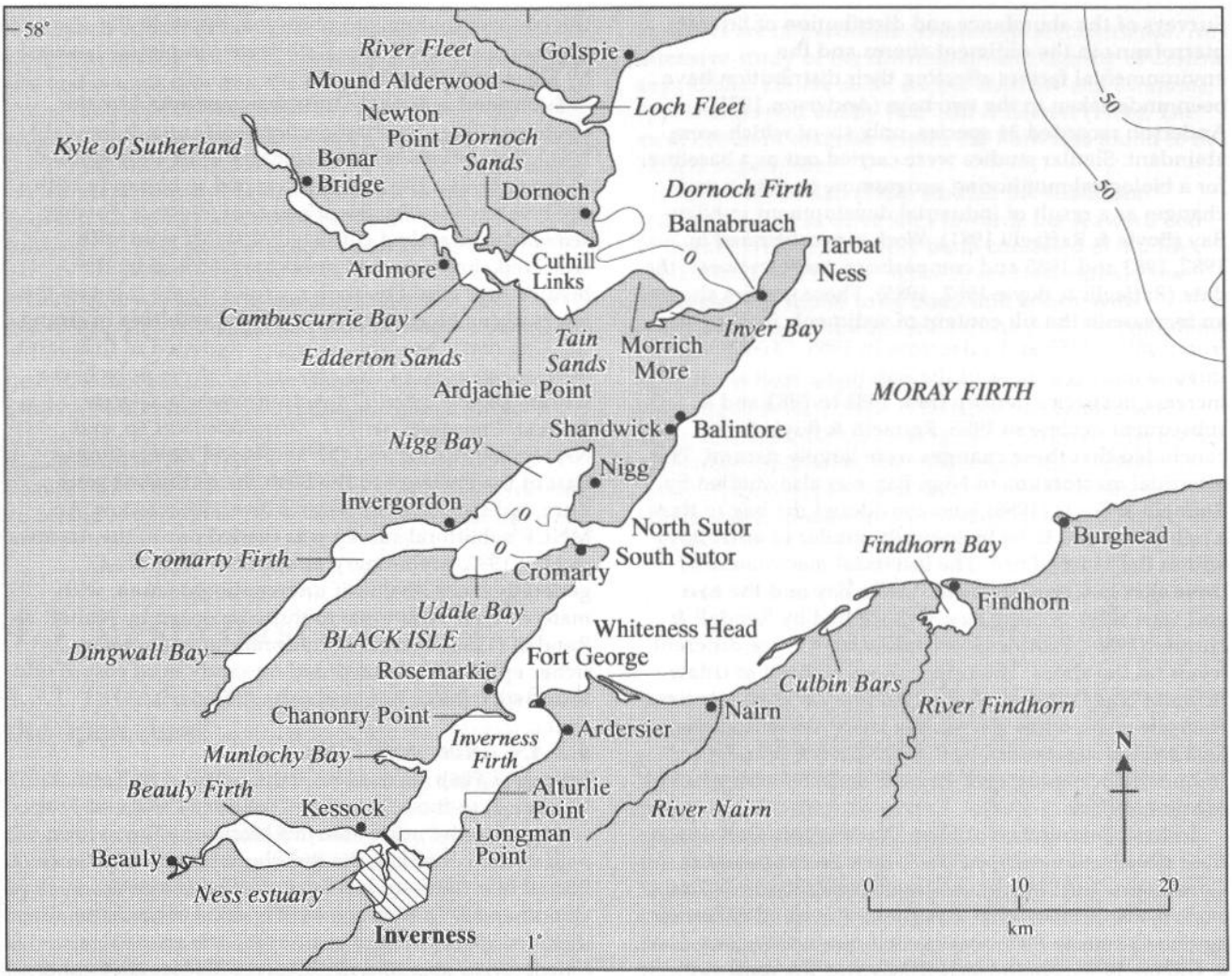

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Figure 4.3. The inner Moray Firth and inlets showing location of places mentioned in the text.

worms was recorded. Ardmore had greater species diversity, 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 polychaetes *Nephtys cirrosa*, *Chaetozone setosa* and *Glycera capitata*, the bivalves *Tellina* (now *Angulus*) *tenuis* and *Venus* (now *Chamelea*) *gallina* and the amphipod *Corophium crassicorne*. At sites exposed to wave action in the outer Firth, the fauna was sparse and dominated by the bivalves *Tellina* (now *Fabulina*) *fabula* and *Venus* (now *Chamelea*) *gallina*. Commercial cockle harvesting at Inver Bay has recently given cause for concern, as at sites elsewhere in the Moray Firth (P. Wortham pers. comm.; Harding-Hill 1993).

4.2.3.3 *Cromarty Firth*

Cromarty Firth is a long natural harbour, used during the two World Wars as an anchorage for the Royal Navy. Since the 1970s it has served as an anchorage for oil platforms, and an oil rig construction yard and oil terminal have been established at Nigg, next to the deep-water channel. Industrial development has taken place on the northern shore, and the Firth's long-standing importance as an anchorage resulted in a history of frequent oil-spills (Currie 1974b). However, throughout the Moray Firth, both the frequency and impact of oil pollution incidents has decreased since the 1970s (MacLennan 1986), and Cromarty Firth remains of international ornithological importance. The Firth is estuarine above Invergordon but seaward of this point the salinity is stable and the water deep, reaching about 50 m between North and South Sutor, where strong tidal streams occur. Collar (1978) considered Cromarty Firth to be a partly mixed estuary approaching a stratified condition.

Two large intertidal bays, Nigg and Udale, lie within Cromarty Firth. Jointly, they include a National Nature Reserve and RSPB reserve, primarily for their ornithological importance, although it is not possible to consider the reserve's conservation value in isolation from the Firth as a whole (Wortham & Brown 1990).

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 decrease in 1985. Changes in the infauna mirrored those of the sediments with an increase in species density from 1981 to 1983 and a subsequent decline in 1985. Raffaelli & Boyle (1985) concluded that these changes were largely natural. The intertidal macrofauna of Nigg Bay was also studied by Raffaelli & Boyle (1986) who considered the bay to have a rich fauna and to be biologically similar to other bays within the Moray Firth. The intertidal macrofauna of three sites in Cromarty Firth, Udale Bay and the east and west sides of Nigg Bay, was studied by Rendall & Hunter (1986). 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 were studied and their distribution mapped by Sphere Environmental Consultants Ltd (1981b). An intensive study of *Zostera angustifolia*, *Zostera noltii*, *Ruppia maritima* and *Salicornia* agg. in Cromarty Firth was carried out in 1986 (Fox, Yost & Gilbert 1986). *Zostera angustifolia* was the most common seagrass in the Firth although *Zostera noltii* was found to be very dense in Nigg and Udale Bays. *Salicornia* spp. was locally abundant farther up the Firth, in Dingwall Bay. The distribution of littoral algae in Cromarty Firth was studied by Currie (1974a).

Studies in relation to industrial (oil, gas and chemical) developments in Nigg Bay 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. Fouling of the Nigg Terminal jetty pilings was studied by Aberdeen University Marine Studies Ltd. (1984b, 1985b). Fouling was analysed by surveying the distribution of species and community composition at different depths, measuring the growth of the organisms, evaluating patterns of fouling and predicting future fouling. This work was summarised by Picken (1986). From 0 m to 6 m below chart datum (bcd) fouling consisted of mussels *Mytilus edulis* overgrown with seaweed; from 6 m to 26 m bcd 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 was monitored by the Highland River Purification Board (Hunter & Rendall 1986). Six stations within Cromarty 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 Firth narrows where it enters the sea between North and South Sutor, 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 species richness and diversity was low. An MNCR sublittoral survey was carried out in the narrows in May 1992; preliminary assessment suggests a generally more diverse if unexceptional fauna, with many species additional to those recorded by Hunter & Rendall (1986), including hydroids and anemones. A richer epifauna was recorded on sandy mud east of Old Shandwick (MNCR, unpublished data).

4.2.3.4 *Inverness Firth*

Inverness Firth extends from the narrows at Kessock, Inverness, to those between Chanonry Point and Fort George. On the north side lies Munlochy Bay, a local nature reserve where the distribution and abundance of littoral invertebrates has been studied (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*. The intertidal muddy sand at Ardersier was found to be fairly rich in species with well developed tellinid and polychaete communities (Bartrop *et al.* 1980). Strong tidal streams occur near the mouth of Inverness Firth. Monitoring within the Firth in relation to the Inverness main drainage scheme involved studies of the hydrography, water quality and communities (Highland River Purification Board 1985a, 1985b). The fauna of the beaches by the sewage outfall at Longman Point was found to be damaged by pollution. Fewer species than normal occurred and large numbers of pollution-tolerant worms such as the polychaete *Capitella* sp. were found, as well as *Enteromorpha* spp. Rendall & 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 diversity. This 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* in addition to *Capitella capitata*.

The sublittoral sediment fauna in Inverness Firth was also investigated by Highland River Purification Board (Hunter & Rendall 1986). In the inner part of the Firth

the seabed consisted of stones overlying clay. Alturlie Deep was muddy with a community of the bivalves *Abra alba* and *Nucula* spp. and the polychaetes *Terebellides stroemi* and *Nephtys hombergii*. Farther seaward the sediment became coarser and sandy with species such as the amphipod *Corophium crassicorne* and the polychaetes *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 polychaetes *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 bivalve *Spisula solida*.

4.2.3.5 Beauly Firth

Beauly Firth lies between Beauly and Inverness, forming an inland extension of the Inverness Firth. The intertidal mudflats are of particular ornithological importance. An intensive study of the distribution and density of *Zostera angustifolia, Zostera noltii, Ruppia maritima* and *Salicornia* spp. was carried out by Fox, Yost & Gilbert (1986). The most common seagrass within the Firth was found to be *Zostera angustifolia*.

Hunter & Rendall (1986) studied the sublittoral sediment fauna at three sites towards the seaward end of Beauly Firth. The Beauly basin consisted of muddy sand with a rich fauna. In the River 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 Beauly Firth at Kessock, 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*.

4.3 East coast

4.3.1 Introduction, general studies and the open coast

This section covers the coastline from Fraserburgh at the south-eastern point of the Moray Firth to Fife Ness at the northern point of the Firth of Forth (Figure 4.4). The coast comprises a mixture of cliffs, rock and sand broken by several estuaries, including those of some of Scotland's largest rivers. There are numerous, often extensive, bays and sandy beaches. Although this section includes Scotland's third and fourth largest cities, the coast away from the cities and towns is largely unspoilt, and most rivers entering the sea are relatively unpolluted. They include several famous salmon-fishing rivers such as the Don, Dee, North Esk and Tay.

The marine algae of Grampian Region were recorded in 1975 (Wilkinson 1979). Eighty species not previously recorded for the area were found, including the first British record of the brown alga *Sorapion kjellmanii*.

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

The distribution of fucoid algae was described for the Ugie (Peterhead), the Ythan (Newburgh), the Don (Aberdeen) and the Dee (Aberdeen) estuaries (Chater 1927). The Ugie and the Don were similar in that they were both small estuaries supporting an abundance of the fucoid alga *Fucus ceranoides*. Much of the Ythan consisted of muddy shores but where rock occurred it supported a variety of fucoids. A range of fucoid algae also characterised the lower part of the Dee estuary but only *Fucus ceranoides*, which can tolerate reduced salinity, penetrated the estuary beyond Victoria Bridge, Aberdeen. The Don was formerly heavily polluted by paper mill effluent, but since the installation of a biological treatment plant, water quality has much improved, and the estuary was declared a Local Nature Reserve in 1993.

The invertebrate fauna of the Dee estuary was studied by Eleftheriou (1964). As might be expected, 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 estuary supported only 10% to 20% of the macrofaunal diversity common to long estuaries such as the Tees in Cleveland; this was attributed to variable salinity and the absence of mudflats (Milne 1940).

Aberdeen serves as a base for the North Sea oil industry and is an important fishing port, although much less so than formerly. 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* (now *Scolelepis*) sp. and the amphipod *Haustorius arenarius* (Hart 1971).

The only major study of the marine environment of Montrose Bay is a confidential report prepared by AURIS Environmental (1991), who also investigated Lunan Bay to the south; this study found the fauna to be typical of exposed intertidal sediments of the north-east coast of Scotland, with a low species diversity dominated by amphipods and spionid polychaetes. More diverse faunal communities were found at one transect to the south of the mouth of the River North Esk. There have been studies of anadromous fish in the River North Esk, for example Shearer (1990).

The algae of the district of Arbroath, a rocky coastline including high sandstone cliffs and bays with 'floors' – shore platforms with rockpools – bounded by Red Head in the north and Arbroath Bay in the south, were listed by Jack (1890). McLusky & Roddie (1984) investigated the brackish pond at Elliot Links, Arbroath. A limited

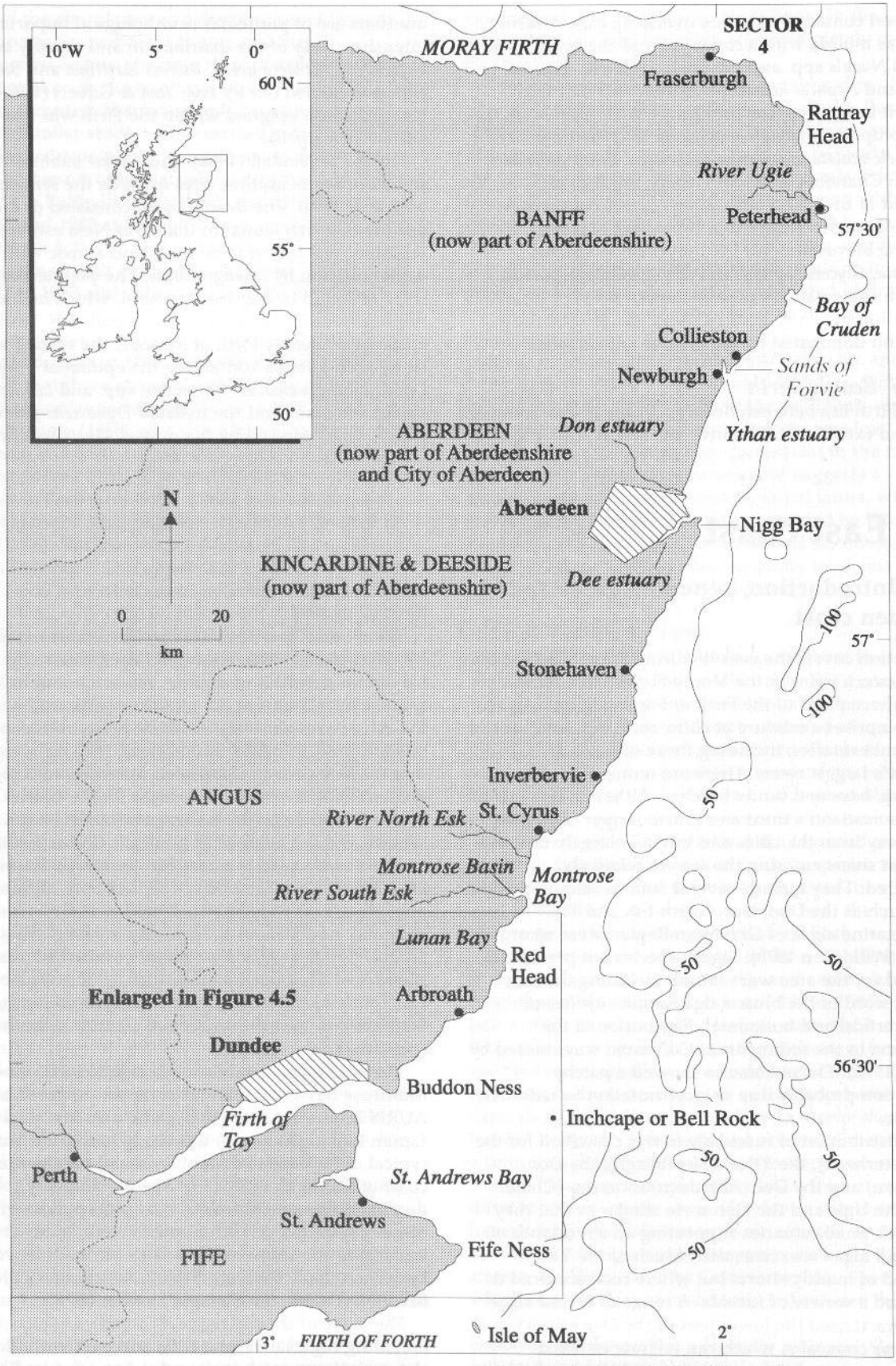

Figure 4.4. The east coast of Scotland, except the Moray Firth and Firth of Forth, showing location of places mentioned in the text.

benthic fauna was found, comprising a mixture of fresh- and brackish-water species, with a rich planktonic fauna dominated by the mysid *Neomysis integer*. To the south-west, the rocky shores and rockpools near East Haven are a favoured site for educational field studies. Dundee Museum holds unpublished species lists dating from the 1930s to the 1970s; Smith, Light & Killeen (1990) provided one of the few published lists.

The sublittoral sediments and fauna near the Inchcape or Bell Rock, 18 km south-east of Arbroath, have been extensively studied in relation to sewage sludge dumping grounds in this area (various reports on behalf of Lothian Regional Council summarised by Moore & Davies (1987), and continuing on an annual basis, reported most recently by Hull & Webster (1991)). The monitoring involves chemical analysis of the sediments, quantitative analysis of the fauna and video recording of the benthos. The sediments consisted of fine to medium grained sands. Over 300 species have been recorded from the area. Moore & Davies (1987) considered that the sediments and benthic macrofauna in the vicinity of Bell Rock did not appear to have been adversely affected by the dumping of sewage sludge. Hull & Webster (1981) reported similar findings, and noted that species diversity in 1990 was the highest recorded since 1981, although the polychaete *Myriochele oculata* had declined significantly in abundance.

