Report for the
Department of Trade and Industry

Synthesis of Information on the Benthos of Area SEA 5

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Contents

1. INTRODUCTION.

The purpose of this report is to present an up-to-date synthesis of current information on the benthic environment and the benthic communities and associations in the Strategic Environmental Assessment (SEA) region 5 and, additionally, to highlight areas considered to be particularly vulnerable to anthropogenic influences.

The synthesis has been prepared from the information available on seabed habitats, species and communities to the east of Orkney and Shetland and extending down the east coast of Scotland. The area includes the major east coast features, the Moray Firth, the Firth of Forth, and the Tay estuary, and the inner Firths of Dornoch, Cromarty and Inverness, the Ythan Estuary and the Montrose basin. It extends offshore to an irregular border at 1° west, east of Wick on the Scottish mainland, proceeds west to 1°45' west off Fraserburgh and then offshore again to 0°45'east off the Tay estuary before rejoining the coast at the Scotland - England border (Figure 1).

The information was obtained from a wide range of sources including recent and historical scientific studies, regional surveys commissioned by the UK government and its agencies, industry reports and by personal communication.

In areas where there is more detailed information available, it has been discussed in relation to previous studies within the region and to similar localities elsewhere.

For the purpose of this report, the benthic fauna in the SEA5 region have been considered and presented as three groups: meiofauna, infauna and epifauna. The meiofauna group, the smallest in size (less than 0.5mm), are generally capable of moving between the sediment particles using the natural spaces. Though these animals can be found in very high numbers, they have not been extensively surveyed because of their microscopic size. Yet they are widely used as biological indicators of environmental effects, both experimentally and in areas of anthropogenic impact. The infauna (or macrofauna) group (greater than 0.5mm) are usually surveyed using grabs or corers, as they live in the upper layers of the sediment. They represent the most commonly surveyed and understood benthic grouping. Epifaunal animals, which live on the surface of the sediment, are generally larger in size than infauna and meiofauna and may be capable of extensive migrations both over the seabed and into the water column. They are surveyed by means of trawls or UW still or video cameras.

2. OVERVIEW

2.1 Hydrography

2.1.1 Introduction

A major factor influencing the geographical distribution of benthic communities is the type of sediment in which they live, and the distribution of the sediments is largely governed by hydrography. Put at its simplest, this means that where there are strong near bottom flows, coarser sediments exist, and where the flow rates are slow, fine sediments are deposited. Some information concerning the background hydrography is essential to an understanding of the distribution of the benthos.

2.1.2 Offshore circulation

The circulation of the water masses in the northern North Sea has been the subject of many investigations, the findings of which have been summarised by Lee (1980). The main inflow from the Atlantic to the northern North Sea, the Fair Isle Current, passes into SEA area 5 via the Orkney – Shetland gap. Thereafter, it flows south along the 100m contour before being directed east at about 57°30'N by the west-east trend in bottom topography (Dooley 1974; Ramster et al. 1975). To the north of this east - west current, velocities are very low, resulting in the sedimentation of finer material in the deeper areas (>140m) in and around the Fladen Ground. (It should be noted that the Fladen Ground does not fall within SEA area 5).

The Fair Isle current reaches near bottom velocities of $25 cm.s^{-1}$ (Dooley 1974) which results in the removal of lighter sediment particles, leaving mainly gravel and various admixtures of sand and gravel as the dominant seabed sediments in the Fair Isle Channel. Areas of rock occur as isolated outcrops to the south of the Fair Isle itself (Andrews et al, 1990). As the residual flow decreases in the offshore area, near bottom velocities are much lower and the finer particles sediment out.

2.1.3 Inshore Hydrography

Turrell (1992) has described the existence of a southerly Atlantic inflow along the east Shetland coast, and in addition, it was long considered that there was yet another significant inflow via the Pentland Firth, between Orkney and the north Scottish mainland. However this latter is now considered to be an area of rapid tidal movement rather than of mass Atlantic inflow (Turrell 1992). The residual tidal flow extends south into the northern Moray Firth giving outcrops of rock on the northern Scottish mainland with gravel and sand further offshore. While the deeper southern areas of the Moray Firth have silty deposits, inshore and to the south, it is sand and gravel that predominate in the areas of higher tidal flows off the Buchan coast. (Gatliff et al. 1994).

Partly because of the lack of benthic data, and partly because the hydrography was better understood, authors tended to divide the North Sea according to the major hydrographic regions (Glémarec 1973; Adams 1987). While the hydrography has a major effect on the sediments and concomitantly, the sediments are a major factor governing the benthic communities, benthic community mapping based on the sediments alone cannot resolve the community boundaries. The large-scale surveys undertaken by Stephen 1922-25 (Stephen 1933,1934), Dyer 1978-80 (Dyer et al. 1982, 1983), Basford and Eleftheriou 1980–85 (Basford & Eleftheriou 1988; Eleftheriou & Basford 1989; Basford et al. 1989, 1990, 1993) represent the major efforts to relate the benthos to their environment and to describe more accurately the benthic communities.

2.2 Sediments

2.2.1 Introduction.

The North Sea sediments derive from the Holocene epoch, their distribution reflecting the glacial history of the area as well as subsequent hydrodynamic processes. Recent sediment inputs are negligible, with the main process being the reworking of older deposits in the areas by tidal and residual currents. In addition, wave action, particularly when amplified by storm surges, adds to the process of sorting and transport of sediments (Draper 1967; Stride 1973). The net sediment transport instigated by these effects follows the residual along-shore currents (Riepma 1980). However, over most of the central North Sea, the weak tidal currents and relatively large depths are not sufficient to cause any large-scale sediment transport. Further offshore, in the deeper areas (>140m), the sediments are virtually at rest (Eisma 1973)

2.2.2 Offshore Sediments.

The BGS sea-bed sediment maps of the region (Figure 2) show the majority of the offshore area between 50 –100m to be flat and sandy, with more extensive gravelly sand in the shallower areas with the deeper offshore areas being muddy sand. However, in the central North Sea, to the south of the residual Fair Isle current (57°30’N) areas of sand waves are recorded (Gatliff et al. 1994).

2.2.3 Inshore Sediments.

In the shallower, more dynamic, inshore regions the BGS reports show sediments grading from bedrock, in the Pentland Firth and isolated areas to the north of the Moray Firth, through gravels, to the offshore sands. In addition the southern Moray Firth and Firth of Forth both have extensive east-west orientated areas of muddy sand (Gatliff et al. 1994). The largest sand waves in the area, at Sandy Riddle, occur at the eastern entrance to the Pentland Firth (Andrews et al, 1990). The area was subject to survey during the DTI cruise of 2003, yielding valuable information on the sandwave structure and the local topography (Figure 3).

3. SURVEYS AND STUDIES

3.1 Historical perspective

The Poseidon survey of 1872 was amongst the first collections of benthic material from the North Sea. Although it concentrated on the Danish coastal region it included several samples from offshore areas such as the Dogger Bank. For a review of the polychaetes see Mobius (1875). Michaelsen (1896) gives a much more comprehensive record of the early polychaete distribution in the North Sea. Later Poseidon cruises (1902 – 1912) supplied material to multiple authors for taxonomic purposes, each often describing single polychaete families, (see Kirkegaard 1969). Between 1867 and 1927 McIntosh, working at the Gatty Marine Laboratory, St Andrews, published his large monograph of the British Annelids.

The main attempts to describe the benthic fauna of the North Sea began at the beginning of the 20th century with the surveys by Petersen off the Danish coast (Petersen & Boysen Jensen 1911; Petersen 1914 & 1915) with the main publication in 1918 (Petersen 1918). This Danish work initiated coastal investigations in several countries (Scotland, England, Denmark and Germany) and led to the wider investigation of the benthos of the North Sea by Blegvad who sampled a line of stations from Lowestoft to Esbjerg on the George Blyth in 1912 (Blegvad 1922). Most of these early investigations attempted to relate the benthos to the fish populations and were therefore centred on the major fishing areas at the time, e.g., the Dogger Bank surveys by Davis during the years 1921 - 1924 (Davis 1923, 1925) and later Ursin (1952) and Kroncke (1990).

Stephen's surveys in 1922 - 1925, taking into consideration Davis (1923, 1925) and Petersen's data (1914,1915) represent the first large-scale survey of the offshore areas in the northern North Sea (Stephen 1933, 1934). However his published studies concentrate mainly on echinoderms and molluscs and did not consider the polychaetes worms which are numerically dominant. Stephen's work, based on over 1,000 sublittoral samples, as well as littoral sampling, was of a preliminary nature, with little quantitative data, but it provides a good historical baseline for further studies. (Kingston & Rachor, 1982) Later, Ursin (1960) reported the results of his 1947–48 surveys of the echinoderm fauna of the North Sea. McIntyre (1958) extended the investigations of the benthos of fishing grounds with surveys off the east coast of Scotland, in Aberdeen Bay, St Andrews Bay, and the Smith Bank at the outer reaches of the Moray Firth.

Subsequently a grid survey of the northern North Sea was undertaken by the Scottish Department of Agriculture and Fisheries (Eleftheriou & Basford 1989), that led to a survey of the benthos of the whole of the North Sea under the auspices of the International Council for the Exploration of the Seas (ICES) between 1980 and 1985 (Figure 4) : (Kunitzer et al.,1992; Heip 1992; Duineveld et al.1991). Preliminary results were also reported by Heip et al. (1990) and Huys et al. (1990, 1992). Further north between 1980-1984 a series of surveys were carried out on the benthos of the area of the North Atlantic Flow between Orkney and Shetland (Basford et al. 1996).