4.3.2 Ythan estuary

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. The estuary has been intensively studied by the University of Aberdeen; a full list of publications and theses relating to the Ythan estuary was compiled by the University's Culterty Field Station (University of Aberdeen, Department of Zoology [1992]), supplementing an earlier bibliography by Raven (1978). The estuary is considered one of the best documented in the world, and the research was briefly summarised by Gorman & Raffaelli (1993). Many studies have investigated the distribution and feeding of various bird species in relation to the distribution and productivity of the invertebrate fauna in the mudflats (for example Chambers 1965; Goss-Custard 1966; Heppleston 1968; Milne & Dunnet 1972; Joffe 1978; Greenstreet 1986; Raffaelli, Falcy & Galbraith 1990). The amphipod *Corophium volutator*, the gastropod *Hydrobia ulvae*, the polychaete *Nereis* (now *Hediste*) *diversicolor* and the tellin *Macoma balthica* were found to be widely distributed while other species such as the cockle *Cerastoderma edule*, the periwinkle *Littorina littorea*, the crab *Carcinus maenas* and the mussel *Mytilus edulis* had a more localised distribution. However, mussels are of considerable importance within the estuary as a major source of food for eider duck. Other investigations have covered the ecology, distribution and abundance of particular groups such as crustacean predators (Raffaelli *et al.* 1989) or individual species, such as the sand goby *Pomatoschistus minutus* (Healey 1971), the common goby *Pomatoschistus microps* (Healey 1972; Jaquet & Raffaelli 1989) and the flounder *Platichthys flesus* (Raffaelli *et al.* 1990).

Long-term changes in nutrients, weed mats and shorebirds in the Ythan estuary were reviewed by Raffaelli, Hull & Milne (1989). It was found that nitrogen levels in the River had increased by some 200–300% over a 25-year period, associated with an increase in the proportion of farmland under cereal production. Inputs from sewage pollution were localised and small by comparison. Biomass of *Enteromorpha* also increased over this period, to the extent that green algal mats covered much of the intertidal area. The polychaete *Capitella capitata* became more abundant under these mats, but other species such as *Cerastoderma edule* and *Corophium volutator* decreased, with *Corophium* declining markedly where the algal biomass (wet weight) exceeded 1 kg m^{-2} and disappearing at 3 kg m^{-2}. Although *Corophium* can recolonise mudflats after weed mats become dispersed or buried, this requires areas of uncovered sediment from which the species can spread. Raffaelli, Hull & Milne (1989) suggested that further eutrophication could result in algal mats blanketing most of the intertidal area through the summer months. The absence of weed-free refuges could cause the disappearance of *Corophium*, the main prey species for most of the fish and shorebirds in the estuary (Milne & Dunnet 1972; Baird & Milne 1981), with serious implications. However, 1989 levels of nutrient enrichment appeared to have enhanced productivity, reflected in an increase in shorebird populations. As a result of concern over nitrate pollution from agriculture, a major part of the Ythan's catchment area was proposed by the Scottish Office for designation as one of Scotland's first Nitrate Vulnerable Zones in 1994.

4.3.3 Montrose Basin

Montrose Basin is the estuary of the River South Esk, linked to the sea by a narrow channel (a second channel was infilled during the 1970s). It is shallow and drains almost completely at low water exposing approximately 8 km^2 of mudflats of ornithological importance. Mussels *Mytilus edulis* were formerly extensively cultivated in the Basin for line bait (Fullarton & Scott 1888; Fullarton 1894), and there is still a mussel farm. The Basin is a local nature reserve, and most recent work has been undertaken for the Scottish Wildlife Trust, who manage the reserve. An investigation of the fauna and flora in 1982 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 with the previous survey owing to a drop in the level of organic enrichment.

The 1982 study was updated and expanded by Atkins, Caudwell & Herbert (1992). This study found domestic sewage contamination to be widespread, and increasing nutrient enrichment was identified as a potentially serious problem. The estuary was found to be apparently more marine-influenced than previous studies had indicated, with major differences from the 1982 results observed in the fauna and flora. Despite

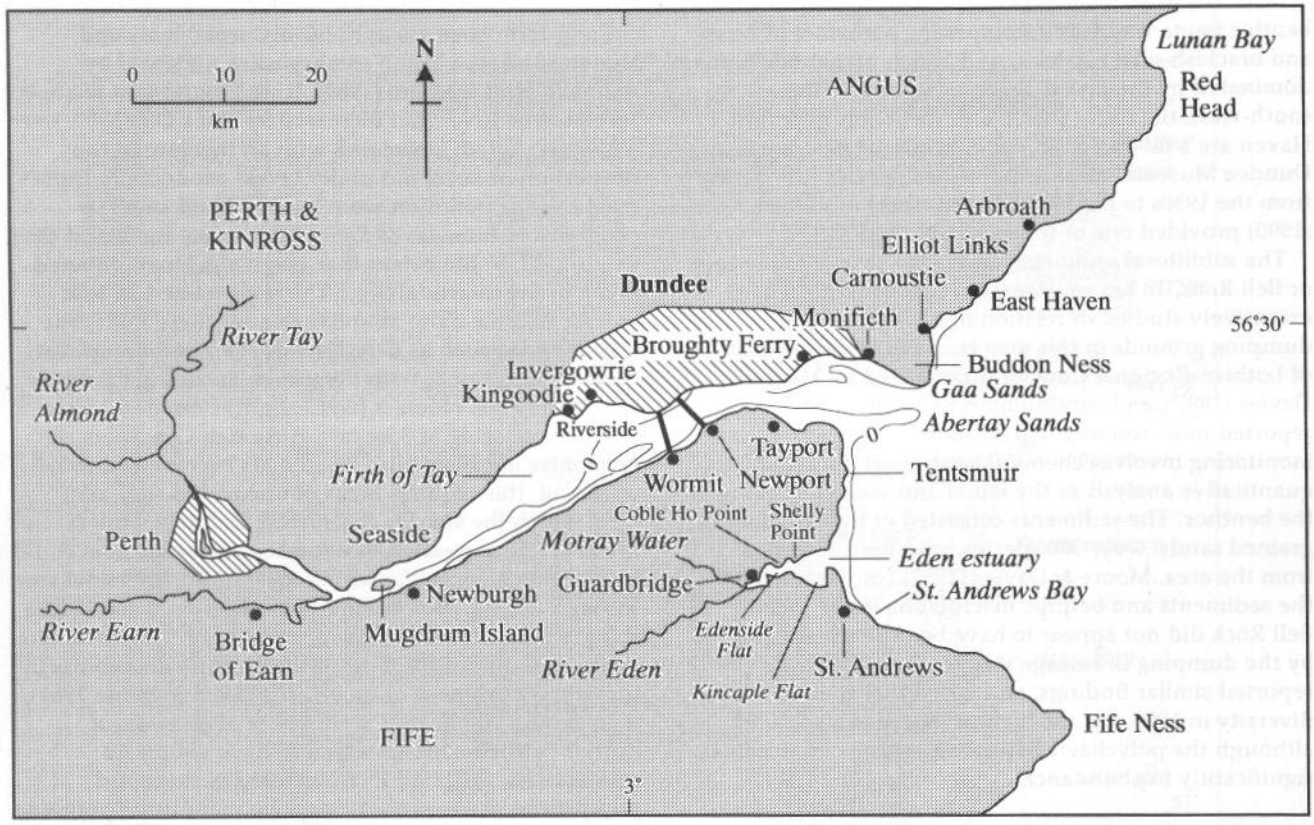

Figure 4.5. St Andrews Bay and the estuary and Firth of Tay showing location of places mentioned in the text.

organic pollution, there had been a marked increase in species diversity, with some marine species also increasing in density and/or extending their range westwards, notably the cockle *Cerastoderma edule* and spionid polychaetes. Fourteen additional species of polychaetes were recorded, many of them typically marine rather than estuarine. The abundance of the estuarine *Hydrobia ulvae* had remained unchanged, and therefore of much less relative importance than in 1982, while the density and extent of *Zostera* spp. had declined. *Mytilus edulis* remained the dominant bivalve. A further five-year programme of work to monitor biological conditions on the tidal flats was commenced in 1993 (for instance, Caudwell & Jones 1994a).

4.3.4 Firth of Tay

The River Tay meets the sea as a major Firth between the sandy peninsulas of Buddon Ness on its north side, and Tentsmuir on the south. The Firth of Tay can be divided into the relatively marine influenced outer Firth, downstream from the Tay Rail Bridge at Dundee, and the more estuarine inner reaches upstream towards Perth (Figure 4.5). Khayrallah & Jones (1975) identified a middle estuary region between Invergowrie and Broughty Ferry Castle; this was found to be the region of maximum variation in salinity, and also of most pollution. However, as a whole, the estuary is a partially mixed one, strongly influenced by freshwater input. The Tay has by far the largest flow of any British river, with a mean flow rate of 198 $m^3 s^{-1}$ and a normal range between 94–276 $m^3 s^{-1}$ (Williams & West 1975); furthermore, the true entrance to the Firth is extended further seawards beyond the apparent mouth by the Gaa and Abertay sandbanks, which restrict water exchange with the open sea. Consequently, although the influence of ordinary spring tides penetrates almost as far as the confluence of the Rivers Tay and Almond, 4 km upstream from Perth, and 50 km inland, saline conditions only penetrate the estuary as far as Newburgh, even under low-flow conditions (Williams & West 1975). Typically estuarine conditions thus occur relatively far downstream, around Dundee, and the high flushing rate means nutrients are rapidly carried out to sea, resulting in an impoverished fauna compared with many estuaries; however, the high flushing rate also produces generally unpolluted conditions. The application of remote sensing techniques has shown the Tay estuary to be a much more complex system than previously known, with many complex frontal systems which have implications for the dispersal of effluent, in addition to natural processes such as sandbank formation (for example, Anderson 1989; Ferrier & Anderson 1990, 1992; Jiao & Anderson 1992).

The majority of studies in the Firth of Tay have been carried out by the Tay Estuary Research Centre and University of Dundee; physical aspects, sedimentology, hydrography and chemistry have generally received more attention than biological aspects, although work

has included investigations on the environment, plankton, bacteriology, species distribution, single species and pollution, including heavy metals (e.g. Jones, Jones & Stewart 1972). A number of recent studies have concentrated on the impact of sewage pollution from outfalls at Dundee. Other work has been carried out by the Tay River Purification Board (TRPB), and is described below.

Several important single volumes contain much of the published information. Corlett (1972) gave an appraisal of knowledge for the Firth of Tay at that time, and a Royal Society of Edinburgh (RSE) symposium held in October 1971, provided an environmental assessment of the Tay and Forth estuaries; a total of four RSE symposium volumes covering the Tay estuary have been published (Anon. 1972, 1975, 1980; McManus 1987). A number of studies relating to the inner estuary were summarised by ECOS Countryside Services (1992) in a report investigating the estuary's potential for a local nature reserve. ECOS Countryside Services (1996) reviewed the natural heritage (biological, earth sciences and landscape aspects) of the Firth of Tay, including the Eden Estuary. The report series of the Tay Estuary Research Centre is another useful source of information, mainly on physical aspects of the estuary and Firth of Tay but including some papers on the biota, such as algae (Peek 1982a) and planktonic copepods (Peek 1982b).

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 and St Andrews Bay was first reported by Mill (1884), while McManus (1966, 1972) provided an account of the geological and geomorphological development of the Tay with reference to sediments in the bed of the estuary. At the limit of tidal influence upstream of Perth, the bed of the river was found to consist of highly compacted clays over which boulders, pebbles and sand were found. Below Perth coarse sands and fine gravels formed bars. Bedrock occurred in the channel and along the south side of the estuary between Perth and Newburgh, with coarse debris from the River Earn 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. These studies were continued and reported by Buller & McManus (1975) and McManus, Buller & Green (1980).

The bathymetry, sediments and species of the Tay were described and mapped by Buller, McManus & Williams (1971). Sediments were divided into three zonational areas; saltmarshes, upper tidal flats, and lower tidal flats. The north shore of the estuary was composed of mud- and sandflats while the south shore ranged from bedrock to mud. Muddy sand occurs near Tayport, while the shores of the outer Firth are mainly of clean sand. Bedrock outcrops in the littoral zone at a few places in the Firth, mainly on the south shore.

There are extensive mudflats, 90% of which are in the inner estuary between Seaside and Kingoodie, and major beds of the reed *Phragmites communis* on the upper shore, mainly between Kingoodie and the confluence of the Earn and Tay, the northern shore, and around Mugdrum Island (Alizai & McManus 1980); introduced to the estuary in the 18th century, this is the most extensive continuous stand of brackish *Phragmites* reedswamp in Britain, and is commercially harvested for thatching.

Alexander (1930) provided an early account of the benthic fauna and flora between Bridge of Earn and the Abertay lightship. An investigation of the sediments and fauna on the southern shore of the outer 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). Clelland (1988) briefly surveyed the intertidal biota of Wormit Bay, and TRPB has also carried out biological surveys and investigation of sediments on the foreshore near Dundee (B. Clelland pers. comm.). Microscopic fungi living in the estuarine sediments were described by Gaertner (1980) and Ulken (1980).

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 estuary showed it to be widely distributed in the littoral sediments of the Tay (Khayrallah 1977). Unusually euryhaline populations of the amphipods *Corophium volutator* and *Bathyporeia pilosa* extended above Newburgh into a region with a maximum salinity of 0.26 ‰, well below the normal lower salinity limit for these species (Khayrallah & Jones 1975). Much of the sublittoral had little or no infauna owing 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 4.6).

The Firth of Tay is relatively unspoilt and unpolluted (Khayrallah & Jones 1975), with substantial untreated sewage discharges occurring only at Dundee. These outfalls are being collected into several new long outfalls, the first of which commenced operation in 1992, but full sewage treatment is likely to be some years off (Ferrier & Anderson 1992). Perth's sewage is treated.

A high-density population of the polychaete *Marenzelleria viridis* discovered at Invergowrie Bay was

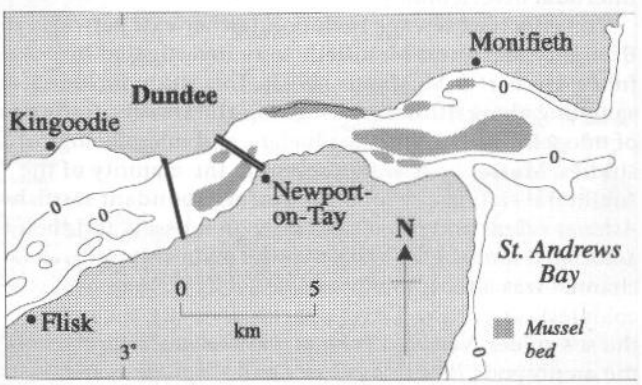

Figure 4.6. The distribution of major mussel *Mytilus edulis* beds in the Tay estuary (from Khayrallah & Jones 1975).

notable as one of the first European records of this North American species (Atkins, Jones & Garwood 1987); its distribution and density around the Invergowrie sewer outfall was negatively correlated with all other species.

The macrofauna of the sediments at Invergowrie and Monifieth were 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. A repeat study in 1989 (Jones, Herbert & McManus 1989) was carried out with the objective of determining the pollution status of Invergowrie Bay prior to the reduction and eventual cessation of discharges through the outfall there. It was found that the macrofauna in the eastern part of the Bay had decreased in abundance, with much of the decline occurring in one species, the amphipod *Corophium volutator*. It was not possible to identify the underlying cause of this change, although a general decline in crustaceans in the Bay and the relative abundance of worms suggested organic pollution. No consistent spatial trends were apparent in nematodes in the sediment. The results indicated that the overall state of Invergowrie/Kingoodie Bay was an environment showing increasing evidence of sewage pollution, exacerbated by poor dispersion and dilution owing to the shallowness of the water. It was also noted that the sediments had varied considerably over the course of the three investigations in 1984, 1986 and 1989, but by 1989 had become quite similar to those originally found. These variations in sediment particle size and organic content were probably attributable to wind and tidal processes. The same report (Jones, Herbert & McManus 1989) described significant levels of sewage contamination farther east, at Riverside; this was attributed to pollution being carried westwards from other outfalls at Dundee. This region of the estuary was expected to improve considerably after commissioning of a new outfall.

Jones, Atkins & Caudwell (1992) found the western half of Invergowrie Bay to have a much richer fauna than a restricted tidal flat to the south of Dundee Airport at Riverside. They attributed this to organic enrichment from sewage in the Bay, and closure of the outfall there was expected to have a negative impact on the infauna and on the birds which feed on the intertidal invertebrates.

The effects of sewage pollution farther east between Broughty Ferry and Monifieth were investigated by Jones, Herbert & McManus (1990). This study included sampling along littoral and sublittoral transects, testing of mussels *Mytilus edulis* for metals, and microbiological studies. Mussel beds were present at the majority of the sublittoral stations, several supporting abundant starfish *Asterias rubens* and other predators on mussels and their associated fauna. One station in the main shipping channel was almost totally encrusted by sponge colonies, supporting a high species diversity, including the sea spider *Nymphon rubrum*, various scaleworms, and the amphipods *Parajassa pelagica* and *Ampithoe rubricata*. Polychaete and oligochaete worms were important or dominant at most of the littoral sites, with *Bathyporeia pilosa* dominant at some stations, diversity tending to increase lower on the shore. Testing of shore-collected mussels for metals found variable levels of contamination, with only levels of mercury and possibly nickel at some stations representing values of possible concern. A further sublittoral survey using grab sampling was undertaken in 1991 by TRPB and the Scottish Office Agriculture and Fisheries Department (SOAFD) as part of the work of the North Sea Task Force UK National Monitoring Programme (A.J. Downie pers. comm.).

The Tay is a famous salmon fishing river, but the majority of studies on salmon *Salmo salar* relate to the Tay's upper reaches and tributaries (e.g. Webb 1989); its sea trout *Salmo trutta* were described by Walker (1990). Thomas & Sackville (1972) recorded a diverse estuarine fish community, and Maitland & Smith (1987) considered the Tay's fish community, particularly the estuarine component, to be the River's most outstanding biological feature. It included one of only three populations of smelt *Osmerus eperlanus* in Scotland, and the only one on the east coast. Dundee Museum formed a collection of fish entrained on the intake screens of Carolina Port Power Station at Dundee between January and April 1979 (Sage 1979). Over 9000 individuals of 24 species were collected and measured, with sprat *Sprattus sprattus* and small herring *Clupea harengus* comprising 41% and 39% respectively of the total numbers caught.

At the mouth of the Firth of Tay, the Abertay Sands form a seaward extension of Tentsmuir Point National Nature Reserve and provide a regular haul-out for common seals *Phoca vitulina*.

4.3.5 St Andrews Bay and the Eden estuary

Many studies have been undertaken in the vicinity of the Gatty Marine Laboratory at St Andrews. However, work on the marine life in the area commenced in the mid-19th century before the establishment of the laboratory with the interest of Professor W.C. M'Intosh, who produced a series of papers on the fauna of St Andrews Bay, and later workers studied the algae of the area. A compilation of records of fauna and flora for St Andrews Bay (defined by a line between Arbroath and Fife Ness), incorporating earlier work and including an important bibliography, was produced by Laverack & Blackler (1974).

The littoral zone of the Eden estuary was studied in relation to shorebird feeding (Johnston, Cobb & Bell 1979). The sediment shores mainly fell into two areas, the Edenside Flat to the west of Martin's Point, and Kincaple Flat to the east. Three main sediment types occurred:

- firm sand was located at the high water mark;
- heavy black mud and mud covered the majority of the area;
- firm sand occurred farther seaward.

Only a few estuarine species, such as the polychaete *Nereis* (now *Hediste*) *diversicolor* and the isopod *Corophium volutator*, both tolerant of low salinity, were found towards the head of the estuary 3 km upstream

from Guardbridge. High densities of *Corophium volutator* occurred at Edenside Flat, while in the more saline area of Kincaple Flat the bivalves *Cerastoderma edule* and *Macoma balthica* were widespread. Seagrass *Zostera marina* occurred in limited abundance on Kincaple Flat only. On the north side of the estuary between Coble Ho Point and Shelly Point the shores were dominated by fucoids. Mussel beds (formerly harvested commercially) occurred on the banks of the river channel. A further survey of the invertebrate fauna and algal flora in the inner estuary was undertaken by TRPB in 1989. This largely confirmed the findings of earlier surveys, but also recorded an abundance of oligochaetes, not previously surveyed. An area of soft mud to the east of the Motray confluence was found to be devoid of macrofauna in places; this was probably due to organic pollution. The location and composition of green algal mats in the estuary was undertaken by Caudwell & Jones (1994b). Adams & Grierson (1974) investigated hydrography and pollution.

The Eden estuary was designated a local nature reserve in 1978, and the management plan (North-East Fife District Council 1987) drew together existing information. A programme to eradicate introduced cord-grass *Spartina anglica* has been underway since the mid-1980s (L. Hatton pers. comm.).

The coast south-east of St Andrews is largely rocky, with a number of small bays. An artificial saline lagoon at Fife Ness, probably originally a lobster pond but subsequently silted-up with muddy sand, was found to have been very successfully colonised by several bivalves tolerant of brackish water, including *Mya arenaria* (Smith 1984). This site was described as "a curiosity".

4.4 Estuary and Firth of Forth

4.4.1 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 Bridges, 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 comprises the area from the Forth Bridge to the seaward limits, and is considered an inlet of the sea rather than an estuary (McLusky 1987a) (Figure 4.7). There is a small estuary where the River North Tyne meets the sea at Tyninghame, in the south-east part of the Firth, which retains the largest surviving area of saltmarsh in the Firth of Forth; more restricted estuarine conditions also occur on the south shore at Aberlady Bay. Both of these sites have been studied by various workers, and this work was summarised in descriptive management plans. (Tyninghame Technical Working Party 1976; Aberlady Bay LNR Working Party 1977).

Much industry has developed around the Firth of Forth especially near Edinburgh and in the estuary at Grangemouth. The wide opening of the Firth narrows at Queensferry but is navigable through the deep channel

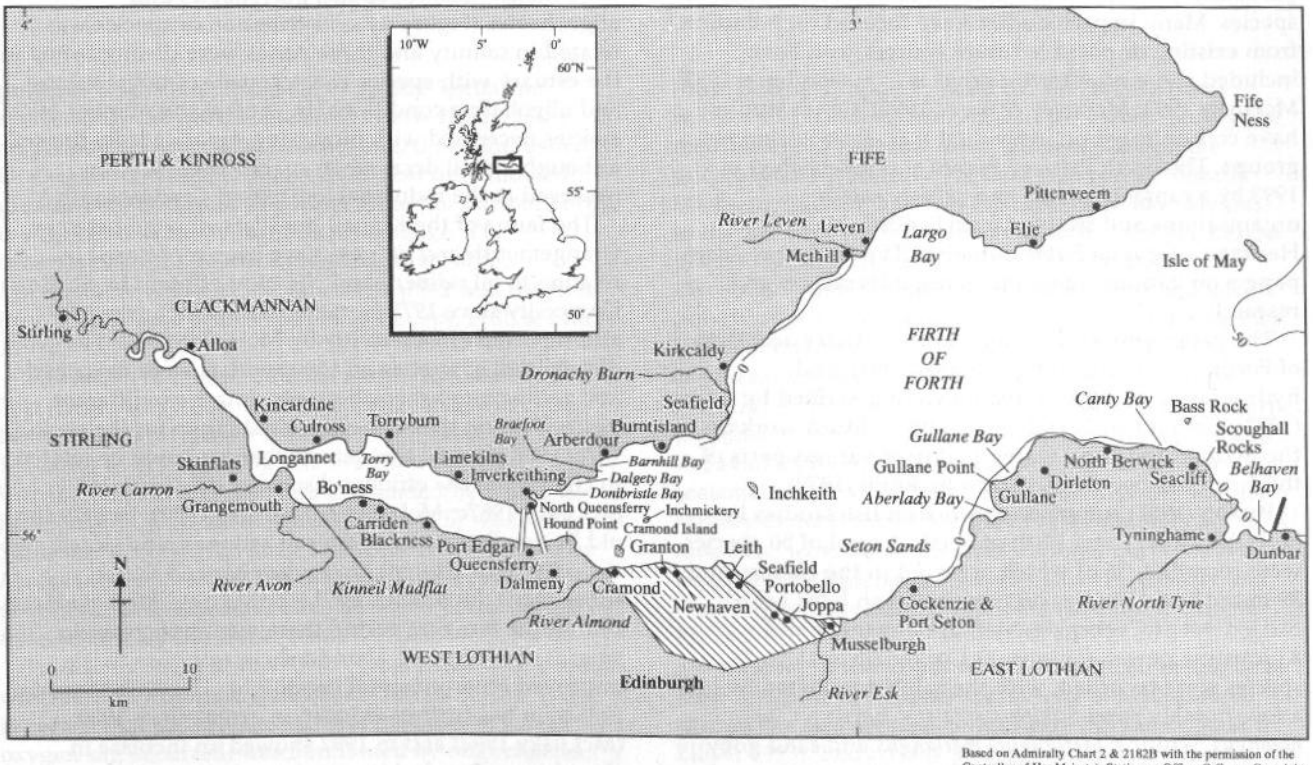

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Figure 4.7. The estuary and Firth of Forth showing location of places mentioned in the text.

up to Grangemouth. The shores and sublittoral environment of the Forth estuary are mainly sedimentary. The coastline of the Firth of Forth is an indented series of sandy bays and rocky headlands, with some more extensive cliffed rocky shores. 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 Isle of May, and shallow areas off the rocky coast at North Berwick. There are several other islands in the Firth, of which Cramond Island and Inchcolm are the largest. Most sublittoral benthic investigations relate to sediment sampling.

The number of marine studies escalated in the early 1970s with the establishment of the Universities of Stirling and Heriot-Watt and the Forth River Purification Board (FRPB). Most work in the estuary and Firth of Forth has therefore been concentrated in the period since 1970. Heriot-Watt University's Institute of Offshore Engineering (IOE) has carried out a number of projects in the Firth. The estuary has been particularly intensively studied by the two universities; McLusky *et al.* [1991] provide a bibliography of this work carried out by the University of Stirling's Department of Biological Sciences. Additional research has been carried out by Napier College (now University), Edinburgh. A symposium held in 1985 on the natural environment of the estuary and Firth of Forth brought together available knowledge at the time (McLusky 1987a), supplementing an earlier symposium volume (Anon. 1972). Goodman, Ferbrache & Martin (1984) reviewed studies in the estuary sponsored by BP since 1973. Many investigations in the estuary have been related to pollution, particularly the effect of effluents on the distribution of species. Many impact studies have focused on pollution from existing or possible future sources, and have included shore monitoring projects (e.g. Goodman 1982; McLusky 1992; McLusky & Berry 1992). Other studies have concentrated on individual species or taxonomic groups. The Forth Estuary Forum was established in 1993 by a range of public and private sector organisations and support from Scottish Natural Heritage's *Focus on Firths* initiative. The *Forum* produces papers on various topics including information and research.

The geography and geology of the estuary and Firth of Forth was described by Browne (1987), and hydrography and water quality were described by Craig (1972), Collett (1972) and Covill (1972). Much work on the hydrography and water quality of various parts of the Forth has been undertaken by FRPB (1979).

Poxton (1987) summarised 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. Studies on entrained fish have been carried out at Cockenzie, Methil, Longannet and Kincardine power stations. At Cockenzie in 1977, 28 species were recorded, with the catch dominated by just a few, notably sprat *Sprattus sprattus*, herring *Clupea harengus*, whiting *Merlangius merlangus* and sand goby *Pomatoschistus minutus*, and with far more species and individuals being entrained during the winter than the summer months (Maitland, East & Morris 1980). Work is continuing under the auspices of the Fish Conservation Centre, Stirling (P. Maitland pers. comm.).

4.4.2 The Forth estuary

4.4.2.1 Intertidal

The sediment shores and macrofauna in the Forth estuary were described by McLusky (1987b). Intertidal sediments predominantly consisted of fine-grained muds and covered an area of 23.3 km^2, the majority occurring at Skinflats, Kinneil and Torry Bay. The salinity ranged between 0‰ and 32‰ along the length of the estuary (McLusky 1987b), and in the upper estuary, the stressed freshwater–seawater interface, with a much reduced fauna, was particularly acute and extensive (McLusky, Hull & Elliott 1993). 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 relatively low compared with other estuaries, which may be attributable to the level of pollutants in the area (McLusky 1987b).

The meiofauna of Kinneil mudflats at Grangemouth has been intensively studied with respect to the effect of industrial effluent outfalls on species diversity and density (Long 1985). Mills (1988) found that meiofaunal species composition changed along a pollution gradient on Kinneil mudflats. Moore (1987) surveyed the meiofauna on the lower shore at 21 sites in the Forth estuary in 1982. The main groups of meiofauna found were nematodes, copepods, polychaetes and oligochaetes (Figure 4.8). 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 local decrease in species diversity was observed at the industrial location of Grangemouth.

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 and reported most recently by McLusky 1992). The distribution of species on the mudflats were 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 (McCrory 1987; McLusky 1987c; McLusky & McCrory 1989). In 1979 the old British Petroleum chemicals effluent pipe closed and the pattern of effluent discharge changed with 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 area of severe pollution has further reduced in extent since 1989 (McLusky 1992) and in 1992 showed an increase in abundance of typical 'marine' species (e.g. the polychaete *Nephtys*, the cockle *Cerastoderma*, and various

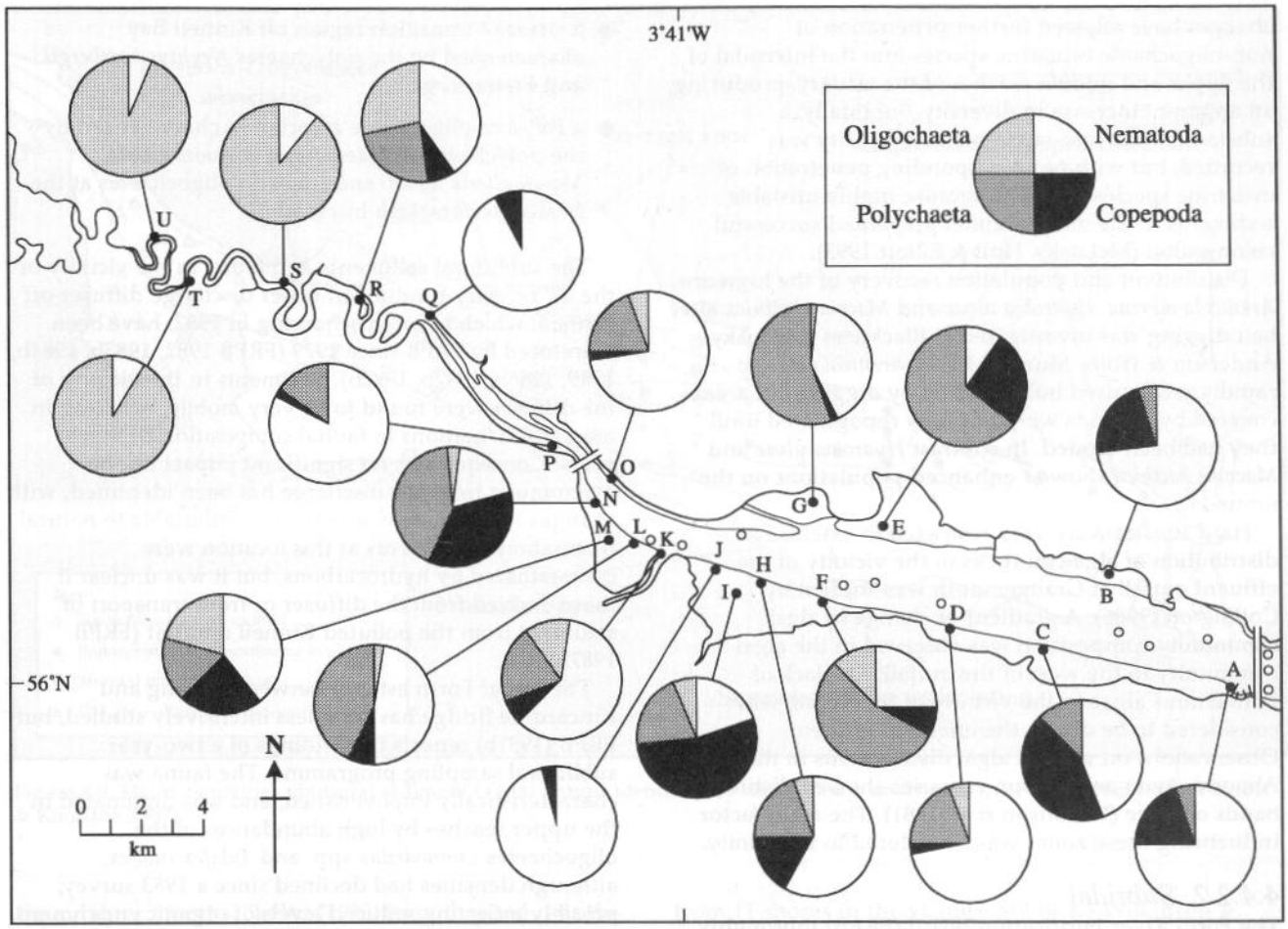

Figure 4.8. Composition of intertidal meiofauna by dry weight along the Forth estuary in summer 1982; open circles indicate sublittoral survey sites (from Moore 1987).

polychaetes), whilst numbers of typical 'estuarine' species (e.g. the polychaete *Nereis* (now *Hediste*), the amphipod *Corophium*) were unchanged or diminished. Dry weather, which reduced river-flow and allowed greater penetration of salt water from the Firth of Forth, is suggested as the reason for this change. The occurrence of the North American polychaete *Marenzelleria viridis* in the estuary in 1982 was the first European record of this species (McLusky, Hull & Elliott 1993).

The fauna of the mudflats at Skinflats, Carriden, Torryburn, Torry Bay, Culross and Blackness has also been studied (McLusky & Brown 1974; McLusky 1978a; 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*. The meiofauna of intertidal sediments at Kincardine, Limekilns and Bo'ness was investigated by Mulhern (1982).

Pollution effects in the Forth estuary as a whole were considered by McLusky, Elliott & Warnes (1978). They reported that the fauna upstream of Alloa, where an oxygen sag occurred, was dominated by oligochaetes, while below Kincardine Bridge mudflat populations were characterised by the snail *Hydrobia ulvae*, *Nereis* (now *Hediste*) *diversicolor*, and the bivalves *Macoma balthica* and *Cerastoderma edule*. In the lower estuary the distribution of *Hydrobia ulvae*, *Macoma balthica*, the polychaetes *Nereis* (now *Hediste*) *diversicolor*, *Nephtys hombergii*, and the bivalves *Cerastoderma edule*, *Mytilus edulis* and *Mya* sp. was described with reference to bird predators (McLusky *et al.* 1976). The seasonal distribution and abundance of oligochaetes and small polychaetes in the estuary was described by Phizacklea (1978) and 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 density and diversity of macrofauna increased (McLusky, Teare & Phizacklea 1980).

Sampling in the upper estuary produced evidence of large spatial and temporal variations in macrofaunal abundance and species composition (McLusky, Hull & Elliott 1993). Reductions in the formerly very large organic inputs from sewage and industry since the early 1980s have reduced oligochaete populations. These

changes have allowed further penetration of non-oligochaete estuarine species into the intertidal of the upper and middle reaches of the estuary, producing an apparent increase in diversity. Subtidally, a substantial decrease in oligochaete density was recorded, but with no corresponding penetration of estuarine species, possibly because highly unstable sediments in the main channel prevented successful colonisation (McLusky, Hull & Elliott 1993).

Distribution and population recovery of the lugworm *Arenicola marina*, *Hydrobia ulvae* and *Macoma balthica* after bait digging was 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.