The UK National Monitoring Plan (NMP) established a network of 87 monitoring stations around the UK coast and included estuarine, intermediate and offshore sites. At each site a range of environmental variables were measured with sampling including grab samples for macrobenthos (0.5 or 1mm depending on sediment type). Thirteen locations in the Moray Firth, the Tay estuary and the Firth of Forth fall within the SEA 5 area.

Many seabed surveys have been conducted by the oil and gas industry in support of their continued operations in the offshore environment. Kingston & Harries (2000) collated all the surveys conducted between 1975 and 1992 into a database under the auspices of the United Kingdom Offshore Operators Association (UKOOA). The surveys are all localised in nature, mainly using a cruciform sampling strategy to examine gradients along, and perpendicular to, the residual current. The database provides a significant resource towards examining localised impacts of offshore installations, but is too spatially restricted to enable wider interpretation of the general seabed ecology.

Stephen also surveyed beaches along the Scottish east coast from the Moray Firth to the Firth of Forth (Stephen 1929, 1930). Eleftheriou & Robertson (1988) reported on the physical status and the intertidal benthos from a number of beaches of the east coast of Scotland from Sinclair Bay (near Wick) to Belhaven in the outer Firth of Forth.

Dyer et al. (1982, 1983) studied the epifauna of the North Sea using a camera attached to the headline of a trawl during general demersal fish surveys and Cranmer (1985) described the regular echinoids taken in the trawl. Basford et al. (Basford 1989,1990) reviewed the epifauna and infauna of the northern North Sea while Frauenheim et al. (1989) compared the epifaunal species taken in consecutive seasons. Jennings et al. (1999) and Zuhlke (2001) undertook surveys of the epifauna of the whole of the North Sea.

Many authors have made attempts to divide the North Sea into different zones using a variety of measurements, e.g., hydrographical conditions, benthic faunal dominance, etc. See Stephen (1923); Jones (1972); Glémarec (1973); Kingston & Rachor (1982); Dyer et al. (1983); Adams (1987); Eleftheriou & Basford (1989); Basford (1989, 1990); Kunitzer et al. (1992).

4 THE PHYSICAL ENVIRONMENT

4.1 Introduction

Benthic faunal samples are usually collected using a mechanically triggered grab or corer. These samplers generally sample no deeper than 30 cm and while some organisms live deeper in the sediment, e.g., *Mya* sp*., Lutraria* sp*., Maxmuelleria* sp*.,* most benthic fauna lives in the surface sediment layer.

Some authors have collected sediment samples at the positions where the faunal samples were collected (Basford & Eleftheriou 1988; Basford et al. 1993). Descriptions of the surface sediments in the present report, however, are based on the British Geological Surveys (BGS) United Kingdom Offshore Regional Reports series (Andrews et al, 1990; Johnson et al.1993; Gatliff et al 1994),
SEA 5 covers two hydrographic areas. The northern area includes the major north Atlantic inflow between Orkney and Shetland and its downstream progression to approximately 57°30'N where the current is directed west due to the seabed topography and a southern area, where there was no residual current from the water flowing into the North Sea (Dooley 1992).

4.2 The Shelf and Offshore Areas

The northern offshore seabed (north of 57°30'N) is predominantly sandy and flat, and covered by 80 to120m of water. However, to the east of Shetland there are several raised areas (Halibut Bank, Pobie Bank). There are also several extensive deeper areas (>160 m), for instance, the Viking Bank and, to the east of Orkney, the Fladen Deeps (the northern extension of a very large deeper area). In general, the shallow areas have coarser sediments, i.e., sandy gravel and gravel, while the deeper areas consist of sandy mud. To the east there is a general improvement in sediment sorting along with a decrease in mean particle size (Johnson et al. 1993). This was also observed by Hartley (1984) who noted a highly significant correlation between depth and silt-clay within the Forties oilfield area. The BGS report indicates an absence of offshore sand waves but mentions the presence of sand ripples. Much smaller-scale features occur in the region of the Cormorant oilfield and the report suggests that they probably occur over much of the sea floor (Johnson et al. 1993).

The western margin of Area 5 extends to the shallower (40 – 80m) ridge between Shetland and Orkney. Much of the North Atlantic water entering the northern North Sea does so through this gap. Apart from a few localised areas of extreme currents (communicating passages such as Yell Sound) maximum surface tidal streams around Shetland and off Fair Isle reach velocities up to 2.8 $m.s^{-1}$ (Johnson et al. 1993) and are responsible for the removal of the finer particles, leaving only sand and gravel.

The southern area (south of 57°30'N) is shallower, predominantly 60 – 80m in depth and most of the sea floor is covered with sand. However, in this region there are two large, irregularly shaped, extensive gravelly sand areas (Gatliff et al. 1994), the northern area being Aberdeen Bank (60-80 m. depth), the southern, the shallower Marr Bank (40-60 m. depth). As in the northern area, within this overall shallower sandy area, there was a tendency for finer sediments to predominate in deeper areas (Johnstone et al. 1993). In the absence of strong residual currents, storm-wave-induced currents are probably mainly responsible for the re-distribution of the offshore sediments. Pantin (1991) estimated that the maximum, storm-induced, orbital current velocities acting on the seabed could reach 4.0m/s in water depths of about 40m and 3.0 m/s at 80m. Stride (1973) calculated that such bottom currents are probably generated on several occasions each year at depths even of 100m. Such storms may account for the extensive areas of sand waves in deeper water (80m) 50km offshore of Aberdeen where waves 8m high and with a wavelength of 160 to 270m are present (Gatliff et al. 1994). It seems more likely, however, that these are relict features from a time when sea level was much lower.

4.3 The littoral shallow sublittoral and voes

In geological terms the east coast of mainland Scotland, the coasts of Orkney and Shetland consist of Old Red Sandstone, high grade metamorphic rock and igneous intrusions. The shore environment is predominantly rocky and backed by cliffs interrupted by sedimentary beaches of variable proportions. In most rocky shores the rock extends sublittorally at a variable depth from the shore, being replaced by sand and mixed sediments (Barne et al.1996). The extensive coastline along the east coast of mainland Scotland, the coasts of Orkney and Shetland differ in terms of their orientation in relation to the prevailing winds and their overall exposure. The shores of mainland Scotland are moderately exposed to wave action having a north-easterly aspect and the complex geology of the area has created a high density of intertidal habitats (Davies 1994).

However the indented coastline of Orkney and Shetland covers the whole range of the exposure spectrum from the extremely sheltered, a condition which in the Scottish mainland can be found only inside the sheltered estuarine systems. Beaches are generally formed of offshore glacial deposits and alluvial material as accretion from cliff erosion is minimal (Barne et al. 1999). Boulder, pebble and shingle beaches are predominant in the more exposed parts of the coast while narrow inlets and small bays have mixed sediments including sand and mud patches in their inner and more sheltered areas.

The mainland coast relevant to SEA 5 stretches from Duncansby Head in the north to Coldingham Bay in the south and is predominantly rocky backed by dunes or by seacliffs, and interspersed with sedimentary beaches often consisting of a range of unconsolidated materials of fluvio-glacial origin. The coast is moderately exposed to wave action and onshore winds from the northern sector of the North Sea and the open and exposed rocky coast and sedimentary beaches are directly affected. The beaches consist of coarse and overall well-sorted grades which are particularly evident in the sandy stretches of North East Scotland, the Lunan Bay area and the extensive sandy shore in Tentsmuir (Irving 1996, 1997; Eleftheriou & Robertson 1988; BGS & Sawyer 1997). Some clean sandy shores of large dimensions are also present south of Fraserburgh and the west sands of St Andrews the latter being traced mainly to the sedimentary source of the estuarine discharge (Ritchie 1979; Irving 1996, 1997). Historical information about early studies is limited to some early naturalistic treatises focussing on the fauna and flora of the estuarine areas, while the areas outside the large firths, despite their accessibility and easy reach of the localities have been given little attention. Consequently most of these studies are relatively recent in origin with Stephen in his pioneering work on several sedimentary beaches (1933, 1934) on several littoral sites from the Moray Firth to the Firth of Forth providing information on the benthic invertebrates and their zonation on the littoral zone. Other authors have dealt with ecological and environmental aspects of the littoral (Eleftheriou & Robertson 1988; Ritchie 1979; Irving 1996, 1997) of the east Scottish coast but the fact remains that there are very few data available from a very long and ecologically important coastline.

The Shetland Island archipelago consists of several islands, both large and small, with extensive and deeply dissected coastlines, with high cliffs, stacks, caves, arches and geos, with deep water occurring close inshore. As a result, the coastline of Shetland shows a transition from wave-exposed rocky habitats to several very sheltered sedimentary shores. Accordingly the intertidal communities range from those characteristic of extreme exposure to wave action, to some algal and animal-dominated shores which are extremely sheltered. There are numerous channels between islands scoured by the tides with extensive rocky outcrops, while the few areas of littoral sediments occur as shingle at the head of very sheltered inlets or voes, or as pocket beaches with mixed sediments in sheltered areas and as sandy beaches on the more exposed coastline (Howson 1999). The sea floor of such voes grades from rock, boulders, cobbles and shelly sand to mud (Howson 1999; Pearson & Eleftheriou 1981) with the presence of patches of submerged peat. Bedrock frequently continues into the sublittoral area with vertical rock reaching a floor of bedrock, boulders or cobbles followed by mixed sediments that eventually are followed by clean sand. The coastal environment of the Shetland Islands has been extensively investigated and the results presented in a series of reports (Institute of Terrestrial Ecology 1975a,b, c, d; Marine Conservation Society, Moss & Ackers 1987, and MNCR, Hiscock 1986, 1988; Howson 1988) compilation of which is presented by Howson (1999).