Hard substrata are very restricted in extent. The distribution of algae on rocks in the vicinity of the effluent outfall at Grangemouth was studied by Collington (1986). A gradient of change in algal community composition 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 effluent. 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 salinity.

4.4.2.2 *Subtidal*

The Forth River Purification Board (FRPB) thoroughly surveyed the sediments and benthic fauna in the Forth estuary (Elliott, Taylor & Davies 1981; Elliott 1983; FRPB 1991b, 1992e). Sediments consisted of sands and muds with shells, clinker, fly-ash and other debris. A decrease in species diversity was found with decreasing salinity and from deep to shallow water. In general polychaetes, principally *Nepthys*, *Polydora* and *Ampharete*, dominated the lower estuary and oligochaetes the upper estuary although certain groups such as tellinids and spionids dominated isolated patches of the estuary bed. The lowermost part of the estuary, off Port Edgar, was found to be characterised by a higher species diversity and abundance owing to the presence of many marine species, and was dominated by the phoronid *Phoronis* sp. and the bivalve *Abra alba* (FRPB 1992e). Four species associations were recognised by classification analysis in the Forth estuary (Elliott & Kingston 1987) (Figure 4.9). These were:

- a supra-estuarine association, characterised by the polychaetes *Dodecaceria concharum* and *Neoamphitrite figulus* and the bivalve *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 at the freshwater/brackish interface.

The sublittoral sediments and fauna in the vicinity of the BP refinery 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, 1992b). Sediments in the vicinity of the diffuser were found to be very mobile, resulting in marked fluctuations in faunal composition between years. Consequently, no significant impact on the macrofauna from the discharge has been identified, with changes in the macrofauna being attributable to natural fluctuations. Sediments at this location were contaminated by hydrocarbons, but it was unclear if these derived from the diffuser or from transport of sediment from the polluted Kinneil mudflat (FRPB 1987b).

The upper Forth estuary between Stirling and Kincardine Bridge has been less intensively studied, but FRPB (1991b) reports the findings of a two-year sublittoral sampling programme. The fauna was characteristically impoverished, and was dominated in the upper reaches by high abundances of the oligochaetes *Limnodrilus* spp. and *Tubifex tubifex*, although densities had declined since a 1983 survey, possibly reflecting reduced levels of organic enrichment. Salinity was considered to be the primary factor governing the distribution of the upper estuary communities.

4.4.2.3 *Fish*

The lower Forth estuary was found to have a lower diversity of fish than other less polluted estuarine areas, with low species richness probably being a result of low water temperature (Elliott and Taylor 1983, 1986, 1989; FRPB 1984c). Studies showed that the estuary was important as a nursery ground for flatfish and gadoids and an overwintering ground for clupeids. Migratory fish populations showed large fluctuations over the year and variations from year to year, with peak populations occurring during the winter months. The estuary supported approximately 0.5% of the North Sea stocks of certain size-classes of some commercially important species (Elliott, O'Reilly & Taylor 1990).

4.4.2.4 *Plankton*

The zooplankton along the length of the Forth estuary, from freshwater to fully marine conditions, was studied over an eighteen-month period by Taylor (1983, 1987) 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 estuary and Firth received incursions of neritic species, especially during

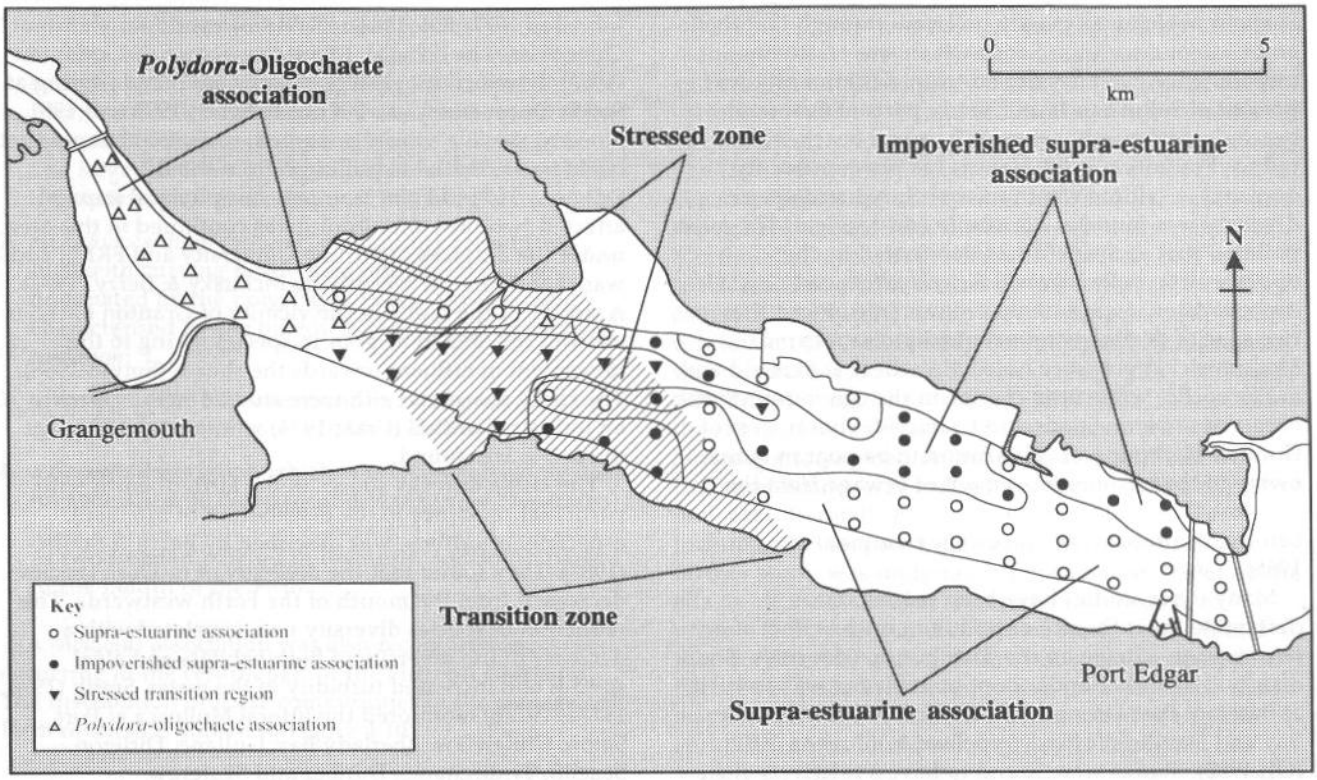

Figure 4.9. Major estuarine sublittoral sediment faunal groups identified by classification analysis in the Forth estuary (from Elliott & Kingston 1987).

the summer months. Taylor (1993) hypothesised that the zooplankton of the upper and middle estuary was dependent for food not upon phytoplankton, but on either anthropogenic inputs of distillery waste and sewage, or upon the microphytobenthos.

4.4.3 The Firth of Forth

The biology of the Firth of Forth has been studied since the 1830s, and the findings of Victorian naturalists provide a valuable base-line for comparison with more recent studies. 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 studied 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 & b) 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 were recorded by Lowe (1935). Algae were surveyed at Joppa and Dunbar in 1961 and 1971 (Johnston 1972; Knight & Johnston 1981). A reduction in the number of species and size of individuals compared with the records of Traill was found at Joppa, formerly a very rich shore, which was considered to be due to the discharge of untreated sewage in the area. In contrast, at Dunbar, the 74 species selected for comparative study with Traill (1890) were still present in the 1961 and 1971 surveys. These findings were confirmed when the marine algae were recorded from 11 shores in the vicinity of Elie by Wilkinson & Tittley (1979). In comparison with Traill (1888), no change was found in species diversity. Comparisons were also made with other sites in the Firth of Forth. At Dunbar species diversity was unchanged, but at Joppa a great reduction had occurred, attributable to the increased level of pollution in that area. Algae collected from a variety of shores between Canty Bay and Dunbar were listed by Norton (1976), and a list of marine algae of Kirkcaldy District was given by Caldwell (1982). The distribution of algae on a variety of natural and artificial substrata at Pittenweem, Leven, Newhaven, Granton, North Berwick and Dunbar was investigated by Rome (1979). Wilkinson, Scanlan & Tittley (1987) mapped and described the algae of the Forth with respect to changing conditions. They found algae-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 the effects of coal mining activity respectively.

4.4.3.1 Intertidal

The sediment shores of the Firth were described by Read (1977, 1987). Shores tended to be poor in faunal diversity which, in some areas, was due to sewage effluent. Four sediment shores, Cramond, Seafield, Portobello and Seton Sands, were studied in detail in relation to the Edinburgh Sewage Scheme (Anderson *et al.* 1981). Before the introduction of the sewage treatment scheme in 1978, 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 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 *Scolelepis foliosa* and *Capitella capitata*. After sewage treatment was introduced 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 owing to the onshore movement of sewage from the Caroline Park and Granton Gas Works that occurred before the introduction of sewage treatment (Smyth 1968).

Many other 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 was 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 (Barnes 1981). The fauna of the shore at Leith Sands was 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 colonisation by opportunistic species such as the polychaete *Mediomastus fragilis* and the oligochaete *Tubificoides benedeni*. Similar studies in relation to outfalls were carried out at Dunbar (FRPB 1981a), South Queensferry (FRPB 1981b), Inverkeithing Bay (FRPB 1984a), Burntisland (FRPB 1986a) and Gullane and Belhaven Bay, Dunbar (Read 1987). Both littoral and sublittoral sampling was repeated at the latter site in 1991 (FRPB 1992a). The sublittoral fauna was found to be moderately diverse, particularly where the seabed was rocky; however, littoral sediments contained a low species diversity and abundance, attributable to the unstable nature and low organic content of the sand.

The distribution and abundance of meiofauna in intertidal sediments has been described for a number of sites in the Firth of Forth and Forth estuary including Inverkeithing Bay (Chong 1985), Seafield, Aberdour, Limekilns, Kincardine, Bo'ness, Granton, Port Seton and Dunbar (Mulhern 1982). In the vicinity of effluent outfalls the density and species diversity of meiofaunal communities was greatly reduced.

A number of rocky shore surveys have been carried out in relation to pollution. The shore at Burntisland was 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). FRPB surveyed four shores at Queensferry in 1975 (M. Elliott pers. comm.). Goodman (1982) described the results of rocky shore monitoring at South Queensferry carried out between 1973 and 1981. None of the five transects studied exhibited changes that could be attributed to pollution from the BP Dalmeny/Hound Point terminal, but physical impact affected two sites. Monitoring has continued in this area under the auspices of Stirling University and FRPB, and was reported most recently by McLusky & Berry (1992). A survey of the fauna in the vicinity of Granton harbour showed the area to be poor in species owing to the movement of effluent towards the shores (Smyth 1968). The rocky shores at Leith were studied with respect to an industrial outfall (Craig 1974) where a limited range of species was found.

The fauna of rocky shores in the Firth of Forth with particular reference to the distribution of Mollusca, especially littorinids, was described by Berry & 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 increased turbidity of the water. Smith (1976, 1977a, 1977b) monitored the littoral Mollusca at Port Seton, Craigielaw, Aberlady Bay, Gullane, Dirleton, Seacliff, Tyninghame, Dunbar and Skateraw.

The habitats and communities of the rocky shores in Largo Bay, Inverkeithing, North Queensferry, Gullane and North Berwick have been surveyed by Heriot-Watt University. Rocky shores east of Aberlady Bay were studied by the Institute of Estuarine and Coastal Studies (1992), with particular emphasis on organisms which could cause fouling at Torness Power Station, south-east of Dunbar.

Studies of the fauna of the diverse shores at Tyninghame were brought together, and the distribution of *Zostera* in the North Tyne estuary recorded, in a management plan for the area (Tyninghame Technical Working Party 1976).

The section of coast between Gin Head (North Berwick) and Dunbar was surveyed by the MNCR in 1992 (Davies 1994), while the North Tyne estuary and adjacent sediment shores at Tyninghame/Belhaven Bay were described by Brazier & Murray (1994). Communities classified on the basis of this survey are described Brazier *et al.* (in prep.).

4.4.3.2 *Subtidal*

A detailed study of the distribution of sublittoral benthic fauna in the Firth of Forth was undertaken by Heriot-Watt University in collaboration with FRPB (Kingston 1977). This work was summarised by Elliott & 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 Forth Bridges. Four principal species associations in the Firth of Forth were identified by classification analysis:

1. an *Abra* community characterised mainly by the bivalve *Abra nitida* covered the majority of the Firth, and 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, which occurred in the eastern part of the Firth off Edinburgh;
2. an *Echinocardium-filiformis* community found from Inchkeith curving north-west into Largo Bay was dominated by the polychaete *Pholoe inornata* and characterised by the burrowing urchin *Echinocardium cordatum*;
3. a *Venus* community was found in two bands, one off Largo Bay and the other off Aberlady Bay;
4. a *Crenella* association which was characterised by the bivalves *Crenella decussata* and *Venus* (now *Timoclea*) *ovata* and the amphipod *Metaphoxus fultoni* 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 4.10.

Various studies have been undertaken on sublittoral sediments in the Firth of Forth in relation to industrial and sewage outfalls, mainly by FRPB. The results of various recent surveys and monitoring projects in the Firth and Forth estuary were reported by FRPB (1993a). The fauna in sediments between Cramond Island and Gullane Point were surveyed in 1972 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 was carried out 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, was studied in relation to heavy metal pollution (Barr 1982). Fewer species were found at Inchmickery compared with other *Modiolus* beds. A further study was undertaken by Anderson (1986) on the effects on 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

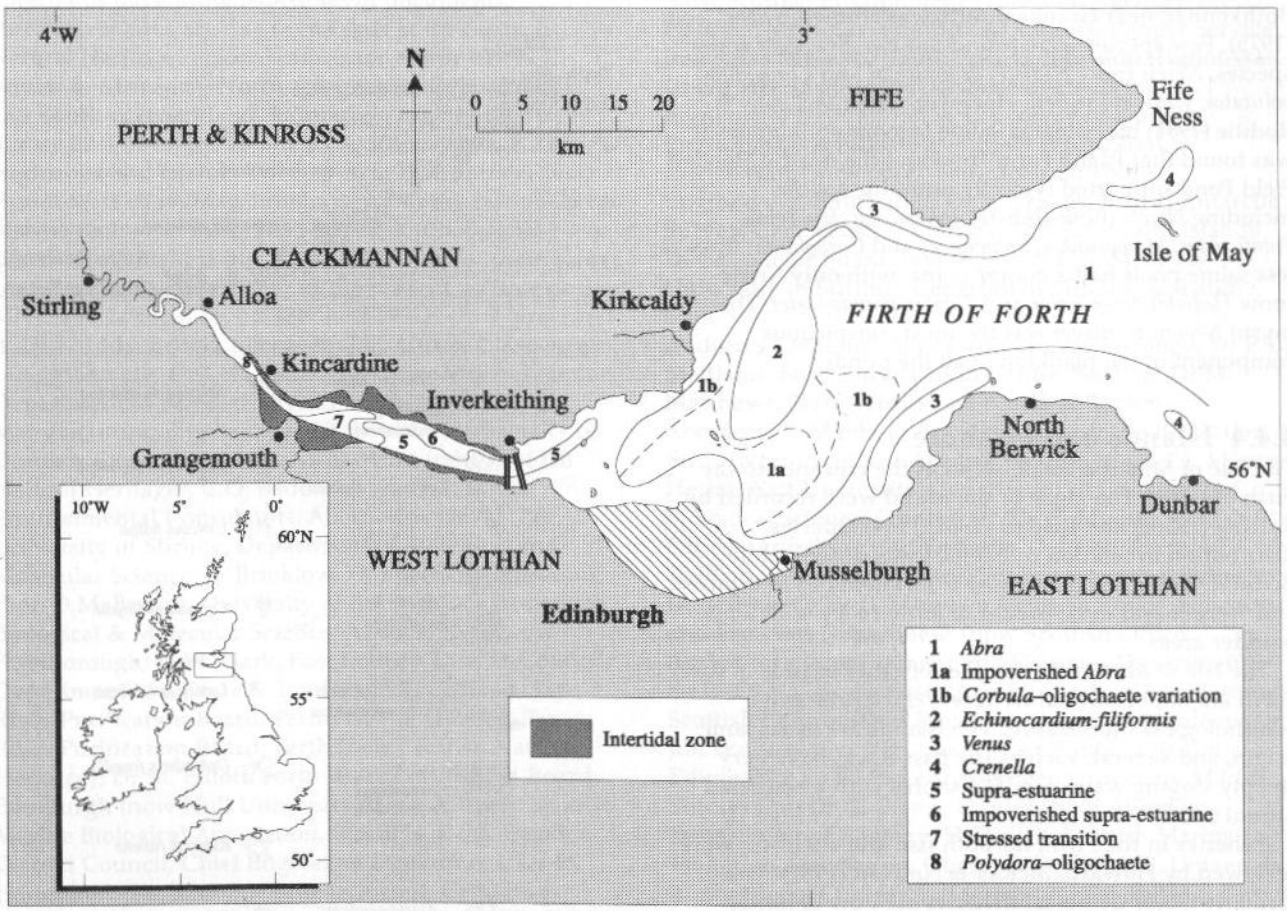

Figure 4.10. The distribution of major sublittoral sediment faunal communities identified by classification analysis in the estuary and Firth of Forth (from Elliott & Kingston 1987).

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).

More recent surveys of the sublittoral benthic fauna and sediments around outfalls in the Firth of Forth were carried out at Granton (FRPB 1993b), Hound Point (FRPB 1992c), Seafield (FRPB 1992a), and at a reference station in the northern central Firth off Largo Bay (FRPB 1991a). The latter site had a moderately diverse fauna typical of the Firth of Forth, dominated by polychaetes, Crustacea and molluscs. However, Seafield had a relatively species-poor macrofauna, notable for the presence of the large polychaete *Neanthes virens*. At Hound Point, the varied nature of the sediments supported a rich fauna, not significantly affected by the outfall, and the Granton fauna also appeared to be unaffected, dominated by the polychaetes *Scoloplos armiger, Terrebellides stroemi, Levinsenia gracilis* and *Scalibregma inflatum*, all typical of the southern part of the Firth.