Eight types of rocky shore were identified by ITE (1975c) ranging from very exposed bedrock through intermediate exposure to very sheltered shores. Forty-three rocky shore sites were surveyed by Hiscock (1981) while Howson (1999) describes in detail the structure and sedimentary characteristics of 739 sites covering the whole range of exposure of littoral and sublittoral shores. Cliffs and extensive rocky outcrops form the main feature of the coastline, alternating with beaches of cobblestones, boulders and mixed sediments. Most of the voes and the inlets have a similar pattern of coarse and finer sediments, in a landscape of rock and unconsolidated stones and boulders, extending into the sublittoral where in many areas shell gravel, gravelly sands and muddy sands predominate. The degree of exposure to wave action in these shallower areas and the strength of the tidal stream determine the sequence in the composition of sediments.

The extensive studies carried out in the Oil Terminal of Sullom Voe, Yell Sound and the surrounding voes (ITE 1975a, b, Moore & Little 1995; Hiscock 1986; Pearson et al. 1994; Westwood 1985; Pearson & Eleftheriou 1981; Hiscock 1981; May & Pearson 1995) give a detailed account of the littoral and sublittoral sediments and also provide a typical example of these voes. The Magnus EOR project involving the construction of a subsea pipeline system to carry gas from the Foinaven, Schiehallion and Loyal fields to the Sullom Voe Terminal (Anon. 2000) produced a photographic record which confirmed the finding of Howson (1999) regarding the sea floor characteristics along the main axis of Yell Sound, a flooded glacial valley in the NE part of the Shetland mainland. Thus in the outer Sound there are hummocky moraines which with the mounds and rock outcrops fall within the current definition of the Habitat Directive (Annex 1) of a “reef habitat”. In the Inner Sound there is a sequence of gravelly sand, stony gravel, muddy stony gravel and leading to finer sediment accumulation in the inner smaller voes and with mud and silt along sand, pebbles and rock.

The Orkney archipelago includes several islands surrounded by a relatively shallow platform. In common with the Shetland Islands, Orkney has a complex coastline varying from extreme rocky shores and high cliffs to extensive sandy beaches on the island of Sanday. The channels between the islands are narrow and shallow and consequently tidal streams and races are characteristic of these narrows. The seabed between the islands consists of rock, boulders, gravel, maerl and occasionally mud while the tide scoured sounds are rock shell gravel and sand (Jones 1975). The complexity of the coastline affords shelter in the many embayments and inner sounds and especially in Scapa Flow where shelter and reduced tidal movement provide calmer conditions and a marine environment different from the other parts of Orkney (Bennett & Covey 1998).

The fine sedimentary beaches of Orkney have been described by Mather et al. (1974) and more recently by Atkins et al. (1985) while the composition of the fauna and flora of the rocky shores has been described by Baxter et al. (1985) in their long-term monitoring studies. A symposium held in 1984 in the Royal Society of Edinburgh on the Marine Biology of Orkney summarised all environmental studies at the time (Jones 1985). On the other hand another symposium by NCC in 1974 (Goodier 1975a) included a number of papers relevant to the geomorphology of the coastline (Mather et al. 1975) and the conservation interests (Goodier 1975b). In 1994 Baxter and Usher published descriptions of the physical environment and the benthic biology of the Orkney Islands. As part of the extensive survey of the MNCR programme, data from 465 sites were collected and the national biotope classification was used to identify the biotopes and the associated fauna and flora (Murray et al, 1999)

Published information on the marine life of Orkney extends back nearly 300 years but it is only since the seventies that intensive work has been undertaken and then mainly in relation to the operation of the oil terminal (Johnston 1977) and subsequently the implications of the oil developments in Scapa Flow (Johnston, 1981).

5 BIOGEOGRAPHICAL CONTEXT DIVISIONS

The east coast of Scotland, Orkney and Shetland have been firmly assigned to the Boreal Biogeographic zone which is flanked by the Boreal-Lusitanian Province of the west coast of Scotland and the Arctic Deep Sea Province to the North. These biogeographical provinces were reviewed in a workshop on Habitat Classifications (OSPAR/ICES/EEA, Oban 6-10 September 1999) and put forward by the AFEN Surveys of 1996 (AFEN 1996) on the basis of the temperature of the water masses. As far as the littoral environment is concerned, with regard to the extensive coastline of mainland Scotland and its northerly extension to the Orkney and Shetland Islands (56-60N), there is an important latitudinal temperature gradient from north to south, which remains a paramount factor in the type of species and composition of the animal and plant communities. However temperature fluctuations along the boundaries of these provinces blur such divisions, with the result that many species tolerant of environmental differences do not conform to their expected distribution (AFEN 1996; Hartley Anderson 2000).

Jones (1972) proposed the division of the North Sea into different zones using fisheries research data and although this system was inconclusive, ICES adopted it in 1978. Adams (1987) suggested that divisions of the North Sea could be drawn along depth contours with distinct physical characteristics and plankton communities, with his North British Coastal and Offshore Northern subdivisions impinging on the Orkney and Shetland areas.

Consequently, in addition to the influence of the water temperature on the littoral zone and shallow sublittoral, the type and distribution of the benthic communities, assemblages and associations are also influenced by exposure to wave action and its influence on the sedimentary factors (Hiscock 1993; Hartnoll 1983; Eleftheriou & McIntyre 1976; Eleftheriou & Robertson 1988; Eleftheriou & Nicholson 1975). The extreme variability of habitats in and along the littoral zone within short distances influence the species and communities, which exhibit important regional differences in their composition and distribution. Such variations of the benthic organisms on rock or on sedimentary beaches have been well documented in marine ecology.

The separation of the North Sea into different regions relating to physical conditions and the benthic communities associated with these conditions was put forward by several authors (Glémarec 1973; Dyer et al. 1983; Basford et al. 1989, 1990; Eleftheriou & Basford 1989; Kunitzer et al. 1990). The thermal stability of the water column was used by Glémarec (1973) to subdivide the North Sea into étages of which his coastal étage circumscribes Shetland and Orkney within the 100 m contour. Lee (1980) assigned regions to the North Sea based on hydrographic characteristics, but did not seek to associate these regions with the biology of the areas. However, with the recent changes in thermal stability within the North Sea due to the variations of the North Atlantic inflow (Hansen 2003) many of these boundaries may need to be reviewed.

6. BENTHIC COMMUNITIES, ASSEMBLAGES AND ASSOCIATIONS

6.1 Inshore areas - littoral and shallow sublittoral

6.1.1 Introduction

The communities of the different habitat types of the littoral hard substrata have been classified by MNCR using physical characteristics such as wave exposure, tidal stream strength, temperature and salinity. Exposure to wave energy is the overriding factor determining the composition of the animal and plant communities and the vertical and horizontal distribution of the different species (for zonation see Stephen 1933; Lewis 1964; McLachlan & Jaramillo 1995).

Climate is another important factor influencing the geographic distribution of species in this area of several water masses with different temperature regimes. The benthic communities, assemblages and associations in the east of Scotland, Shetland and the Orkney Islands have much in common with those in the North Sea, the west coast of Scotland and Ireland, and the NE Atlantic. Similar ecosystems with the same or similar faunistic and floristic elements have the same structure under relatively similar conditions.

However the prevailing conditions in the SEA 5 area are quite extreme and are responsible for a corresponding modification in their structure and distribution of these communities. In this way, severe exposure is responsible for modifying the distribution of the different species, while the temperature component is responsible for the incursion of southern and Arctic species in this area where they are found correspondingly at the northern or southern limits of their distribution. Hence Boreo-Lusitanian species from the west coast of Scotland are found in these waters, extending as far as Orkney and Shetland and to a lesser extent along the east coast of Scotland. Boreo-Arctic species are found in Shetland and Orkney, entering the North Sea and appearing at the east coast of Scotland.

In the present report, the intention is not to provide complete faunistic and floristic lists from the different habitats, but rather to focus on those distinct elements of the different communities which make them different from those in the adjacent biogeographic zones and characteristic for the SEA 5 area.

6.1.2 The Orkney Islands

6.1.2.1 Introduction

The littoral habitats of Orkney range from those exposed to extreme wave action on the west coast to very sheltered conditions between the islands (Bennet & Covey 1998). A detailed study carried out by the MNCR programme in the marine environment of Orkney provides a detailed account of the marine habitats and communities (Murray *et al*. 1999) and a hierarchical classification of the biotopes (OSPAR/ICES/EAA Workshop, Oban 1999).

6.1.2.2 Rocky littoral and shallow sublittoral

Exposed littoral rock is inhabited by typical encrusting species found in exposed conditions, such as *Mytilus edulis* and barnacles with the limpet *Patella* spp., the barnacles *Chthamalus, Semibalanus balanoides*, and some lichens and brown algae such *as Fucus distichus* sub sp. *anceps* and *F. spiralis f. nana*, *Corallina officinalis,* *F. serratus* and a few red seaweeds (*Chondrus crispus, Mastocarpus stellatus, Rhodothamniella floridula*). In the sheltered parts of the rocky coast and on mixed sediments there were dense fucoids such *as Pelvetia canaliculata, Fucus spiralis, F. vesiculosus*, barnacles and in the very sheltered areas *Ascophyllum nodosum* was present (Murray *et al*. 1999). It should be mentioned that the fucoids *Fucus distichus and F. spiralis f. nana* found on exposed shores on Orkney generally have a northern distribution, although the latter is absent from the whole North Sea. Elements of the southern fauna, species such as the barnacles *Chthamalus stellatus*, and *C. montagui*, as well as the gastropods *Littorina (Melaraphe) neritoides* and *Gibbula umbicalis* are also present on the Orkney shores. However the limpet *Patella ulyssiponensis* reported from the northern isles (Doody *et al*. 1993) does not appear in the faunal list of the detailed studies of Murray *et al.* (1999) of the Orkney area.

The shallow rocky sublittoral and other exposed hard substrata were dominated by the alga *Laminaria hyperborea* along with several brown algae such as *Alaria esculenta, Mytilus edulis* and several species of red algae, while in some wave-surged south coast sites dense growths of encrusting sponges (*Dendrodea/Clathrina*), ascidians, bryozoans and hydroids were present. In the less exposed areas, *Laminaria hyperborea* was replaced by *L. saccharina* with the presence of coralline crusts and other seaweed communities.

In the deeper and exposed sublittoral, faunal crusts with the polychaete *Pomatoceros triqueter*, the barnacle *Balanus crenatus* and bryozoans were present while dead man's fingers *Alcyonium digitatum*-dominated communities were found on moderately exposed rock. Bryozoans, mussel beds (both *Mytilus* and *Modiolus*) brittle stars and faunal and algal encrusting species with the presence of the sea urchin *Echinus esculentus* form the characteristic species of these communities.

In the shallow sublittoral mixed sediments, *Laminaria saccharina* and filamentous red seaweeds dominated while the bivalves *Venerupis senegalensis* and *Mya truncata* inhabited the muddy gravel in these areas. *Modiolus* beds are also present on these substrata. In the open coast and the outer areas of the sounds, maerl beds of *Phymatolithon calcareum* with red seaweeds, hydroids and echinoderms on coarse sediments are dominant while bivalves such as *Spisula elliptica* and venerid species are found on shell gravel. With a decrease in the median diameter of the benthic sediments there is a succession of benthic communities which are characteristic of the type of substratum conforming to Petersen's/Thorson's (1957) classic definition and description of shallow water communities. Thus we have shallow muddy sand communities of the sand urchin *Echinocardium cordatum* and spionid polychaetes and in the deeper areas bivalves (*Abra alba, Nucula nitida, Corbula gibba*), ophiuroids (*Amphiura filiformis, Ophiura* sp) but also the sea pen *Virgularia mirabilis* being dominant. In very sheltered areas, tube-building amphipods, polychaetes and synaptid holothurians were present.

6.1.2.3 The Sedimentary Shores

In the more sheltered conditions of Scapa Flow in the variable sediments, the species showed an uneven distribution (SOAFD- unpublished data). Sedimentary beaches found in most of the inlets of Scapa Flow had a fauna dominated by the spionid polychaetes *Pygospio elegans* and *Spio martinensis*, while at the lower shore *Tellina (Angulus) tenuis* was present. Sublittoral fine sandy sediments in the central basin supported communities characterised by the bivalves *Thyasira flexuosa, Pecten maximum, Dosinia exoleta*, the polychaete *Prionospio fallax* as well as sea pens and brittle stars. In the outer reaches of the Flow coarse sediments supported a community characterised by the sea cucumber *Neopentadactyla mixta* and the polychaete *Lanice conchylega* (Murray et al. 1999). On the coarse sediments of most shores, diversity was greatest with populations of molluscs such as *Chaetoderma nitidulum* and several species previously unrecorded in Orkney, while in the finer sediments of the northeastern part, diversity and abundance were low.

The coastline of Orkney with a complex configuration allows the presence of a range of sediments. The sandy beaches of Orkney were surveyed by Mather et al.(1974) with regard to their physical characteristics and the degree of anthropogenic impact. Sandy shores occur on the exposed parts of the islands and were either devoid of fauna or else inhabited by a sparse fauna of cirolanid isopods (*Eurydice pulchra*) and amphipods such as *Pontocrates* sp. and *Bathyporeia* spp. with some polychaetes such as *Pygospio* sp., reminiscent of the exposed sedimentary beaches of the east and north coasts of Scotland. In the inlets the percentage of finer sediments including a mud fraction favoured the presence of polychaetes such as *Arenicola marina* and a few species of bivalves such as *Macoma balthica* and *Cerastoderma edule* (Murray et al. 1999). However some beaches being more sheltered had a more prolific fauna of polychaetes and amphipods but yet again without any other groups (e.g., bivalves). In some sheltered beaches the presence of fresh water gave an estuarine character with a fauna dominated by oligochaetes (*Tubificoides* spp) and polychaetes such as *Capitella, Fabricia* and *Heterochaeta.*

6.1.3 The Shetland Islands

6.1.3.1 Introduction

The Shetland Islands, the most northerly land of the British Isles, are also exposed to severe wave action. They are separated by very deep water from the Faroe Islands and by a less deep channel from Orkney. Most of the islands surround the Shetland “mainland”, creating a mass of inlets, voes or firths and geos which show a transition from the severely exposed areas from the south and west to the extremely sheltered areas in the inlets and voes. Furthermore, the proximity of deep water to the coastline, particularly along the coast where the 80m isobath is found close inshore, is particularly noteworthy. Wave action and strong tidal streams play an important part in structuring the habitats in these islands. The bottom water temperature is permanently rather low (7°-11°C seasonally) influenced by oceanic water masses.

The geographic position of Shetland implies that the islands’ fauna and flora should be enriched by the presence of northerly species. In an extensive review of the Scottish macroalgae, by Maggs (1986), it was shown that, although 71 southern species were found in Shetland, only two northern species reached their southern limit in Shetland (according to the principle of a reduction in species richness with increasing latitude) (Howson 1999).

There is a substantial volume of data concerning the fauna and flora of Shetland that has been compiled in several reports and publications. The MCNR review series of extensive surveys in Shetland, together with the data of the surveys commissioned by the oil industry in the Sullom Voe oil terminal as well in connection with the oil extraction platforms and pipeline, provide a substantial amount of information on the Shetland fauna and flora. Further surveys were carried out on the continental shelf E-NE of Shetland in connection with the prospected oil development on the West Shetland shelf. More recently, work has been initiated in connection with the oil-related accidents at sea around Shetland. This has dictated a series of biotope mapping surveys with the data being processed and compiled by MCNR (Howson

1999). The coast was classified by the Institute of Terrestrial Ecology using its basic physical characteristics.

6.1.2.3 Rocky littoral and shallow sublittoral

On exposed littoral rock in the outermost locations are barnacles such as *Semibalanus balanoides,* the limpet *Patella spp., Fucus distichus* subsp*. anceps* and *F. spiralis f. nana*, *Blidingia* spp. *Mytilus edulis*, *Corallina officinalis, Himanthalia elongata* and accompanying species were characteristic. In moderately sheltered conditions, barnacles and fucoids such as *Fucus vesiculosus* and *F. serratus,* several red seaweeds such as *Palmaria palmata, Gelidium pusillum*, *Chondrus crispus, Porphyra purpurea* and several others were typical of this biotope. The sheltered littoral rock was dominated by the alga *Ascophyllum nodosum* and had a low diversity of fucoids. On mixed sediments and boulders, *Littorina littorea*, barnacles and mussels were present (Howson 1999). It appears that in conditions of intermediate exposure the species diversity is greatest. The sides of geos on exposed rocky shores had a rich fauna of encrusting forms (sponges, ascidians and hydrozoans) in the inner part, and barnacles the mussel *Mytilus edulis* and hydroids in the outer reaches. In the sheltered parts of the voes and in many inlets, the littoral is almost exclusively rocky with boulders, cobble, shingle and mixed sediments being present in the inner parts. *Ascophyllum nodosum* was characteristic of such biota accompanied by *Pelvetia canaliculata* and *Fucus vesiculosus,* while in gravelly and stony beaches there were amphipods, littorinids such as *Littorina saxatilis*, *L. littorea* and *Mytilus edulis*. At the outer and moderately exposed parts of the voes, rocky outcrops are animal-dominated, with the barnacles *Semibalanus balanoides*, limpets *Patella vulgata*, mussels *Mytilus edulis* and the dogwhelk *Nucella lapillus* with red algae such as *Laurencia pinnatifida, Porphyra umbilicalis, Mastocarpus stellatus, Corallina officinalis* and accompanying species. Fucoids were generally absent but brown algae such as *Laminaria digitata* was found lower down on the shore. The oil-related development in Sullom Voe sparked large and long-term studies of the benthic fauna and flora as a reference for possible future changes. The ecology of rocky shores was studied by Hiscock (1981) and subsequently by Moore & Little (1995), and the MNCR data conforms to these findings (Howson 1998, 1999). In the extensively surveyed Sullom Voe, the gastropod *Gibbula umbilicalis* was found, thus extending its northernmost distribution, a fact not recorded by Doody *et al*. (1993). On the other hand, many species of *Cystoseira* spp., and *Anemone sulcata*, *Chthamalus stellatus, Chthamalus montagui, Monodonta lineata, Littorina neritoides, Patella depressa* and *P. ulyssiponensis* are southern species which are nonetheless present in Shetland. Furthermore, the non-native Australasian barnacle *Elminius modestus* (Howson 1988, 1999) is present in small numbers in Sullom Voe (Hiscock 1981) as well as in other voes. Hiscock (1981), who compiled several years' data, produced lists about the common rocky shore littoral animals and plants in Shetland in connection with such organisms in the British Isles. He found that certain species such as *Lichina pygmaea, Margarites helicinus, Lacuna pallidula, Acmaea tessulata* are present in Shetland but were either absent or rarely recorded from areas further to the south in the British Isles. In the same way the fucoid *Fucus distichus*, represented by two subspecies *distichus* and *anceps* (*sensu* (Chapman 1985) is found in Shetland in the southern limits of its distribution.