4.4.3.3 *Lagoons*

A study of lagoons in the vicinity of the Firth of Forth was conducted by M. Wilkinson (pers. comm.). The brackish water pond at Home Farm (Island Farm), Bothkennar, near Grangemouth, was studied by McLeod (1975). Few species were found but two brackish water species, *Nereis* (now *Hediste*) *diversicolor* and *Corophium volutator*, were identified. However, when McLusky & Roddie (1984) investigated saline lagoons at Skinflats, it was found that Island Farm Pond and the nearby Flooded Field Pond supported typically estuarine species including *Nereis* (now *Hediste*) *diversicolor, Hydrobia, Tubificoides, Manayunkia, Spiophanes* and *Corophium*; three less saline pools had a poorer fauna, with only *Nereis* (now *Hediste*) *diversicolor* and *Tubifex pseudogaster*. The mysid *Neomysis integer* was the most conspicuous component of the plankton in all the ponds.

4.4.4 Islands and offshore

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

The Isle of May and a number of other islands in the Forth are important nature reserves, of primarily ornithological significance. The islands are of volcanic origin, and several, such as the Bass Rock, have very steeply sloping wave-exposed shores with a restricted littoral zone.

Fisheries in the Firth, for both fish and shellfish, were reviewed by Howard, McKay & Newton (1987). The formerly major demersal fisheries are now of minor significance, while fisheries for Norway lobster *Nephrops norvegicus*, common lobster *Homarus gammarus* and edible crab *Cancer pagurus* have assumed greater importance.

Records on the abundance and distribution of invertebrate fauna and fish species in the Firth of Forth have been published since the 1830s, and most earlier fish references are cited in Poxton (1987). Naturalists also recorded species from locations such as Granton and Joppa (Allan 1886; Lindsay 1886). Oyster *Ostrea edulis* and queen scallop *Chlamys opercularis* beds in the Firth were described by Fullarton (1889) and Fulton (1896). The decline and, by 1900, extinction, of the Forth's formerly extensive oyster beds due to overfishing, pollution and smothering by peat from the drainage of lowland peat mosses upstream of Stirling in the 18th century, was summarised by McLusky (1978b).

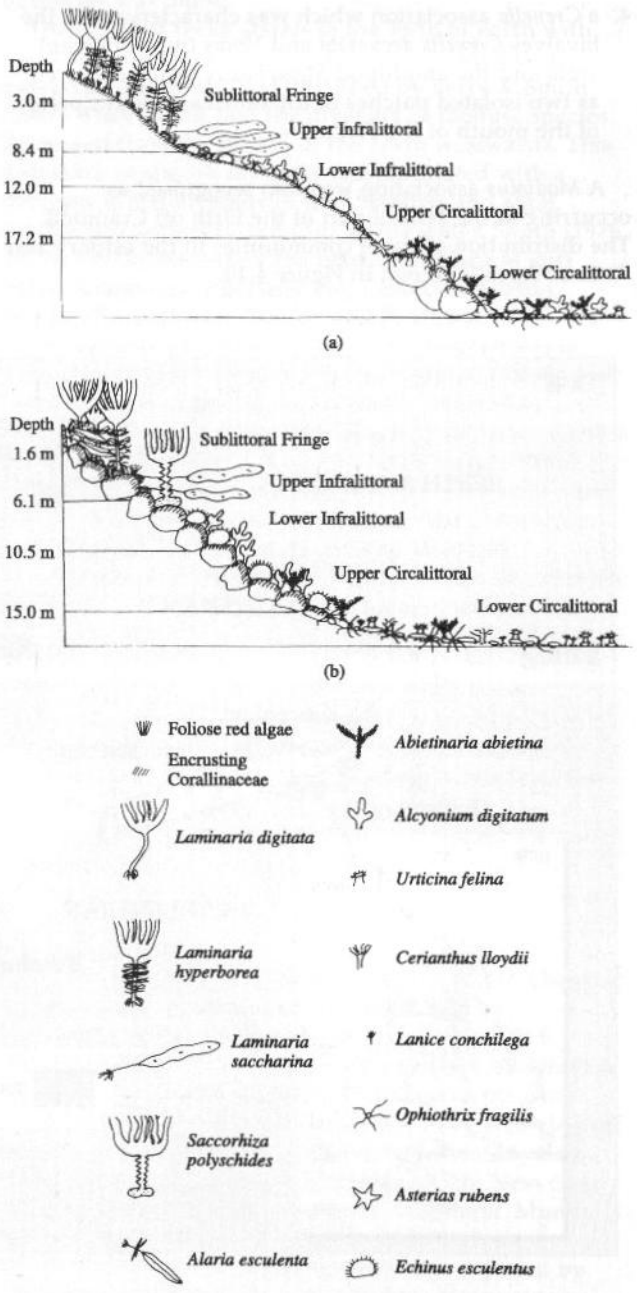

Figure 4.11. Generalised profiles of the seabed on (a) the east side and (b) the west side of the Isle of May (from Bennett 1989).

The largest colony of grey seals *Halichoerus grypus* in the Firth of Forth breeds on the Isle of May (Harwood & Wyile 1987). Many of these seals were traced from the Farne Islands, Northumberland.

Sublittoral diving surveys have been carried out at 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 4.11a). 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 4.11b). 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 brittlestar beds with *Ophiothrix fragilis* and *Ophiocomina nigra*. Two uncommon anemones, *Bolocera tuediae* and *Stomphia coccinea*, occurred (Bennett 1989).

A Phase 1 sublittoral habitat survey of the coastline between North Berwick and Berwick-upon-Tweed investigated the south-eastern part of the Firth of Forth, including Bass Rock (Foster-Smith & Carrie 1992). Bass Rock was notable for its extensive walls with *Alcyonium digitatum*, and some semi-sheltered boulder/sand habitats supporting the ascidian *Ascidiella aspersa*, while Dunbar had the greatest diversity of shallow sublittoral habitats within the survey area, including extensive rocky platforms and sandy plains. The area including Bass Rock was surveyed in 1992 by a MNCR survey team, and a sublittoral benthic grab sampling survey covering sites south-east from the Bass Rock was commissioned as part of this project. The results are incorporated in Davies 1994, and the communities classified in Brazier *et al.* (in prep).

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Chapter 5: South-east Scotland and north-east England (Dunbar to Bridlington) (MNCR Sector 5)*

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Synopsis

The area from Dunbar to Bridlington has been extensively surveyed and includes a very wide range of habitats. To the north of Newcastle-upon-Tyne, the coast is predominantly rocky both on the shore and underwater and is exposed to strong wave action. Broken often extensive rocky shores include a wide range of habitats with some extensive rock pools, and rich underboulder and overhang communities. Underwater, the kelp forest extends to several metres below low water beyond which a range of animal-dominated communities, including species characteristic of North Sea habitats, occurs. Offshore of about 30 m depth, the seabed is predominantly sedimentary. Intertidal sediments occur in bays and, in the region of Lindisfarne (Holy Island), over particularly large areas. Some of these sediment shores have extensive seagrass beds and provide important habitats for wading birds. Major estuaries are the Tyne and Tees which are also greatly industrialised, chronically polluted and have been modified biologically as a result. To the south, the Yorkshire coast includes a generally eroding shoreline with extensive rock platforms south to Reighton where the high cliffs and steep shores of the chalk coast extend to Flamborough Head and Bridlington.

5.1 Introduction

The south-east Scotland and north-east England sector extends from Dunbar in Lothian to Bridlington in Humberside. The coastline is relatively simple with a predominantly east-north-easterly aspect, and a varied geological sequence produces a mixture of cliffs and rocky shores contrasting with sometimes extensive sandy bays.

Two major estuaries, the Tyne and the Tees, in the central region of Sector 5, support important commercial ports, and several smaller ones, the Tweed, Coquet, Blyth, Wear and Esk, are sites of active leisure craft, fishing and other industries.

Few islands exist off this coast. Of these, however, the Farne Islands, which number as many as 28 depending on the state of the tide, occur off the mid-Northumberland coast. These lie between approximately 2.5 km and 7.5 km off the mainland and consist predominantly of igneous quartz dolerite, an outcrop of the 'Great Whin Sill'. They represent the most southerly point on the British North Sea coast at which rocky shores shelve rapidly into relatively deep, clear water (Edwards 1983). They are important breeding sites for seabirds including puffins (e.g. Hawkey 1991), and for grey seals (e.g. Hickling 1962). Farther south, Coquet Island, situated just off the mouth of the River Coquet, consists of a sandstone platform and it too is noted for its breeding seabirds (Charlton 1984). In addition, Holy Island (also known as 'Lindisfarne'), off north

* This review was completed from published sources of information on benthic habitats and communities as well as interviews with relevant workers undertaken up to 1991 and published in Bennett (1991). It has been further revised to take account of major additional studies by the second author up to the end of 1994 and up to the end of 1996 by the series editor. It does not include benthic survey information summarised for or published in the MNCR *Regional Reports* series or work now being undertaken to map biotopes in candidate Special Areas of Conservation. For information on conservation status and an analysis of rare and scarce seabed species, the reader is referred to the *Coastal Directories* series.

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Figure 5.1. The location of places in south-east Scotland and north-east England (northern section) mentioned in the text.

Northumberland, and St Mary's Island, off the coast of North Tyneside, are tidal islands, each being linked to the mainland by a causeway at low tide.

Most of the coast in the central zone of this sector (Blyth to Teesside) is urban and industrialised. Industry is particularly extensive at Newcastle-upon-Tyne, Sunderland and Middlesbrough . The region north of Blyth is used primarily for agriculture and leisure activities. Some sections, especially in south-east Scotland and north Northumberland are particularly rural. Much of the Scottish part of the coast, and virtually the entire Northumberland coast from the Scottish border to the Tyne, is an SSSI, the sediment shores being notified chiefly on account of their importance for migratory waders. The southern part of the coast, between Middlesbrough and Bridlington, is mainly rural with some urban sections and is an important holiday area.

Much marine biological study on the Northumberland coast has been carried out from the Dove Marine

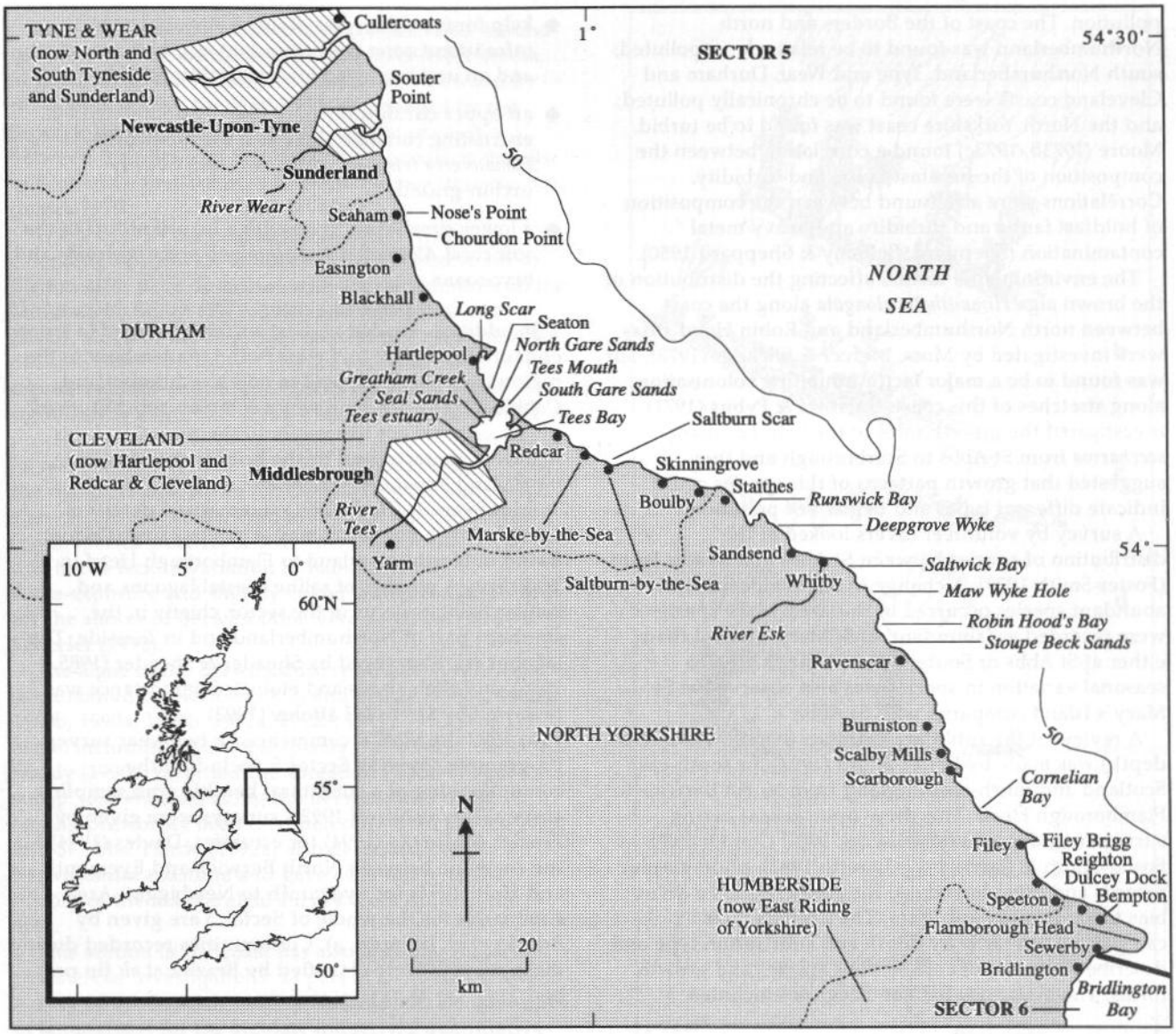

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Figure 5.2. The location of places in south-east Scotland and north-east England (southern section) mentioned in the text.

Laboratory, which is part of the University of Newcastle-upon-Tyne, from Durham University and from Analytical and Environmental Services Ltd. (now Entec Europe Ltd), now at Gosforth, Newcastle-upon-Tyne. Studies were also undertaken in the vicinity of the Welcome Laboratory at Robin Hood's Bay. (This Laboratory was run by the University of Leeds, but closed in 1982.)

For convenience, Sector 5 is subdivided into three parts:

- Dunbar to Berwick-upon-Tweed (5.2);
- Berwick-upon-Tweed to Redcar (5.3);
- Redcar to Bridlington (5.4).

The literature relating to each area is considered separately except for those studies which extend over the major part of the sector, which are reviewed first. Most of these general studies examine species distributions in relation to environmental factors. Bennett (1991) reviewed available marine biological knowledge for this coastal sector, and Potts & Swaby (1993) gave a bibliography for coastal fish in the area.

Kelp holdfast fauna has been the subject of much study between St Abb's Head and Flamborough Head. In particular nematodes, bryozoans and crustaceans occurring in the holdfasts were investigated by Moore (1971a, 1971b, 1972, 1973a, 1973d, 1974). Studies by Bellamy *et al.* (1972) and Jones (1969, 1970, 1971, 1972, 1973) related a reduction in holdfast fauna to increased

pollution. The coast of the Borders and north Northumberland was found to be relatively unpolluted; south Northumberland, Tyne and Wear, Durham and Cleveland coasts were found to be chronically polluted; and the North Yorkshire coast was found to be turbid. Moore (1973b, 1973c) 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 (Sheppard, Bellamy & Sheppard 1980).

The environmental factors affecting the distribution of the brown alga *Himanthalia elongata* along the coast between north Northumberland and Robin Hood's Bay were investigated by Moss, Mercer & Sheader (1973). Silt was found to be a major factor inhibiting colonisation along stretches of this coast. Burrows & Pybus (1971) investigated the growth rates of the kelp *Laminaria saccharina* from St Abbs to Scarborough and they suggested that growth patterns of this species could indicate different types and degrees of pollution.

A survey by volunteer divers looked at the distribution of species between St Abbs and Souter Point (Foster-Smith 1979). A change in the composition of abundant 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 with St Abbs.

A review of the sublittoral habitats (0 m down to 35 m depth) was made by Foster-Smith (1992) for south-east Scotland and north-east England from North Berwick to Flamborough Head. This drew upon recent diving surveys (e.g. Pagett 1983; Hiscock 1984; Connor 1989; Foster-Smith & Carrie 1992; Loretto 1992), photographic records and diver log books; the study reflects a diver bias towards rocky substrata. The habitats were categorised primarily by depth and substratum type and described in terms of conspicuous species and growth forms. The main rock habitat categories included:

- kelp forest, which was divided into an upper infralittoral zone with abundant epiphytic red algae, and an urchin-grazed lower infralittoral zone;
- an upper circalittoral zone visually dominated by encrusting coralline algae and the tubeworm *Pomatoceros triqueter* which was also heavily urchin-grazed;
- a lower circalittoral zone with a luxuriant turf of the soft coral *Alcyonium digitatum* and erect hydroids and bryozoans.

In addition, shaded vertical surfaces covered in a rich epifaunal and algal turf were found, particularly in the region from St Abb's Head to mid Northumberland. Cobble mixed with sand was a common substratum in the circalittoral zone throughout the region and this habitat is characterised by the brittlestar *Ophiothrix fragilis* and *Pomatoceros triqueter.*

Frid, Evans & Clark (1991) summarised details of coastal morphology and coastal habitats from Coquet Island in Northumberland to Flamborough Head in Yorkshire. A number of saline coastal lagoons and similar habitats occur in the sector, chiefly in the southern part of Northumberland and in Teesside. The lagoons were surveyed by Sheader & Sheader (1985, 1986), and their status and biological importance was reviewed by Smith & Laffoley (1992).