Many researchers have carried out extensive surveys of the sublittoral of the Shetland Islands and the results are available in a large number of reports and publications including Irvine (1974a, 1974b, 1980) Institute of Terrestrial Ecology (1975e), Earll (1975, 1982), Moss & Ackers (1987), Hiscock (1986a, 1988), Addy (1981), Howson (1988), Pearson & Eleftheriou (1981) and May & Pearson (1995).

Data collected by the Institute of Terrestrial Ecology (1975c) distinguished six zones and communities. Subsequently four major site types, as opposed to zones of communities, were identified (Earll 1975) and classified as follows:

- Open coast sites with rock extending below the laminarian zone
- Bedrock in shallow water in extremely exposed sites
- Moderately exposed sites at the outer voes
- Sheltered muddy sand and gravel

A further analysis identified thirteen communities in the shallow sublittoral (Earll 1982) and highlighted the importance of the existence of dense beds of *Modiolus modiolus*. Moss & Ackers (1987) described nine major habitat and community types which to a great extent correspond with those described by Earll (1982).

For the purpose of this report and in order to curtail the large amount of information available in the literature, the description of the biotopes and the corresponding communities has followed the description and classification found in Howson (1999) which highlights the substratum type and the communities' dominant species.

Thus in the shallow sublittoral hard substrata are found *Alaria esculenta*, *Laminaria hyperborea, L.digitata* and *L.saccharina* with a variety of epiphytes including the northern species *Callophyllis cristata* (Howson 1999). In areas of strong wave surges, sponges, such as *Dendrodea* and *Clathrina,* barnacles such as *Balanus crenatus*, spirorbid worms, bryozoans and coralline algae occur. With increase in shelter *Laminaria digitata, L.hyperborea* with coralline crusts, red seaweeds, *Halidrys siliquosa, Polyides rotundus*, *Chondrus crispus,* as well as *Echinus esculentus*, brittle stars and coralline crusts, and on vertical walls, *Metridium senile*, *Alcyonium digitatum*, and *Corynactis viridis* are present. With increase in depth and shelter, faunal crusts including coralline crusts, *Cariophyllia smithii, Haliclona* and *Corynactis viridis* on rock and the polychaete *Pomatoceros triqueter* and the barnacle *Balanus crenatus* on cobbles are present and *Alcyonium digitatum* on vertical rock. Under conditions of greater shelter, bryozoans (*Flustra foliacea*), hydroids (*Sertularia argentea*) with other hydroid species, the mussel *Modiolus modiolus* and brittle stars (*Ophiothrix fragilis, Ophiocomina nigra*) as well as *Echinus esculentus* and *Alcyonium digitatum* and algal crusts in the deeper rocky substratum. Very sheltered conditions promote brachiopod and solitary ascidian communities (*Ascidia mentula, Ciona intestinalis, Ascidiella aspersa*, as well as the anthozoan *Metridium senile, Antedon bifida* and beds of *Modiolus modiolus*.

6.1.3.3 The Voes and Sounds

The sublittoral sediments consist mainly of gravel and sands with rocky outcrops, boulders and cobbles. Maerl beds consisting of *Phymatolithon calcareum* and *Lithothamnion glaciale* are common in the outer parts of sounds and voes but where there is clean sand or shell-gravel bivalves such as *Spisula elliptica* and venerids with *Fabulina (Tellina) fabula* and the polychaete *Magelona mirabilis* dominate. In less exposed habitats where *Zostera* beds are apparent in the muddy sand of the inner voes, a diverse community consisting of the heart urchin *Echinocardium cordatum*, the bivalve *Ensis* sp., a variety of spionid polychaetes (*Spio filicornis, Spiophanes bombyx*), several bivalves such as *Abra alba, Nucula nitida* and echinoderms, *Echinocardium cordatum* and *Ophiothrix fragilis* were present. The deeper areas of the voes were frequently characterised by muddy sediments with amphipods and polychaetes (*Arenicola* sp.), synaptid holothurians, sea pens

(*Virgularia* spp) and burrowing megafauna. In the deeper mixed sediments *Laminaria saccharina*, filamentous seaweeds (*Chorda filum*), bivalves (*Venerupis senegalensis* and *Mya truncata*) with *Modiolus* sp. beds and dense populations of the cerianthid *Cerianthus lloydii* were characteristic of these muddy communities (Howson 1999).

Sullom Voe, the longest and deepest of the Shetland voes, is a typical fjordic system, sheltered from wave action, and has been extensively and intensively surveyed for almost the last thirty years. It displays the whole range of habitats as described above, with all the corresponding animal and plant communities (Pearson & Eleftheriou 1981, Addy 1981, May & Pearson 1995). A very abundant fauna inhabits the varied substrata of the sublittoral with dense *Modiolus* beds, *Echinus*, the bivalve *Chlamys opercularis* and the red alga *Phyllophora,* several species of ophiuroids, asteroids and ascidians. The fine sediments were inhabited by a large variety of polychaetes with contributions from bivalve molluscs, echinoderms and crustaceans. There were changes in their distribution with depth and differences in their abundance. However there was evidence that the sediments of the inner parts of this voe and perhaps of other voes with the same configuration, become anoxic in the summer months as a result of an enhanced organic output from the surrounding areas. This results in a radical modification of the diversity and abundance of the macrobenthic infauna consisting mainly of small deposit feeding species. It is interesting to note that Addy (1981) in his study on the macrofauna of Sullom Voe concludes that the macrofauna of Sullom Voe (and perhaps other voes) in terms of species richness is similar and among the highest of undisturbed coastal areas on the British Isles mainland.

Yell Sound, a flooded glacial valley (<100m) dividing the Shetland mainland, is the largest sound in Shetland, with the sea floor consisting of a range of habitats which are modified by the very strong currents which structure the bottom and its sediments. The outer Yell Sound is characterised by hummocky moraines and the mounds fall within the current definition of the Habitat Directive “reefs” habitat. These structures formed by small rocks and pebble debris, host rich encrusting communities with brittle stars (*Ophiothrix fragilis* and *Ophiopholis aculeata*) and featherstars (*Antedon bifida*) while between the mounds there are coarse sediments and in parts exposed rock surfaces. Characteristic communities reflecting the sediment types and the hydrographic conditions accompany the progressive increase in finer grades in the inner part of Yell Sound. In gravelly sands, populations of *Echinus* starfish *Asterias*, and bivalves are present, while in the shallower and muddy parts sea pens (*Virgularia*) and sea urchins (*Echinus*) form the principal visible fauna. The horse mussels *Modiolus modiolus* and brittle stars appear in large but localised concentrations. In the shallows *Laminaria saccharina* and sea urchins are present on stony ground and gravel, while in the sheltered conditions a more prolific and diverse benthic fauna was found. The proposed construction of a subsea pipeline system to carry gas from the Foinaven, Schiehallion and Loyal fields to Sullom Voe and thence to the Magnus field included a large-scale study on the Atlantic margin west of Shetland and in Yell Sound. Sonar, photography and video-recording along the prospected route of the pipeline provided visual documentation as to the sequence of bottom structures and communities along the Yell Sound (Anon. 2000; Hartley Anderson 2001).

6.1.3.4 The Sedimentary Shores

An extensive survey by ITE (1975d) produced detailed descriptions of these sedimentary beaches and their fauna. Two main associations were recognised: the first was found on muddy sand and was characterised by the bivalve *Macoma balthica* with the polychaete *Arenicola marina* and the bivalves *Mya arenaria*; the second was found on clean sand and was characterised by the bivalve *Tellina (Angulus) tenuis* with *Arenicola* and the bivalve *Ensis* spp. The fauna of these beaches was comparable to that found on similar locations on the mainland. The small sedimentary stretches found in the shelter of voes and inlets have coarse sediments but also fine sands where large populations of polychaetes dominated by spionids (*Scoloplos armiger, Pygospio elegans, Aonides oxycephala*) and accompanying species of bivalves such as *Tellina (Angulus), Venerupis rhomboides* and *Crenella decussata* along with the isopod *Eurydice pulchra* and the talitrid amphipod *Orchestia gammarellus*. Pearson *et al*. (1994) described two variants of the *Macoma balthica* community, one in sediment with high shell contents accompanied by the polychaetes *Fabricia sabella* and *Tubificoides benedeni*. The other included the polychaete *Travisia forbesi*, the bivalve *Crenella decussata* and the isopod *Eurydice pulchra*. Shingle or gravel shores were close to a barren condition often inhabited by the isopod *Eurydice pulchra*, the bivalve *Venerupis senegalensis* and the polychaete *Arenicola marina* (Howson 1988). Several exposed sandy beaches had a restricted fauna consisting of highly mobile crustaceans (the isopod *Eurydic*e, the amphipods *Talitrus saltator* and *Echinogammarus pirloti*) but devoid of other groups (Howson 1998). Some sedimentary beaches at the head of voes are extremely sheltered and characterised by the polychaete *Nereis (Hediste) diversicolor* and the decapods *Pagurus bernhardus* and *Carcinus maenas* (Howson 1988).

Overall the sedimentary beaches of Shetland exhibited a benthic faunal complement that presented no surprises, akin to the fauna of the whole range of sedimentary beaches found in Orkney as well as further south in the mainland.

6.1.4 The East Coast of Mainland Scotland

6.1.4.1 Introduction

The shores from Duncansby Head to Coldingham Bay are predominantly rocky, interrupted by sandy beaches which are more prominent on the NE coast of Scotland (Rattray Head and north of Aberdeen), south of Montrose (Lunan Bay) and south of the Firth of Tay (Tentsmuir, West Sands). The coastline northeast of the Firth of Forth consists of rock platforms while beyond Cockburnspath the coast is almost entirely cliffed as far as the English border. In all cases the littoral rocky shoreline extends sublittorally in outcrops of bedrock of variable extent and size. The large Firths of Forth, Tay and Moray form major indentations in the coastline and there are also several smaller estuarine areas along the coast. The inner parts of these areas comprise a large variety of habitats from rock and cobble beaches to mixed sediments, fine sands and mud flats.
Because of the onshore winds (not prevailing winds), an absence of oceanic swell, and no proximity to deep water, the coastline could be considered as moderately exposed. Most of the coastline is much simpler, and does not present the complexity observed in the northern islands, with a high diversity of habitats and a corresponding proliferation of animal and plant communities.

Early work by McIntosh published in the mid-19th century on the marine life of St. Andrews, and McGillivray in 1843 on Scottish marine molluscs, was followed by papers from several authors published over the following fifty years. Compilation of these data was produced in a single volume by Laverack and Blackler (1974) on the fauna and flora of St. Andrews Bay. At a later date Stephen's work (1933,1934) Eleftheriou & Robertson (1988) and a series of MNCR Reports (Barne et al 1996, 1997) remain so far the main sources of information on the littoral and sublittoral communities of animals and plants of the open sea coasts of mainland Scotland.

6.1.4.2 Rocky Littoral and Sublittoral

For the greater part, the shores of the east Scottish mainland are moderately exposed to wave action, having a northerly or northeasterly orientation and the complex shore geology has created a high diversity of intertidal habitats. On vertical surfaces barnacles and limpets replace fucoid algae as the dominant cover organisms. The communities of plants and animals occurring on hard substrata between the tidal extremes are dependent mainly on a combination of factors: wave exposure, shore topography, geology and geographical location. However, it should be noted that important stretches of hard substrata on the east coast are either scantily surveyed or in some cases there is no information available.

The macro algae of the rocky outcrops of north eastern Scotland were recorded by Wilkinson (1975) who found 80 species not previously recorded from the area, including the first British record of the brown algae *Sorapion Kjelmanii* (from Bennett & McLeod 1998). Early records by Jack (1890) provided information on the marine algae of the rocky shores in the vicinity of Arbroath. However a large Marine National Nature Reserve (MNCR) survey programme at St. Abbs on the south east coast of Scotland produced a wealth of published information on the benthic communities and associations mostly of the sublittoral hard substrata. Smith (1979, 1983) and Smith & Gault (1983) described these shores with special reference to the molluscs. Although habitats did not differ significantly, species differed according to the type of rock, being richest on sandstone. The kelp holdfast fauna was given particular attention with nematodes, bryozoans and crustaceans being investigated by Moore (1971a, 1971b, 19782, 1973a, 1974) and Jones (1969, 1970, 1971). The littoral shores near St. Abbs consisted of shore platforms hosting a rich fauna which, when compared to other rocky substrata further north, was found to have a lower diversity, perhaps as a result of the limited variation in habitats, wave exposure and lower water temperature (Bennett & Foster-Smith 1998). Sublittoral communities along this coast showed important similarities with those found in Shetland and Orkney. Northern species such as the hydroid *Thuiaria thuja*, the anemone *Bolocera tuediae,* and the algae *Callophyllis cristata*, *Odonthalia dentata*, *Phyllophora truncata*, *Ptilota plumosa* and *Rhodomela lycopodioides*, were recorded. On the other hand, through compilation of information from different MNCR databases (Plaza, 1997) the presence of additional northern species from the vicinity of St. Abbs was revealed. The hydroid *Tamarisca tamarisca* and the bryozoan *Bugula purpuropincta* at the edge of their distribution were recorded from the lower shore and the sublittoral. Southern species such as the algae *Schottera nicaeensis* and *Rhodymenia pseudopalmata* were also present in the same area having an overlapping distribution (Bennett and Foster Smith (1998). Brittle stars encrusting Corallinaceae, the soft coral *Alcyonium digitatum*, the polychaete *Pomatoceros* sp. and the dominant sea urchin *Echinus esculentus* were also present in the kelp forests. However, there was a noticeable absence of sponges and ascidians. In 1990 the hard substrata fauna was investigated by Kluijver (1993) who also described seven communities and sub-communities on the shallow bedrock. On the stipes of *Laminaria hyperborean*, epiphytes such as the algae *Palmaria palmata, Ptilota plumosa*, *Membranoptera alata*, and *Phycodrys rubens* showed a zonation pattern according to depth (John 1968; Whittick 1983; Hiscock 1984). Beyond the kelp forest unconsolidated material ranging from cobbles, boulders and molluscan shell fragments formed a shell gravel habitat which was inhabited by molluscs and polychaetes characteristic of such substratum (Bennett & Foster-Smith 1998). Additional data on the distribution of littoral and sublittoral marine molluscs from the east coast of Scotland have been given by McKay & Smith (1979) in a comprehensive report which also provides an extensive bibliography of published records.

The reported area stretches from Sinclair's Bay in Caithness to the English Border and, although the authors do not always provide precise information on the exact sampling site, nevertheless these data, even when of a more general nature, still remain invaluable for complementing the existing information on the biogeography of the benthic species on the east coast of Scotland. In this report, a large number of common and widespread species in the east coast of Scotland such as chitons, gastropods and bivalves have been recorded from many habitats along the coast. On rocky shores chitons (*Lepidochitona* and *Acanthochitona*), gastropods such as *Nucella lapillus, Patella aspera, P. vulgata, Margarites helicinus,* and several species of *Littorina* and nudibranchs (*Onchidoris* spp., *Archidoris, Facelina, Aeolidia*) were present. There was a large gastropod fauna including *Helcion pellucidum*, several species of *Lacuna* and some pyramidellids that were associated with *Fucus* fronds and laminarian stipes.

6.1.4.3. The Sedimentary Shores.

The open coast beaches, because of their easterly and northeasterly orientation, are moderately exposed to wave action, wind and tidal streams. The intertidal area varies both in length and breadth, and consists mostly of unconsolidated sediments of different grades which vary from coarse to fine sand, depending on the degree of exposure and their geological history. In their extensive survey from Sinclair's Bay to the Firth of Forth, Eleftheriou & Robertson (1988) described the fauna of the east coast sandy beaches and ascribed it to a variation of the north-temperate water community, characterised by the bivalve *Tellina tenuis,* polychaetes and crustaceans, as described and commented on by Stephen (1930) and Eleftheriou & McIntyre (1976). Eleftheriou & Nicholson (1975), using the sediment characteristics of the different beaches, distinguished between exposed and sheltered beaches and described the associated fauna which reflected these conditions. From these studies it became evident that extreme exposure limits species richness by eliminating or restricting the sedentary forms of many bivalves and polychaetes, which favours the presence of a fragile fauna of crustaceans. This was the case for the Aberdeenshire and Angus beaches where the fauna was characteristically dominated by haustorid amphipods (*Haustorius arenarius* and *Bathyporeia pelagica*) and in some cases the spionid polychaete *Nerine (= Scolelepis) cirratulus* (Hart 1971). Similar results were obtained by AURIS (1991) from a later survey of Lunan Bay.

In a rare study on the vertical and horizontal distribution of the meiofauna of the sandy sediments north of Aberdeen, Seaton (1975) found a restricted fauna with a patchy distribution due to the local differences in the variation of the grades of sediment.