In 1992 the MNCR commenced a two-year survey programme covering Sector 5, including the commissioning of a sublittoral benthic grab sampling survey. The results of 1992's surveys were given by Brazier & Murray (1994) for estuaries, Davies (1994) for the coastline between North Berwick and Eyemouth, and Holt (1994) for Eyemouth to Newbiggin. Area summaries for the whole of Sector 5 are given by Brazier *et al.* (in prep. a). Communities recorded during these surveys were classified by Brazier *et al.* (in prep. b).

5.2 Dunbar to Berwick-upon-Tweed

This section of coastline consists predominantly of rocky shores with a few sediment beaches and bays and a number of small estuaries. An MNCR survey programme covered this area in 1992, reported by Davies (1994) and Holt (1994). Rocky shores at Dunbar, Barns Ness, Chapel Point, Thorntonloch and Pease Bay were studied by the University of Hull, Institute of Estuarine and Coastal Studies (1992), with particular emphasis on organisms which could produce fouling at Torness nuclear power station. This study also monitored fish entrainment at the power station intake screens. Monthly sampling between July and November 1991 produced a total of 27 fish species, with saithe *Pollachius virens* being predominant in most samples, and sea snail *Liparis liparis* and fifteen-spined stickleback *Spinachia spinachia* becoming more important in November. Macro-invertebrates were also recorded. Intertidal and subtidal studies were continuing under this programme (M. Elliott pers. comm.).

In 1984, an artificial reef was constructed 3.4 km south-east of Torness Point, by depositing some 210,000 tonnes of limestone rock onto the natural seabed substratum of mixed sand, pebbles and embedded cobbles at a depth of approximately 20 m (Todd, Bentley & Kinnear [1993]). Photographic surveys using a remotely-operated vehicle between 1987 and 1988, and sampling by various methods between 1988 and 1990, indicated that the reef had produced a local enhancement of cod *Gadus morhua* and lobster *Homarus gammarus* populations; some large invertebrates such as sea-urchins *Echinus esculentus*, starfish *Asterias rubens* and encrusting bryozoans had also colonised the reef (Todd, Bentley & Kinnear [1993]).

Most other marine studies have concentrated around the St Abbs area, which is popular with SCUBA divers. St Abb's Head is a National Nature Reserve owned by the National Trust for Scotland and managed by the Scottish Wildlife Trust, while the section of coast between the village of St Abbs and Eyemouth is the site of Scotland's first Voluntary Marine Nature Reserve (James 1979).

The shores in the neighbourhood of St Abbs, extending north-west to Redheugh Farm and south to Burnmouth, were described with special reference to the Mollusca by Smith (1979, 1983) and Smith & Gault (1983). Much of the intertidal zone of this area consisted of shore platforms with sheltered rock pools and wave exposed gullies and ridges. Habitats did not differ significantly along this section of coast but the species present varied with the rock-type. Shores were found to be reasonably rich with those on sandstone supporting the richest fauna. However, compared with some other sites on the east coast, such as Dunbar and St Andrews, fewer species were recorded. This was considered to be due to the lack of variation in habitats and wave-exposure and slightly colder water. Faunal records for the shores of Berwickshire were listed by Hardy & Wheeler (1992).

The algae of the Berwickshire coast have been well documented by Norton (1976) and Hardy (1988a, 1988b, 1989b, 1990a, 1990b, 1992a, 1992b, 1993). A total of 197 algae, including sublittoral species, have been identified. Hardy (1990c) recorded the spread of *Codium fragile* subsp. *tomentosoides* along the Berwickshire coast, having previously been recorded only from Pettico Wick and St Abbs. Hardy (1992a) also described the Berwickshire coastline and gave a summary of the history of the marine algal survey work done in the area.

This section of the coast has also been the subject of commercial investigations: as part of a subtidal 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 tonnes of *Laminaria* was found to occur in 1,400 ha.

The Marine Conservation Society carried out sublittoral surveys to describe the habitats and marine life in the St Abbs area, between Fast Castle and Burnmouth, including studies on the sea-urchin *Echinus esculentus* (Earll 1981, 1982; Pagett 1983). 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 Abb's Head. The sublittoral communities were considered to be similar to those of Shetland and Orkney. Northern species such as the hydroid *Thuiaria thuja*, the anemone *Bolocera 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 were the algae *Schottera nicaeensis* and *Rhodymenia pseudopalmata*. Communities included rich, deep kelp forests which occurred in the clear water and dense brittlestar beds. Where *Echinus*

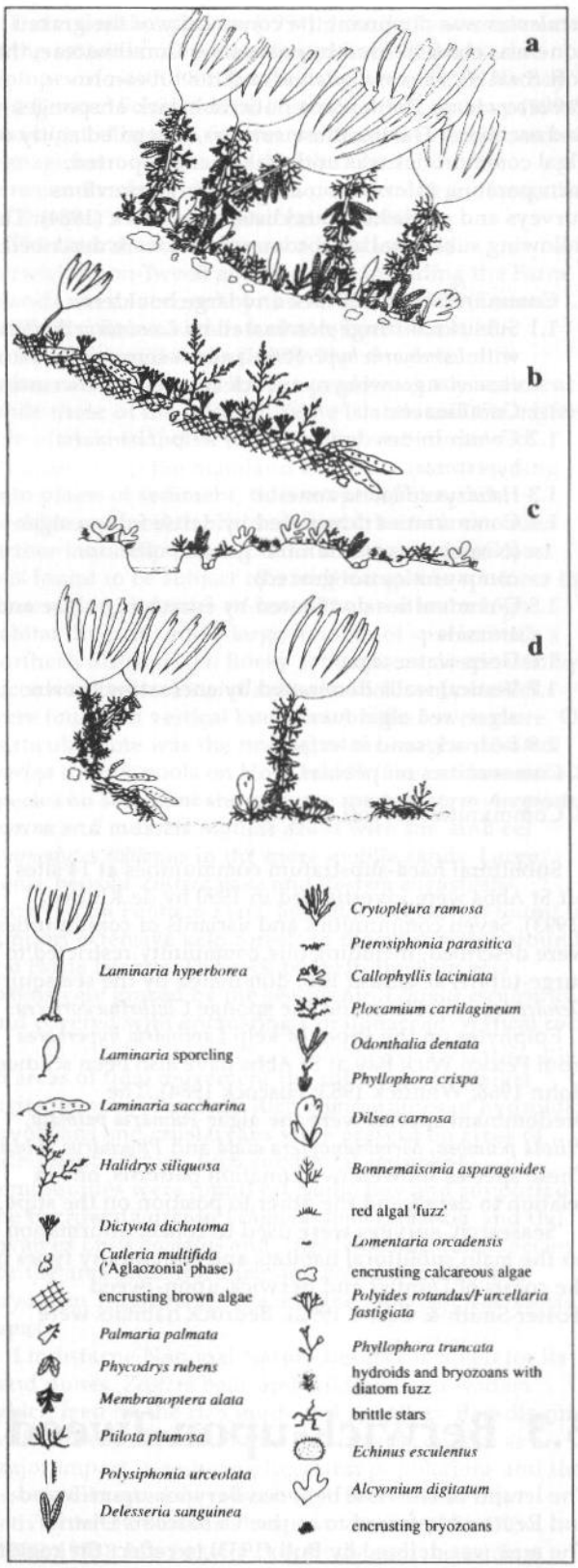

Figure 5.3. Examples of algal communities at St Abbs. a. *Laminaria hyperborea* forest at 3 m depth, Coldingham Bay (exposed to wave action, not heavily grazed). b. *Halidrys siliquosa* and dense foliose algae zone at 11.5 m depth, Lumsdaine. c. Offshore community of foliose algae and animals at 16.5 m depth, Coldingham Bay. d. Flora at the bedrock – sand interface at 5 m depth, Coldingham Bay. From Hiscock (1984).

esculentus was dominant the community of the grazed zone was characterised by encrusting Corallinaceae, the soft coral *Alcyonium digitatum* and the tubeworm *Pomatoceros* sp. There was a noticeable lack of sponges and ascidians. During those surveys, a detailed study of algal communities was undertaken and reported, incorporating information available from previous surveys and published checklists, by Hiscock (1984). The following sublittoral algal communities were described:

1. Communities on bedrock and large boulders
   - 1.1 Sublittoral fringe dominated by *Laminaria digitata* with *Laminaria hyperborea* and, at some sites, *Alaria esculenta* growing over rock covered by encrusting Corallinacea
   - 1.2 Communities dominated by kelp (*Laminaria hyperborea*)
   - 1.3 *Halidrys siliquosa* zone
   - 1.4 Communities dominated by dense foliose algae (Nearshore communities grazed, offshore communities not grazed)
   - 1.5 Communities dominated by encrusting algae and animals
   - 1.6 Deep water algae
   - 1.7 Vertical walls dominated by encrusting brown algae, red algal fuzz
   - 1.8 Bedrock/sand interface
2. Communities on pebbles
3. Communities on soft substrata

Sublittoral hard-substratum communities at 14 sites off St Abbs were investigated in 1990 by de Kluijver (1993). Seven communities and variants of communities were described, including one community restricted to a surge-tunnel at Celicar Rib, dominated by the sea squirt *Dendrodoa grossularia* and the sponge *Clathrina coriacea*.

Epiphytes on the stipes of kelp *Laminaria hyperborea* from Pettico Wick Bay at St Abbs have also been studied (John 1968; Whittick 1983; Hiscock 1984). 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 to position on the stipe.

'Seasearch' surveys were used to collect information on the main sublittoral habitats and community types on the coasts of Dunbar and Berwick-upon-Tweed (Foster-Smith & Carrie 1992). Bedrock habitats were generally of two types: extended shore platforms dropping down in a series of steps to 30 m, and, where igneous intrusions and folded strata occur, rock steeply shelving into the sublittoral forming underwater cliffs and pinnacles. The dominant community on shallow bedrock was *Laminaria hyperborea*. Below the kelp forest was a mixture of encrusting coralline algae and the tubeworm *Pomatoceros triqueter*. Many of the better-lit surfaces just below the kelp zone supported growths of foliose brown and red algae, such as *Dictyota dichotoma* and *Brongniartella byssoides*. Vertical shaded surfaces were dominated by *Alcyonium digitatum* and *Pomatoceros triqueter*. Areas of cobble and small boulders overlay bedrock and the broken tubes of *Pomatoceros triqueter* formed a substantial shell-gravel in some places. Areas of predominantly medium-grained sand were found almost everywhere in the survey area. Extensive areas supporting *Lanice conchilega* and the razor shell *Ensis siliqua* were found off the Tyne. The diversity of habitats and communities appeared to be much reduced compared with St Abb's Head and mid-Northumberland.

The sediments and fauna off St Abb's Head have been extensively studied in relation to sewage 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; Heap, Elliott & Rheinallt 1991; Heap, Hull & Webster 1992). This work includes 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 290 species have been recorded from the area. In general, sludge dumping was not considered to have adversely affected the communities in the sediments, although very slight organic enrichment towards the centre of the St Abbs site has been detected since 1990 (Heap, Hull & Webster 1992).

The Berwickshire coast from Siccar Point to south of Burnmouth is designated the 'Berwickshire Marine Consultation Area' (Nature Conservancy Council 1990). The area was considered to be of conservation interest owing to the presence of deep-water rock close inshore, the wide range of littoral and sublittoral rocky habitats and associated communities which occurred in the clear, unpolluted water, and also because of the rich fauna and flora which included several species at the southern limits of their distribution.

5.3 Berwick-upon-Tweed to Redcar

The length of coastline between Berwick-upon-Tweed and Redcar is referred to as the 'Cullercoats District'. The area was defined by Bull (1933) to reflect the region studied from the University of Newcastle-upon-Tyne's Dove Marine Laboratory at Cullercoats, and subsequently modified by Bull (1963).

Many studies within this area have been undertaken from the Dove Marine Laboratory. A bibliography covering the literature on marine flora and fauna for the Cullercoats District was compiled by Bull (1933) and one for the fauna was compiled by Foster-Smith (1984c). Distributional records of algae for Northumberland and Durham have been made since the 1860s (Brady 1861, 1862, 1863, 1864b; Lacey & Robertson 1953; Hardy & Aspinall 1988). Earlier records exist for the fauna, dating from the 1830s (Johnston 1835; King 1846; Alder, Fryer & Hancock 1850; Alder 1858, 1864; Norman 1863, 1864, 1867; G.S. Brady 1864a; H.B. Brady, 1864; Canon, Norman & Brady 1909; Bolam 1919; Moore 1989).

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

Taxonomic group(s)	Reference(s)
Seaweeds	Hardy 1985, 1987b
Porifera	Bull 1963
Anthozoa	Bull 1939
Coelenterata & Ctenophora	Evans 1978
Kinorhynca	Bamber 1989b
Priapulida, Echiurida, Sipunculida	Bull 1966a
Entoprocta	Eggleston & Bull 1966
Chaetognatha	Bull 1966b
Hirudinea	Hussain & Knight-Jones 1989
Oligochaeta	Kendall 1988
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
Leptostraca	Garwood 1989
Mysidacea	Bamber 1986a
Cumacea	Garwood 1989
Tanaidacea	Bamber 1986b
Isopoda	Sheader 1988
Amphipoda	Sheader 1983
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, Solenogasters, Polyplacophora, Gastropoda, Scaphopoda, Cephalopoda	Foster-Smith 1986
Mollusca: Bivalvia	Kingston 1980
Ectoprocta	Eggleston 1975
Echinodermata	Buchanan 1966
Fishes	Davis 1983b
Zooplankton	Evans 1985
Cetacea	Stephenson & Bull 1964

Berwick-upon-Tweed is located on the north Northumberland coast, at the mouth of the River Tweed. A small fishing port is situated at Tweedmouth. The shores at the mouth of the Tweed estuary and to the south consist of sand. To the north of Berwick-upon-Tweed and to the south, around Scremerston, rocky shore platforms backed by cliffs occur. Offshore the seabed is predominantly 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). Estuaries from the Tweed in the north to the (North Yorkshire) Esk in the south were surveyed by the MNCR in 1992 (Brazier & Murray, 1994).

Foster-Smith & Davies (1994) provided an assessment of the nature conservation importance of the marine biotopes of north Northumberland between Budle Bay and Craster. Foster-Smith, Foster-Smith & Gubbay (1994) investigated options for the marine nature conservation management of the north Northumberland coast between Bamburgh and Amble, and collated information on the area's current conservation status.

The littoral and sublittoral zones 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 farther 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. Rich communities were found on vertical limestone on the lower shore. Of particular note was the finding of the seagrass *Zostera marina* in rock pools on Holy Island. The predominant species on 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 nana* and *Zostera angustifolia* 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 areas of 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*, and the bivalves *Ensis arcuatus* and *Angulus tenuis*. Rare species for the area were the anemone *Bolocera tuediae*, the bryozoan *Tricellaria ternata* and the wolf fish *Anarhichas lupus*.

Lindisfarne National Nature Reserve is noted for its sand dunes, *Zostera* beds and wildfowl and waders which feed on the rich mud- and sandflats. Bait-digging within the Reserve at Budle Bay causes concern as a major impact in reducing lugworm populations and the associated sediment community. The scale of this activity in relation to damage was assessed by Olive (1986, 1993). In a heavily dug study area measuring 1,000 m × 200 m, studied during the winter of 1984, the density of *Arenicola marina* fell from 40 m^{-2} to 1 m^{-2} within a period of about six weeks. The population recovered within a few months as a result of migration of worms into the area from the extensive mudflats surrounding the study site. However, there is evidence from monitoring programmes carried out in the Nature

Reserve from 1980 that the decline in lugworms caused by digging at this site resulted in a fall in numbers of shorebirds (Fowler 1992), and the disturbance to the sediment effected by digging caused heavy metals (cadmium and lead) to be mobilised and taken up by infaunal invertebrates (Howell 1985). Consequently, Budle Bay was closed to bait diggers in 1987. Lead originating from wildfowling has also been detected in intertidal plants (*Zostera* spp., *Salicornia europea*, and *Enteromorpha*) which are grazed by wildfowl (Palmer & Evans 1991). A further problem at Lindisfarne is the introduced cord-grass *Spartina anglica*, which has invaded over 10% of the intertidal mudflats in the Reserve (Millard & Evans 1984). An eradication programme is in its experimental stages.

In 1991, Evans, Arnott & Wahju (1994) found that an oligochaete-dominated community had become established in the north-west part of Budle Bay, probably as a result of local eutrophication by sewage and/or agricultural run-off. Otherwise, the species and communities present were very similar to those recorded in 1931 (Brady 1943).

The Farne Islands form a major tourist attraction and visitors take boat trips from Seahouses to view the seabirds and seals. Owned by the National Trust, they were declared a National Nature Reserve in 1993. The shores and general ecology of the Inner Farne Island were described by Sowerby (1958) and Thompson *et al.* (1966), with the habitats and algae described by Moss (1959) and the aquatic fauna by Gascoigne (1969). A bibliography of the Farne Islands was provided by Thompson and Hickling (1973). Most published papers on the Farne Islands relate to the grey seal *Halichoerus grypus* population (e.g. Coulson 1959, 1981; Coulson & Hickling 1964; Hickling 1983; Hickling & Hawkey 1986).

The coastline from Beadnell to Dunstanburgh Castle consists of sandy bays separated by rocky headlands. Sublittorally, shallow reefs run at right angles to the shore and either extend into extensive areas of horizontal bedrock or shelve into sand. The shores were surveyed in 1983 (Hodgson 1984). A more extensive 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 colonisation by a community characterised by the burrowing urchin *Echinocardium cordatum*, and the razor shells *Ensis ensis* and *Ensis arcuatus*. Other rare habitats in the area included prominent headlands, extensive individual reefs and steep boulder beaches. The study area was considered to have a wide range of habitats and a high species richness, with records of over 460 species. The survey described rich underboulder communities which were further described in a survey of eight sites on the Northumberland coast carried out by Foster-Smith (1989). Detailed descriptions of the habitats were made and species found on the undersurfaces of boulders were listed for each site.