On the other hand the sheltered, fine sandy beaches of Tentsmuir and St. Andrews (Ritchie 1979) in Fife, the result of post-glacial sedimentation, had a rich and varied fauna including the above faunal elements but dominated by bivalves such as *Angulus tenuis* and *Donax vittatus*, the polychaetes *Nephtys cirrosa, Spio filicornis, Scolelepis squamata* and the cumaceans *Bodotria pulchella* and *Cumopsis goodsiri*. In those beaches with a flattish profile and a high retention of seawater there was evidence of an incursion of subtidal species well into the intertidal, such as *Tellina fabula*, as well as the amphipod *Bathyporeia guilliamsoniana*, mysids, the polychaete

Nephtys hombergii and several cumaceans (Eleftheriou & Robertson 1988). This agrees with Stephen's observations (1933) who also surveyed a number of sandy beaches from the Moray Firth to the Firth of Forth, and noted the presence of a *Tellina tenuis* community on these beaches and the presence of *Donax vittatus* and *Tellina fabula* in the sublittoral dredge samples. The same author using variations in the density of lamellibranchs and the changes of the dominant species separated the northern North Sea in four distinct zones one of which was identified as the littoral zone stretching from the high water mark to about 4m depth in the sublittoral of the Aberdeen, Carnoustie and St. Andrews beaches (Stephen 1929). East of Dunbar as far as Coldingham Bay there are only a few sandy bays, moderately exposed with a northerly or north-easterly aspect, interspersed in the almost continuous rocky shore which extends to the English Border. The littoral area of these beaches has not been surveyed but Davis (1991) provided data on a rich sublittoral infaunal community on a sandy bottom off Siccar Point which had dense populations of heart urchins and the burrowing crab *Corystes cassivelaunus.* McKay & Smith (1979) in their work on the marine molluscs of the east coast of Scotland reported an additional number of bivalve species such as *Musculus discors, Hiatella arctica* and *Kellia suborbicularis* found in cryptic habitats, while at the lowest level of the intertidal beaches small numbers of sublittoral species of bivalves such as *Ensis siliqua, Chamelea gallina* and *Mactra stultorum* were also present.

6.1.5 The Moray Firth

6.1.5.1 Introduction

The Moray Firth is a large triangular embayment, bounded on two sides by land, the outer extremity of which is considered as an arc reaching from Duncansby Head to Kinnaird's Head, near Fraserburgh. It is the largest firth on the east coast of Scotland and contains within it three smaller firths, the Dornoch, Cromarty and Inverness or Beauly Firths and a number of other smaller bays or inlets (Munlochy Bay, Loch Fleet, Findhorn Bay) (Harding-Hill, 1993)

The Inner Moray Firth was originally defined by a line drawn from Helmsdale, on the north coast, to the River Spey on the south. However this coincides roughly with the boundaries of the present candidate Special Area of Conservation (cSAC) in the inner Moray Firth (which stretches from Helmsdale to Lossiemouth) and for the purposes of this report the boundaries of the latter will be used.

These limits are, of course, artificially imposed and in reality the Moray Firth forms an integral part of the North Sea sharing large-scale environmental factors such as water circulation and climate patterns.

The Moray Firth has a coastline at the high water mark of some 650km, 43% of which can be considered as cliff-like, 9% as low sandy coast, 11% as low rocky shore platform and the remainder (37%) as intertidal flats ((Smith, 1986). The deeply penetrating firths of Dornoch, Cromarty and Inverness/Beauly are fringed by extensive intertidal flats. The best-known geological structure in the Highlands, the Great Glen fault, is reflected in the straight coastline from Inverness to Tarbat Ness. The physiographic evolution of the coastline in general is a result of glaciation, deglaciation and sea level change. The inner firths of Dornoch, Cromarty and Inverness/ Beauly are low energy environments. In particular, the Beauly and Dornoch Firths are shallow, containing large areas that are dry at extreme low tides (springs). The deeper Cromarty Firth has extensive sandflats at the innermost part of the firth and on the north coast at Alness and Nigg and south coast at Udale Bay in the outer area of the firth. There are no firths of any significance on either side of the outer Moray Firth.

The majority of the deeper sublittoral sediments in the north of the firth are composed of sands, with muddy sands, with some patches of mud predominating in the southern part (Andrews et al. 1990). The shallow sublittoral of the outer Firth is dominated by sandy gravel and gravelly sands on both coasts (Figure 5). There are also occasional banks with coarser sediments such as the Smith Bank in the outer firth and Guillam Bank in the inner firth; unique to the Western North Sea a deep trough off Fraserburgh (the Southern Trench), reaches a depth in excess of 200m (Figure 6a). According to Andrews et al. (1990) the sediments in the bottom of this trench are muds similar to the local sediments surrounding the top of the trench. However, recent work by DTI and FRS suggests that the bottom of the trench is much coarser with numerous pebbles and cobbles (Hartley, pers comm).

Conservation areas within the Moray Firth cover about 50% of the coastline; there are 34 Sites of Special Scientific Interest, one National Nature Reserve (Nigg and Udale Bays), one National Scenic Area (Dornoch Firth) and the major area, the candidate Special Area of Conservation in the Inner Moray Firth. These areas are discussed in detail elsewhere in SEA5 but are mentioned here to emphasise the importance of the Moray Firth in terms of a marine resource in need of conservation.

6.1.5.2 The Littoral Zone

Rocky shores occur from Duncansby Head to Brora on the north coast of the firth, along the Tarbat Ness peninsula and from east of Burghead to Fraserburgh on the south coast. The range of intertidal habitats available on the east coast is significantly less than on the west coast leading to a considerably less rich flora and fauna (Bartrop et al. 1980). There are very few sheltered shores in the outer Moray Firth but those at Helmsdale, Kintradwell and Portmahomack can be considered as such (Terry and Sell, 1986). At these sites *Pelvetia canaliculata* formed a small zone on the upper bedrock shores but was absent from the shingle shores. The *Fucus spiralis* zone below this was often well developed and had an understorey restricted by the grazing of *Patella vulgata* and *Littorina saxatilis* to *Verrucaria* sp and *Hildenbrandia* sp. *Fucus vesiculosis* dominated the mid-shore with *Ascophyllum nodosum* being ubiquitous but achieving blanket coverage only occasionally. *Fucus serratus* replaced *F vesiculosis* in the lower shore and was itself succeeded by *Laminaria digitata* and *L hyperborea* in the sub-tidal. The Littorinids *Littorina saxatilis*, *L. obtusata* and *L. littorea* were found in shallow pools and damp hollows on these sheltered shores as were *Patella vulgata* on flat horizontal rocks where they restricted algal growth to cracks; *Gibbula cineraria* was common in the low mid-shore.

The zonation on exposed shores in the Moray Firth starts with the black lichen *Verrucaria maura* in a wide band at the top of the shore. This was followed by a zone of Cyanophycea which breaks down during the summer. Some shores have a zone of *Porphyra umbilicalis*, but this is generally poorly developed. *Prasiola stipitata* may also be present in a well-defined band. *Littorina saxatilis* is the dominant animal of the upper shore, being particularly abundant in cracks and crevices. The barnacle *Semibalanus balanoides* occupies the upper mid shore, below which is either a zone dominated by *Fucus vesiculosis* with a patchy mussel understorey or simply a dominant colony of *Mytilus edulis* with little fucoid cover. Barnacle populations tend to have predatory populations of *Littorina* sp. associated with them. The dog whelk, *Nucella lapillus* can be locally abundant.

The only soft shore area of significance on the northern north coast is Sinclair's Bay, 5km long with a long narrow beach consisting mainly of sand and patches of shingle (Eleftheriou & Robertson 1988).The Burn of Lyth enters the beach at the centre of the bay, recirculating sand that has been blown inshore (Mather and Ritchie, 1970). The sediments of this stable beach are fine to medium sand lying on a shingle subsurface. The fauna was sparse with some levels devoid of animals. The fauna was dominated by the cirolanid isopod *Eurydice* and several species of the amphipod *Bathyporeia*, mainly *Bathyporeia pelagica*. Only a few specimens of polychaete (including *Paraonis fulgens*), oligochaete and Nemertea were found. Small concentrations of the sand-hopper *Talitrus* sp. were found with the *Eurydice* at the top of the beach and *Haustorius sp.* was present near MLWS. Crustaceans accounted for more than 87% of the total fauna.

Generally the beaches of the inner firth (Dornoch and Nairn) showed higher diversity than those of the outer firth (Fraserburgh and Sinclair's Bay) with the beach at Burghead showing diversity between the two extremes. Crustaceans demonstrated a significant presence on all the beaches with the isopod *Eurydice pulchra* and amphipods of the genera *Bathyporeia, Pontocrates, Haustorius* and *Talitrus* being consistently present. The beaches also all had populations of *Tellina tenuis* although in some locations they were dominated by *Cerastoderma edule* and *Macoma balthica*. The polychaete *Paraonis fulgens* was present at all the beaches; polychaetes contributed up to 50% of the abundance at some of the beaches and species such as *Nephtys cirrosa*, *Spio filicornis and Spiophanes bombyx* occupied the lower part of the beach. Where the beach was gently graded, species such as the polychaetes *Spio filicornis, Paraonis fulgens* and *Pygospio elegans* and the crustaceans of the genera *Bodotria, Cumopsis* and *Pontocrates* extended their zonation significantly. The species complement of the fauna over the beaches was in agreement with the descriptions of Stephen (1929, 1930) (see below), and Eleftheriou and McIntyre (1976) and showed patterns of distribution which could be attributed to the exposure of the beach (Eleftheriou & Nicholson 1975).

Stephen (1929) reported results from beaches at Nairn and Lossiemouth. The fauna to the west of Nairn, as could be expected from the sediments, was generally poor. *Tellina tenuis* was virtually ubiquitous but not numerous, and the only other species he recorded were *Arenicola marina*, *Nephtys caeca* and *Aricia* (now *Orbinia*) *latreillii*. Such poor returns when compared with the more up-to-date accounts are probably attributable to the use of a 2mm sieve rather than the more common 1mm or 500µ mesh. To the east of Nairn a greater number of species was obtained including T*. tenuis*, *Macoma balthica* and *Cardium* (now *Cerastoderma*) *edule*, and six species of polychaete including *A. latreilii*, *Nerine foliosa* and *Nereis* (now *Hediste*) *diversicolor.* Near Boars Head Rock, at Lossiemouth, Stephen found the sediments to be clean sands mixed with pebbles. The accompanying fauna was very poor, with only *Tellina tenuis*, *Nephtys caeca* and *Nerine foliosa* being present.