Figure 5.4. Community on a midshore to lower shore reef on the coast from Beadnell to Dunstanburgh dominated by fucoids (*Fucus vesiculosus* midshore, *Fucus serratus* lower shore), shrubby algae (*Mastocarpus stellatus, Cladophora rupestris, Laurencia pinnatifida*, and *Corallina officinalis*), mussels *Mytilus edulis*, limpets *Patella vulgata* and barnacles, *Semibalanus balanoides*. From Foster-Smith & Foster-Smith (1987). Drawing by Bob Foster-Smith.

Newton Haven has been intensively studied. The littoral habitat types, flora and fauna were described by Foster-Smith (1983), and a checklist of 72 plant and 346 animal species with notes on their distribution and abundance was provided by Foster-Smith (1984a). 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 in the intertidal 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 owing to silt derived from boulder clay which fills the interstices of coarser sediments. The distribution of species was not uniform across the beach, with the sandy shore in the south part of Newton Haven supporting a high diversity of bivalves. Overall, Newton Haven was considered to have a rich and diverse polychaete, mollusc, crustacean and interstitial fauna. The seabed of the Haven, landward from a line drawn between mid low water at the outer ends of Lobster Carr to the north and Emblestone Reef to the south, is leased and managed by the National Trust (Foster-Smith 1988b).

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 backing sandy beaches with outcrops of rocky shore. Sandy beaches backed by dunes stretch for 4 km to the south of the village. The intertidal fauna of the Aln estuary was investigated by Howcroft (1983). The algae of the Alnmouth area between Seaton Point and Birling Carrs have been recorded since the 1880s (Amory 1884, 1885, 1887). Past and more recent

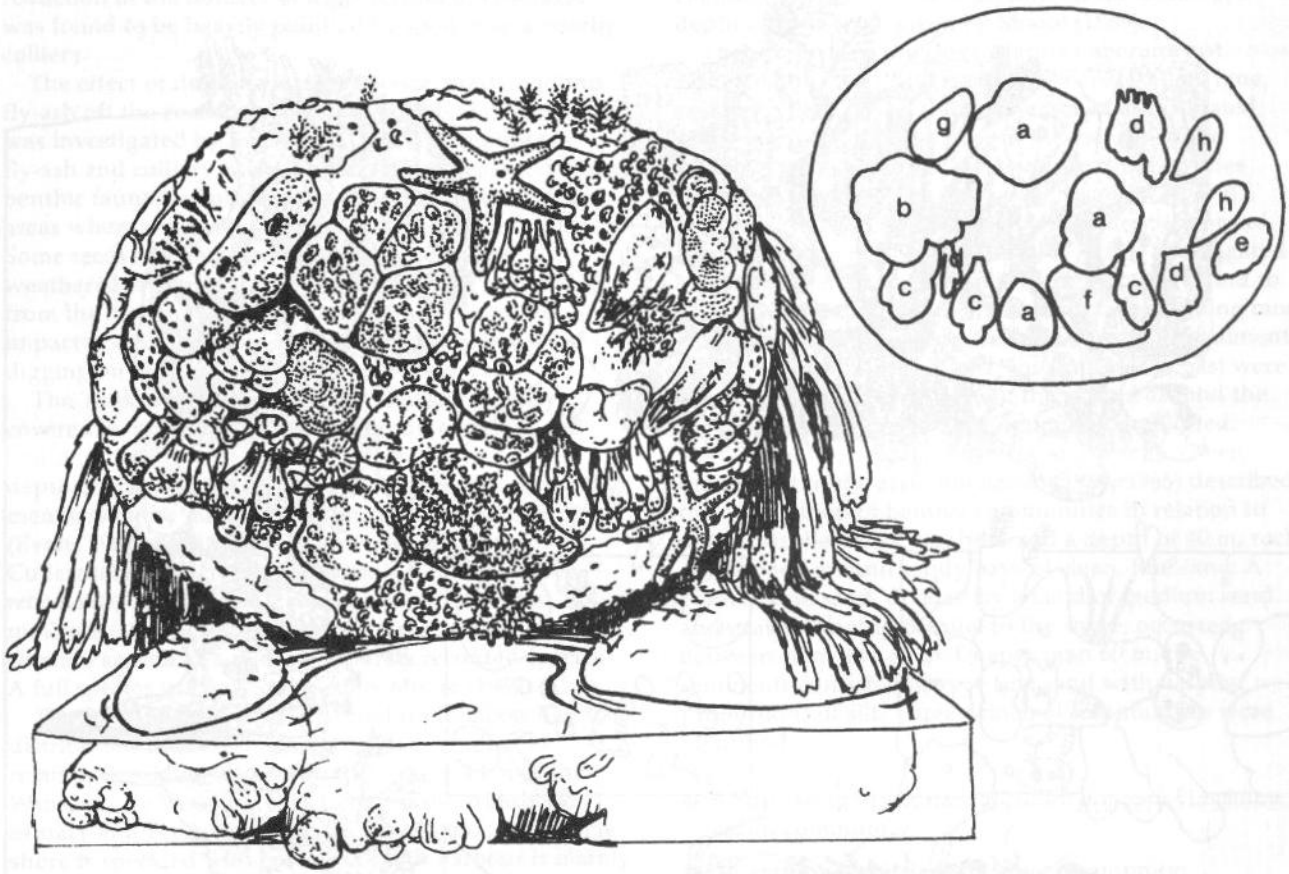

Figure 5.5. A rich underboulder assemblage from fucoid dominated shores in Northumberland. From Foster-Smith & Foster-Smith (1987). Drawing by Bob Foster-Smith. Key: a. *Aplidium proliferum*; b. *Polyclinum aurantium*; c. *Aplidium punctum*; d. *Sidnyum turbinatum*; e. *Dendrodoa grossularia*; f. *Botrylloides leachii*; g. Didemnidae indet.; h. *Ascidia conchilega*.

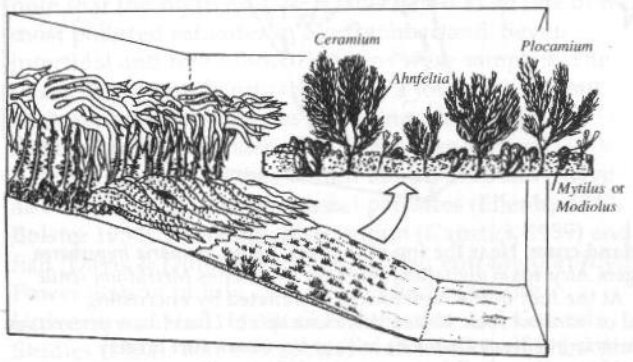

Figure 5.6. Infralittoral reef slope off the Northumberland coast where rock extends to sand. Zones of kelps, *Laminaria hyperborea* and *Laminaria saccharina*, extend to a sand-matted community characterised by red algae and mussels. From Foster-Smith & Foster-Smith (1987). Drawing by Bob Foster-Smith.

algal data (Hardy 1987a) was drawn together by Hardy (1989b). Amory (1884) recorded a total of 107 species from this area but only 39 have been recorded in the 20th 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 (Foster-Smith & Hardy 1987).

Amble lies to the south of Alnmouth at the entrance to the River Coquet; the mouth of the Coquet estuary is known as Warkworth Harbour. The Harbour was once a small coal port but it is now used by fishing boats and is the location of a popular marina. From the River Coquet to just south of the river Tyne the shale, sandstone and coal beds of the Coal Measure Series occur. This part of the coastline consists of a series of sandy bays backed by sand dunes or low cliffs of glacial till between rocky headlands fronted mainly by rock shore platforms. The geological and ecological features from Amble to Hadston Carrs were described and marine species recorded with a view to interpretation for visitors to the area (Foster-Smith 1987b).

South of Hadston Carrs lies the great expanse of sandy beach 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 of Cresswell Skeres. Data provided include the particle structure of the fine sediments and records, with an indication of abundance, of the flora and fauna of the four habitats. A polychaete worm new to science, *Baldia johnstoni* (Garwood & Bamber 1988), was found at the northern end of the bay and also in the nearby bay of Fluke Hole. Also, the Devonshire cup coral *Caryophyllia smithii* was recorded at a new southern limit of its North Sea distribution and

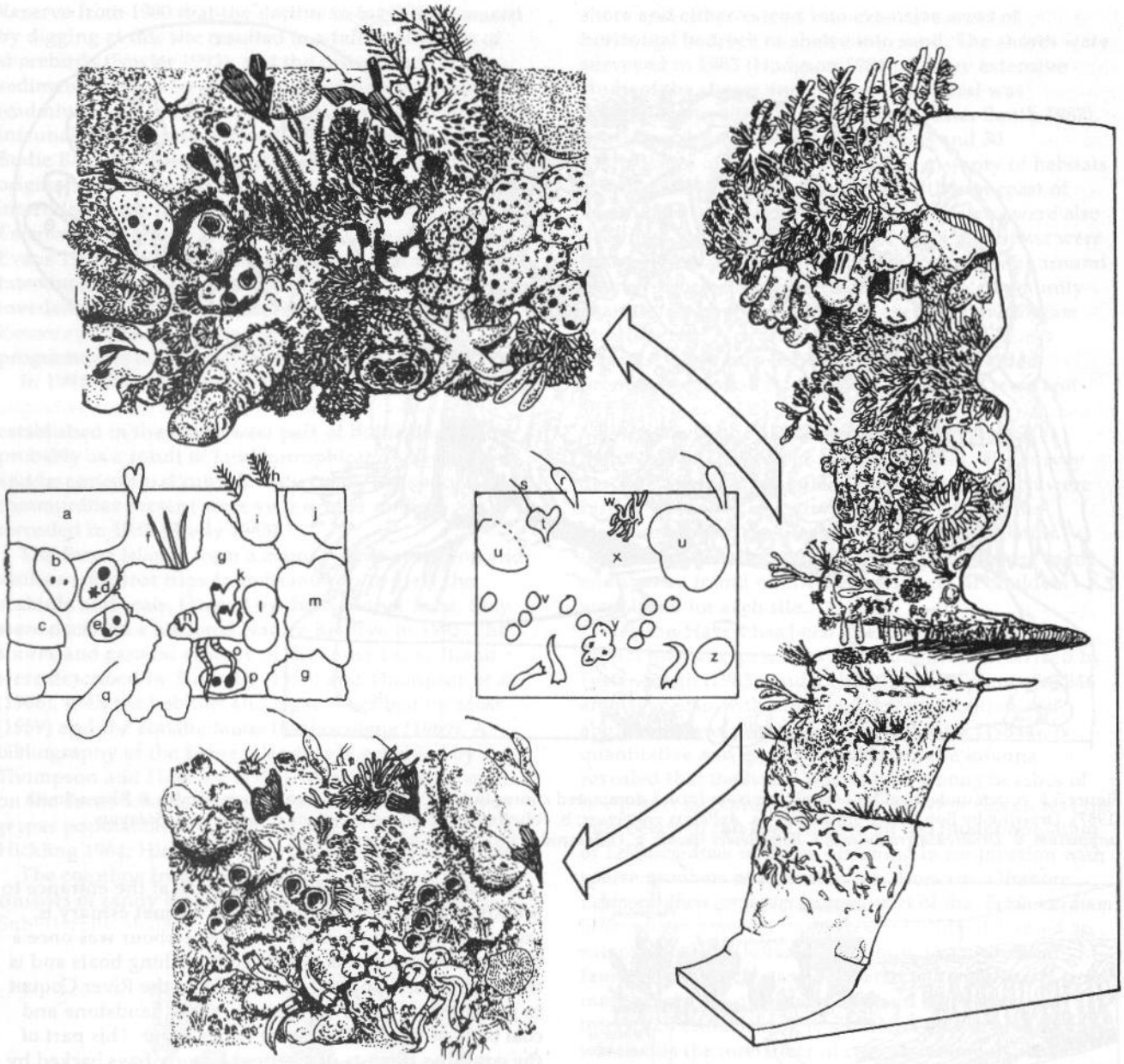

Figure 5.7. A vertical reef face in the infralittoral off the Northumberland coast. Near the top of the reef, kelp *Laminaria hyperborea* and foliose algae dominate. Under the overhang are dead mens' fingers *Alcyonium digitatum*, plumose anemones *Metridium senile* and massive sponges. The middle part of the face is shown in detail. At the foot of the reef, rock is dominated by encrusting coralline algae and the keeled tube-worm *Pomatoceros triqueter* typical of scoured rock. Key: a: *Haliclona* sp.; b: *Lissoclinum perforatum*; c: *Botryllus schlosseri*; d: *Ascidia conchilega*; e: *Ciona intestinalis*; f: *Ophiothrix fragilis* or *Ophiactis balli*; g: bryozoan turf largely *Scrupocellaria scruposa*; h: *Hiatella arctica*; i: *Clathrina coriacea*; j: *Escharoides coccinea*; k: *Polycarpa rustica*; l: *Morchellium argus*; m: *Polyclinum aurantium*; o: *Ophiopholis aculeata*; p: *Zirfaea crispata*; q: *Botrylloides leachii*; r: *Alcyonidium diaphanum*; s: amphipod whip; t: small red algae, often *Myriogramme bonnemaisonii*; u: *Cellepora pumicosa*; v: *Sabellaria spinulosa*; w: *Leucosolenia botryoides*; x: *Polydora* sp.; y: *Balanus crenatus*; z: *Umbonula littoralis*. From Foster-Smith & Foster-Smith (1987). Drawing by Bob Foster-Smith.

the 'southern' polychaete *Bispira volutacornis* was recorded for the first time for the Cullercoats District. The submerged Cresswell Skeres are located offshore to the southern end of the bay. A full species list, including notes on habitat and abundance, was given by Bamber (1989a). Sublittoral habitats and species on the Skeres were surveyed by Foster-Smith (1987a). 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 resulted in a list of 44 species (Walker 1984). Fish species have also been recorded at Lynemouth (Davis & Dunn 1982a). The algae of five rocky shores between Cresswell and Newbiggin-by-the-Sea were described by McAllister (1973). Cresswell was found to be the richest in terms of number of species (42) and abundance owing to the wide range of habitats and distance from sources of pollution. Beacon Point, Newbiggin Point and South Spital Carrs appeared to lie 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 a nearby colliery.

The effect of dumping colliery waste, dredgings and fly-ash off the coast between Lynemouth and Seaham was investigated by 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. Lynemouth Bay is excluded from the Northumberland coast SSSI owing to the impact of colliery waste and the secondary impact of digging on the foreshore to recover waste coal.

The Trink, a sublittoral ridge of limestone partly covered by gravelly sediment with some cobbles and boulders, lies 030°, 16 km from Blyth Lighthouse at a depth of about 55 m. Agassiz trawls over this ground by members of the marine recording society, 'Porcupine', (Evans 1989) produced four new records for the Cullercoats District: the pycnogonid *Copidognathus reticulatus*, the decapod *Eualus gaimardii*, and the molluscs (shells only) *Aporrhais serresianus* and *Tridonta elliptica*, as well as a number of rarely recorded species. A full species list was compiled by Moore (1989).

The River Wansbeck discharges into Cambois Bay. The distribution of the flora and fauna was studied in relation to salinity and substratum along 4 km of the Wansbeck by Vasisht (1965). Between the Wansbeck estuary and Blyth, the 3 km stretch of sand and shingle shore is speckled with coal dust. Blyth harbour is mainly used for importing wood pulp and alumina and exporting coal and grain but it is also port to several fishing and sailing boats. The macrofauna of the Blyth estuary is described by Frid & Garwood (1991) who also note that the Blyth estuary is considered to be one of the most polluted estuaries in Northumberland. Seven intertidal and five subtidal stations were sampled. The fauna was typically estuarine with a low diversity but high abundance of species including *Manayunkia aestuarina, Hediste diversicolor, Tubificoides* spp and *Capitella capitata*. Studies within the Blyth estuary have also been carried out on mussel parasites (Ellenby 1947; Bolster 1954), nematode distribution (Capstick 1959) and fish (Davis & Dunn 1982b, 1982c). Fish entrained at Blyth Power Station in July 1991 were collected by the University of Hull, Institute of Estuarine and Coastal Studies (1992), when 29 species were recorded. Plankton was recorded in Cambois and Blyth Bays by Bossanyi (1957). The shore from Blyth to Seaton Sluice consists of a 3 km stretch of sandy beach.

At Seaton Sluice, Colywell Bay is predominantly rocky, and to the south, a series of rocky headlands enclose sometimes extensive sandy beaches such as Whitley Bay and Tynemouth Long Sands. These highly mobile sediments support an impoverished fauna, and have been largely ignored by macrofaunal biologists. The fauna and flora of the rocky shores at St Mary's Island, which can be reached on foot at low water, were studied by Foster-Smith (1984b). Two species rarely recorded along this section of coast, the polychaete *Amblyosyllis formosa* and the pycnogonid *Endeis spinosa*, were found. Species lists for the shore at St Mary's Island and an area of hard ground off the island at a depth of 36 m were given by Moore (1989).

The presence of the Dove Marine Laboratory at Cullercoats and a University of Newcastle-upon-Tyne research vessel based at Blyth harbour has facilitated many marine studies. Shores in the vicinity of the laboratory have mainly been used for single species studies (e.g. Allen 1969; Daly 1978; Evans *et al.* 1991). Offshore research carried out includes descriptions of the physical conditions. Evans (1957, 1959) investigated sea currents and tidal streams. Currents were found to be wind-dependent, with a southerly current being most common in the prevailing westerly wind. The sediments off the Northumberland and Tyne and Wear coast were described by Buchanan (1964); the seabed around the mouth of the River Tyne was found to be polluted.

Many benthic community studies have also been carried out in the area. Buchanan (1963, 1965) described the distribution of benthic communities in relation to sediments. 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 m and 60 m. Deeper than 60 m, the sediments consisted of very fine sand with varying proportions of silt. Three principal communities were identified:

- a burrowing brittlestar *Amphiura filiformis-Amphiura chiajei* community;
- an amphipod *Haploops tubicola* community;
- a bivalve *Chamelea gallina* community.

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 m to 80 m the sea-urchin *Brissopsis lyrifera* formed a community with *Amphiura chiajei*.

Warwick & Buchanan (1970, 1971, 1973) investigated the structure and stability of an offshore meiobenthic nematode population. Species composition and population density were shown to remain relatively consistent throughout the year of study (October 1968–September 1969). Buchanan, Sheader & Kingston (1978) assessed the spatial and temporal variability in the benthic macrofauna for the period 1971–1976 using data from five monitoring stations located between Blyth and the Tyne estuary, and two broad surveys. Variation in winter temperatures appeared to cause changes in community structure and species abundance. Christie (1981) examined the population ecology of 16 species of polychaete from three locations off the south Northumberland coast. In general, species that produced planktotrophic larvae spawned in spring or autumn, whereas species producing larvae with direct development spawned in winter. The effects of fly-ash dumping on benthic fauna were examined by Bamber (1984) at a fly-ash dumping ground off Blyth. The density, diversity and biomass of benthic species were all reduced at the centre of the dumping ground as compared with the surrounding natural sediments.

Long-term monitoring of two benthic stations off Blyth has shown community stability interspersed with periods of change caused by fluctuating winter temperatures and organic flux, in the form of phytoplankton, on the seabed (Buchanan & Moore 1986a, 1986b; Buchanan *et al.* 1986; Buchanan 1993).

There is an abundance of 19th-century offshore dredging data for this region (e.g. Alder, Fryer & Hancock 1850; Alder 1858; Mennell 1862; Norman, 1863, 1864; M'Intosh 1872), and many of the related specimens are now held in the Hancock Museum, Newcastle-upon-Tyne. A grab-sampling survey of the benthos from Cambois Bay south to Bridlington (Turner *et al.* 1993) was commissioned by the MNCR.

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 1973, 1977, 1978, 1985; Wilson 1981; Roff, Middlebrook & Evans 1988; Evans & Edwards 1993). Fish plankton in particular were recorded by Harding & Nichols (1987), while a historical review of records of Northumberland fishes was compiled by Davis (1983a) and details of capture or sightings of rare fish species from the Northumberland coast were noted by Davis (1991).

A number of studies have been undertaken in the Tyne estuary, mainly in relation to pollution. Bull (1934) described the chemical and physical condition of the estuary in relation to salmon smolt mortality. Water quality in the estuary was monitored over the period 1971-1976 (Douglas & Edwards 1976). Water quality, nutrient discharges and bacteriological conditions were also studied (James 1972, 1973; Ord 1988). 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 consisted predominantly of capitellids, oligochaetes, nematodes and the polychaete *Polydora* sp. Pomfret *et al.* (1988) assessed the effects of pollution in the Tyne estuary and provided evidence of increased abundance of fish in relation to improvements in water quality. In a comparison between the fish communities of the Tyne and Forth estuaries, Pomfrett *et al.* (1991) described the distribution of fish in the Tyne in relation to ecological types and water quality.

Evans, Arnott & Wahju (1994) found that the macrofaunal species and communities present in 1991 at Black Middens in the Tyne estuary and at Cullercoats Bay were very similar to those recorded in 1931 by Brady (1943).

Sewage sludge dumping off the mouth of the Tyne estuary began in 1980. The sediments and fauna at the dumping site were studied and the effects of sludge disposal monitored by Northumbrian Water Authority (Pomfret & McHugh 1983; Pomfret 1988) and the Ministry of Agriculture, Fisheries and Food (Rees *et al.* 1985). The results of benthic fauna sampling by trawls and bacteriological sampling undertaken on the sludge dumping ground were described by the Northumbrian Water Authority (1987a). 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. However, Rees *et al.* (1992) provided evidence of localised effects of dispersing sludge particles at the seabed. Increased numbers of individuals of a range of common species occurred in the immediate vicinity of the disposal site, but there was no evidence of gross change in community composition.

The solid geology of the area between the Tyne and Hartlepool consists of upper Magnesian limestone. This section of the coast typically consists of cliffs up to approximately 45 m high backing rocky shore platforms, shingle and sandy bays.

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 was 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 species 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.

Several surveys on the Durham coast, including the Tyne, Wear and Tees estuaries, have indicated the effects of pollution on the distribution of marine algae. Bellamy *et al.* (1967) estimated a reduction of 70% of common species of marine algae on the Durham coast since Brady's (1861) list, although this discrepancy was disputed as being exaggerated by Moss & Frankton (1969). Edwards (1975) calculated that there had been a 16.6% reduction in common algal species along the Durham coast over the preceding century. As this reduction in algae was comparatively low in relation to the considerable increase in industrialisation and urbanisation, it appeared that pollution was having only a minimal effect on species diversity on the open coast where there was good water circulation. Mercer (1976) attributed the absence of *Himanthalia elongata* on the Durham coast to the effects of silting and the instability of the Magnesian limestone substratum, which easily erodes. Hardy, Evans & Tremayne (1993) compared the macroalgal flora of the Tyne, Wear and Tees estuaries with data obtained by Alexander, Southgate & Bassindale (1935), Edwards (1972) and Wilkinson (1973). Brown and red seaweeds have evidently decreased in diversity since the early 1930s in the Tees estuary and since the 1970s in the Tyne and Wear estuaries. There were, nevertheless, some signs of recovery of macroalgal populations following recent clean-up measures.

Sublittoral areas off the Durham coast have been investigated in relation to possible effects of colliery waste disposal operations. A Marine Conservation Society 'Seasearch' survey (Loretto 1992) described the seabed within the survey area as predominantly sedimentary and highly mobile. Inshore, there was evidence of smothering of the seabed by colliery waste and dredge spoil, and species diversity was low. Exposed subtidal rock in the north of the area was

depleted of life. Further offshore, the seabed was muddy with boulders and mixed sediments dominated by animal communities, particularly *Alcyonium digitatum*, hydroids and bryozoans on the hard substratum. The water in these areas was turbid and a fine dark silt covered all the sites investigated. A study of the same area by the Directorate of Fisheries Research of the Ministry of Agriculture Fisheries and Food (Limpenny, Rowlatt & Manning 1992) concluded that there was no significant accumulation of colliery waste in the nearshore zone and no evidence of any smothering of areas which provide habitat for crabs and lobsters.

Hartlepool is located on a rocky limestone headland with sandy beaches stretching to the north and in Tees Bay to the south. South of Hartlepool, the Magnesian limestone is replaced by the less resistant Triassic sandstones and mudstones as far as Saltburn. Here, low cliffs and glacial deposits backing sandy beaches are representative.

Owing to 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) (now Zeneca Ltd). Since the early 1970s water quality in the estuary has gradually improved, and in order to assess the impact of that improvement, a monitoring programme involving quantitative surveys of the estuarine benthos was established in 1979. There is some evidence that, over the period 1979–1990, the benthic communities became more diverse and abundant (Shillabeer & Tapp 1989; Shillabeer 1990; Tapp, Shillabeer & Ashman 1992). The distribution and abundance of fauna and flora in the Tees from Yarm to the sea was studied by Alexander, Southgate and Bassindale (1935). Benthic meiofauna was studied in the Tees estuary by Gray (1971). Comparisons with 1935 data showed there to be no major reduction in species diversity. However, numbers of macrofaunal species, particularly bivalve molluscs, were lower than in 1935 (Gray 1976).

Studies in relation to pollution have also investigated 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 owing to the discharge was found (Newell 1984). The Northumbrian Water Authority (1987b) also monitored water quality, sediment and benthos in the Creek.

After land-claim affecting a large proportion of Seal Sands, three areas of sediment remained at Tees Mouth: North Gare Sands, South Gare Sands and the remainder of Seal Sands. Kendall (1976) studied the sediments and fauna at these three sites. 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, and, although only 15 species were recorded, numbers of individuals were abundant. 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*. A barrage, which will render the upper reaches of the Tees estuary entirely fresh water, was completed in 1995.

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.

Long-term studies of the water quality and the benthic populations of Tees Bay indicated that the benthic fauna remained stable. However, studies of biomass and *Fabulina fabula* growth rate did indicate a difference between the areas close to the mouth of the Tees and those remote from it (Shillabeer & Tapp 1990).

The recent sludge dumping ground off Tees Bay has been monitored by the Northumbrian Water Authority to investigate possible changes in sediments and fauna (Pomfret 1986, 1988). The benthic infaunal populations of a liquid waste disposal area 16 km offshore from the River Tees and a control area were studied over a five-year period by Shillabeer (1991). There was no evidence that disposal operations have altered the diversity or abundance of the benthic fauna. The different faunal groupings found appeared to be related to sediment type.

5.4 Redcar to Bridlington

Redcar is a popular resort with sandy beaches and accessible areas of rocky shore. The environment and species of Redcar Rocks were described in a popular guide (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 extensive shore platforms backed by high, sheer cliffs mainly of Jurassic Lias clays and shales, rising to 120 m, with a few sand and/or pebble pocket beaches and bays. Large areas of sandy beach occur at Saltburn, Whitby and Scarborough. As part of a monitoring scheme for the potash industry, sediments have been analysed and species recorded at an outfall site 1.25 km off Boulby by Craig, Shillabeer & Parr (1993). Changes in the sediment characteristics and a decline in the benthic fauna occurred after the commencement of discharge of fine inorganic waste. Studies on the growth rate of *Flustra foliacea* as a possible bio-indicator of pollution were carried out over a

number of years at sites off Boulby (Craig & Shillabeer 1990; Shillabeer & Craig 1992; Brown & Craig 1993). Correlations were found between growth rates of *Flustra foliacea* and distance from the outfall of potash mine waste.

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 papillicornis* (now *Magelona mirabilis*) and *Chaetozone setosa* and the amphipod *Pontocrates arenarius*. The area was considered to have a low species diversity. Sublittoral infaunal communities off the coast at Sandsend Bay and Maw Wyke Hole were studied by Atkins (1983, 1985). At Sandsend Bay the sediments consisted of well sorted, fine sand with a fauna low in diversity and dominated by tubiculous (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 was described in terms of habitats, fauna and flora and features of conservation importance (Foster-Smith 1988a). Apart from the shore platforms, boulders formed an important habitat. Rocky shores varied in exposure to wave action and communities were characterised by mussels *Mytilus edulis*, barnacles and fucoids. Boulder beaches provided overhangs, and in deeper channels between boulders where sand and silt accumulated, the tubeworm *Sabellaria spinulosa* was commonly found. Exposed sandy beaches supported low numbers of lugworm *Arenicola marina*. A subjective assessment of biological diversity along this section of the coast showed Skinningrove, Deepgrove Wyke, Saltwick Bay and Ravenscar to support the greatest number of interesting communities.

The National Rivers Authority (NRA) Yorkshire Region carried out biological surveys on the Yorkshire coast. A survey of the intertidal invertebrate fauna of Yorkshire's bathing beaches was undertaken in 1991 (National Rivers Authority, Yorkshire Region 1992). The fauna consisted of amphipods and polychaete worms. Species zonation was apparent on most of the beaches and there was evidence that the sandy beach fauna was related to exposure to wave action. The rocky shores at seven sites between Staithes and Flamborough Head were also investigated (Bird & Morris 1992). At each site the shore was described and semi-quantitative records of the species found were given. The species included the isopod *Zenobiana prismatica* which is mainly confined to south-western Britain. The effects of sewage pollution on Scarborough's rocky shores were described and discussed (National Rivers Authority Yorkshire Region 1990, 1991a), and a study of the levels of tributyltin- (TBT) induced imposex in the dogwhelk *Nucella lapillus* was carried out (NRA Yorkshire Region 1991b).

The seabed off the Yorkshire coast was described, especially in relation to crab stocks, by Edwards (1967). Between Redcar and Flamborough Head to approximately 3 km offshore the bottom was found to be rugged. Beyond this, extending 3 km to 10 km offshore, the seabed was sandy with outcrops of rocks and stones. South of Flamborough Head, in Bridlington Bay, the seabed was sandy. Sublittoral grab sampling and diving surveys carried out in 1988 and 1990 off Scalby Ness and Scarborough were reported by Wimpey Environmental (1993).

Naturalists have recorded the fauna and flora at Robin Hood's Bay since at least the 1930s (Anon. 1933). The existence of the University of Leeds Welcome Marine Laboratory at Robin Hood's Bay until 1982 resulted in numerous studies being undertaken in the vicinity. Some of these concentrated on single species such as mussels *Mytilus edulis* (Seed 1967), dogwhelks *Nucella lapillus* (Feare 1969, 1970, 1971), the upper shore isopod *Ligia oceanica* (Willows 1984) and the barnacle *Balanus* (now *Semibalanus*) *balanoides* (Kendall *et al.* 1985). Other work involved small groups of sandy shore animals, for instance, the amphipods *Bathyporeia* spp. (McGrorty 1972), and rocky shore species including nudibranchs (Todd 1977), nematodes (Cramp 1985), pool-dwelling serpulids and spirorbids (Hanna 1989; Grahame & Hanna 1989) and limpets *Patella* sp. (Bowman & Lewis 1986). Lewis (1964, 1977) examined the local shores during investigations on the dynamics of rocky shore communities.

The fauna in the upper few centimetres of Stoupe Beck Sands (Robin Hood's Bay) 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 Sands and compared with that of the less exposed Filey Beach (Gray & Rieger 1971). The meiofauna at Filey was found to be more abundant and more species diverse than at Stoupe Beck.

The marine algae of the coast between Scalby Mills and Cornelian Bay were recorded by Massee (1885) and the algae and rocky shores from Robin Hood's Bay to Flamborough were described by Perkins (1953).

The intertidal area and species in the Scarborough area were described by Lewis (1987b) 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 1987a).

The shore south of Filey Brigg is sandy until the chalk exposures of Flamborough Head are reached. From Speeton to Flamborough Head, Cretaceous chalks are exposed as cliffs that rise in height as far as Bempton, and farther south are lower and capped by glacial deposits around Flamborough Head to Bridlington. Also in this region are small sandy coves between rocky headlands and shore platforms. Flamborough Head projects eastwards, forming a major peninsula of the English coast.

From Dulcey Dock around Flamborough Head to Sewerby, the chalk cliffs lead down to boulders and shore platforms. Naturalists have been active in

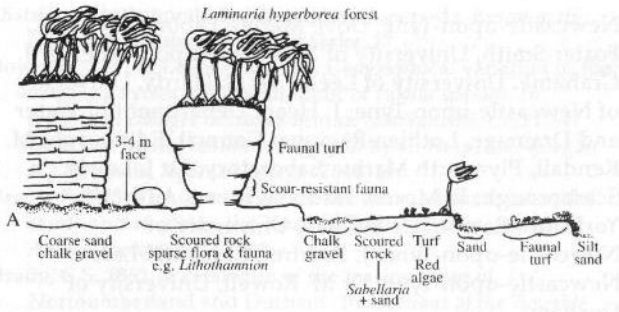

Figure 5.8. Seabed profile adjacent to the shore at Cat Nab, Flamborough Head. From Wood (1988). Drawing by Bob Foster-Smith.

recording the algae and fauna, in particular the molluscs, from the Flamborough area since the 1890s (Hey 1894; Pearsall & Mason 1923; Philip 1934; Norris 1973).

The chalk shores around Flamborough Head were surveyed for the then Nature Conservancy Council 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. Owing to the hardness of the chalk erosion is slow, and there has been no need for coastal protection, so the cliffs 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 are more sheltered behind broader shore platforms. George *et al.* (1988) studied shores of varying exposure, and a total of 270 invertebrate and 112 algal species were recorded. The more sheltered sites supported a greater diversity of species compared with 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 with the south side, and were slightly different from those found elsewhere in Britain.

A sublittoral survey of Flamborough Head showed the seabed 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 m 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 m to 4 m. The vertical chalk faces were colonised mainly 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 the soft coral *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 the urchin *Echinus esculentus* and fish. The sublittoral flora and fauna included some species with a northern distribution, for example the red algae *Odonthalia dentata* and *Ptilota plumosa* and the hydroid *Thuiaria thuja*, and others with a southern distribution, such as the brown alga *Taonia atomaria*, the red algae *Schottera nicaeensis* and *Rhodymenia holmesii*, the sponge *Polymastia boletiformis* and the ascidian *Archidistoma aggregatum*.

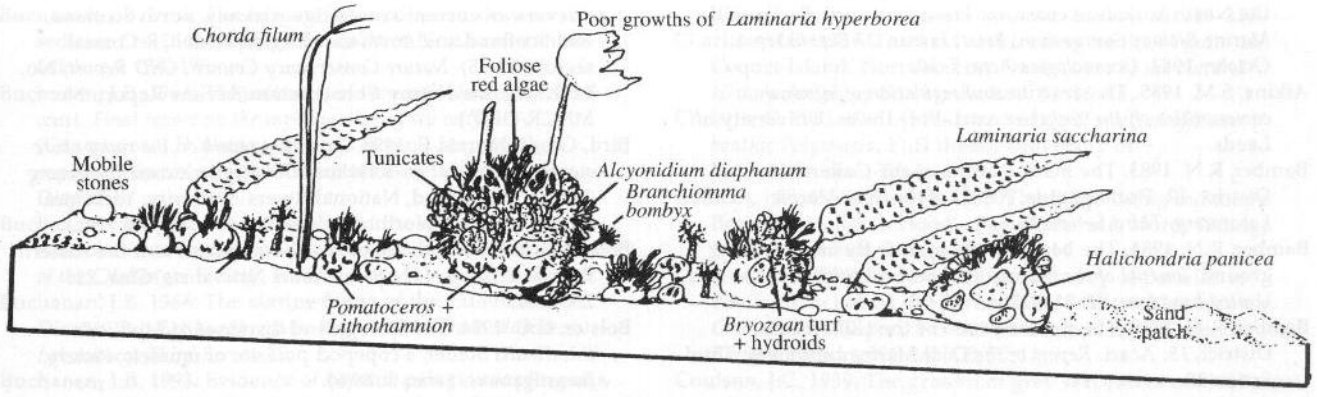

Figure 5.9. Seabed communities at 2.5 m depth off South Cliff, Flamborough Head. From Wood (1988). Drawing by Bob Foster-Smith.

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