6.1.5.3 The Sub-littoral zone

If we accept a wide definition of the term 'benthos' as representing invertebrate communities, then the work of Picken (1986) may merit consideration. Picken conducted a survey of the fouling communities of the Moray Firth, citing data from Nigg Terminal Jetty, buoys in the Cromarty Firth and from the steel jacket of the Beatrice oil platform and comparing the latter with the offshore platforms of the Forties oilfield. As might be expected from the geographic distribution of the study sites, fouling communities in the Moray Firth exhibited an increase in diversity from the Nigg Terminal site to the Beatrice platform.

The cylindrical steel piles on the jetty at the Nigg Terminal displayed a background cover of solitary tubeworms (*Hydroides norvegicus* and *Pomatoceros triquiter*) and barnacles which was overgrown to varying extents by other organisms. To a depth of about 6m this overgrowth consisted mainly of *Mytilus edulis* (the edible mussel) which themselves were colonised by epiphytic growth of species such as *Alaria esculenta*, *Laminaria digitata* and *Laminaria saccharina*. In some piles this mussel growth was replaced by barnacles, again with partial overgrowths of algae and hydroids. Mussel cover decreased below 6m and below 11m depth they were absent, the overgrowth consisting of species such as the soft coral *Alcyonium digitatum*, the anemone *Metridium senile* and the sponges of the genus *Halichondria* sp.

The six buoys in the Cromarty Firth exhibited a similar pattern of fouling. A zone extending from the waterline to about 15cm above was colonised by blue-green algae and *Ulothrix* sp. The submerged portion of the buoy itself was colonised by a range of algae including *Chaetomorpha* sp., *Ectocarpus* sp., *Enteromorpha* sp., *Laminaria digitata, Laminaria saccharina, Polysiphonia fibrata, Ulothrix* sp. and *Ulva* sp. Large areas of the lowest parts of the buoys were covered with *Mytilus edulis* with occasional *Laminaria* growths. The free-hanging portions of the anchor chains were completely covered with mussels, with large numbers of the starfish *Asterias rubens*. The 'working part' of the chain was free of all macro-fouling due to its interaction with the sediment but the anchor blocks were again covered with the polychaete tubes of *Hydroides norvegicus* and *Pomatoceros triqueter* with a patchy overgrowth of the hydroid *Obelia longissima.*

The Beatrice platform site yielded the most diverse community of the three under investigation, with a total of 10 species of algae, six species of bivalve molluscs, four species of polyzoa and three species of barnacles. Due to the complex construction of the platform there was a much greater range of depth and orientation available to be populated by fouling organisms. Additionally, studies were conducted from the initial placement of the structure, giving a temporal element to the description provided by Picken. The patterns shown in time and space still resembled those at the other sites. Initially the calcareous tubes of the polychaetes *Hydroides norvegicus* and *Pomatoceros triqueter*, supplemented by those of the barnacles *Balanus balanus, Balanus balanoides* and *Balanus crenatus,* occupied the entire structure. However, by year 3 of the study these organisms were overgrown to a variable extent by other foulers and by year 4 the greatest extent of exposed tubeworm growth was found in the deeper strata. A major contributor to the other foulers was the mussel *Mytilus edulis* which, by year 3, made up more than 40% of the organisms around the mean sea level location and by year 4 gave 100% cover. Seaweeds were first observed in year 3, occupying the 0-12m zone with the greatest cover in the 0-4m zone. By year 4 extensive areas of seaweeds were found at 8m on horizontal members of the structure.

The soft growth, including the hydroids, soft corals and ascidians also made a significant contribution to the community in the Beatrice location. Hydroids (principally *Bougainvillea ramosa* and *Tubularia larynx*) were found throughout the depth range after year 1. By year 4 they formed only a minor part of the community in the 0-4m zone but below this level they provided up to 70% of the cover at a number of locations, mainly those not colonised by seaweeds and which had an element of shade. The soft coral, *Alcyonium digitatum*, is recognised as a ubiquitous fouler on oilfield infrastructure throughout the North Sea. The first significant accumulation at Beatrice was recorded in the third year of the study at 26m. By year 4 the range had increased to cover a zone from 13m to 36m with the greatest densities being recorded on the underside of a horizontal frame at 26m. The ascidians *Ascidiella aspersa* and *Ciona intestinalis* were initially observed in year three, but their abundance became significant only in year 4 when they constituted 30% cover at a depth of 36m.

The Moray Firth candidate Special Area of Conservation (cSAC) which lies west of a line drawn from Helmsdale on the northern coast to Lossiemouth on the southern coast, has a resident population of the Bottlenose Dolphin, *Tursiops truncatus*, which is an Annex II species and forms the basis of the SAC classification. In addition the cSAC potentially contains representatives of an Annex I Habitat (sandbanks that are slightly covered with water all the time). None of these sandbanks has yet been characterised in terms of the topography or benthic fauna but FRS Marine Laboratory and Scottish Natural Heritage jointly conducted an initial acoustic survey of the Guillam Bank area in 2003 (Moore, *pers comm*). The acoustic surveying was accompanied by the collection of material for sea-truthing and benthic community analysis. Acoustic techniques of swathe bathymetry and bottom discrimination showed a well-formed bank rising to 10m below MTL from a base in about 40m of water (Figure 6b). Benthic samples from the bank and the surrounding area showed a high diversity fauna which is polychaete dominated with little evidence of opportunists. Species abundance ranges from 40 to 94 and numbers of individuals from about 230 to more than 600. Analysis of these data is not yet complete, but the fauna includes amongst it's dominants the polychaetes *Diplocirrus glaucus, Lumbrineris gracilis, Mediomastus fragilis, Apistobranchus tullbergi, Scalibregma* *inflatum, Rhodine gracilior, Pholoe baltica, Prionospio banyulensis,* the bivalves *Tellimya ferruginosa* and *Mysella bidentata* and the brittle star *Ophiothrix fragilis*. (Evanthia Karpouzli, pers comm)

Smith Bank is a shallow bank (40m), with relatively coarse sediment (sand - shelly gravel) with occasional outcrops of rock. McIntyre (1958) noted that *Echinocyamus pusillus* was the numerically dominant species, with polychaetes and molluscs being numerically dominant and the lamellibranch, *Cochlodesma praetenue* making up most of the biomass.

The Beatrice Oilfield lies on the Smith Bank, 12 miles from the north coast of the Moray Firth in about 45m of water. Over the period 1977 to 1981, a series of benthic surveys were conducted around the platform, based on a gridded approach (Hartley & Bishop 1986; Bishop & Hartley, 1986). The surveys were conducted in the pre-production situation as a baseline against which future changes caused by drilling and production operations at the field might be measured. The information was also collected in order to conduct an environmental impact assessment for the platform.

Although they did not fully describe the hydrography in the area, preferring to refer to Adams & Martin (1986), they did indicate that the tidal currents in the vicinity of the platform run northeast – southwest and are comparatively weak at about 0.75kts at maximum spring velocity. The area is open to east and northeast winds which have a fetch of more than 250 miles and it can therefore be expected that the seabed of the area will be influenced by wave-induced oscillatory currents during prolonged gales.

There is a clear gradient in the sediments over the area correlated with water depth with coarser sediments found at stations in the shallower north east of the survey area while the deeper western area showed finer sediments. The sediments on the Smith Bank (in <40m water to the east) were of moderately to poorly sorted fine to medium sands. The fines (<63µ) in these sediments were between 1.4 and 2%. The central area, lying between 40 and 50m had moderately sorted fine sands with between 2 and 5% fines while the deeper northwestern area had sediments that were composed of moderately sorted fine to very fine sands with 5 to 15% fines. The organic matter (measured by combustion) over the area ranged from 0.07% to 2.54% showing a strong positive correlation with the fines present. The area also showed extensive shell gravel deposits that the authors concluded might be periglacial relicts since there was no correlation between this coarse material and the water depth.

The authors noted a total of 376 quantitatively recorded species and a further fifty species which were recorded as present, concluding that the high species richness was in part a reflection of the range of habitats sampled. However they also indicated that the fauna of the individual stations was considered as rich, suggesting the area to be naturally highly diverse. Abundances were about twice as high as offshore sites with similar characteristics, from data from the Forties Oilfield, but were similar to inshore areas such as Sullom Voe. In common with much of the North Sea at that time the major contributor to the species richness was the Annelida which accounted for about 40% of the species found in 1977. Mollusca accounted for 30% of the species, Crustacea for 20%, Echinodermata for 5% and the ‘others’ category accounted for the remainder. Five main patterns of distribution were identified from the data. Species such as the polychaete *Spiophanes bombyx* and the bivalve *Cochlodesma praetenue* were present throughout the area of the survey. *Travisia forbesi* and *Ophelia borealis* (both polychaetes), *Bathyporeia* spp. and the bivalve molluscs *Tellina pygmaea* and *Crenella decussata* were restricted to or attained their greatest abundance in the north east sector of the survey area. On the Smith Bank (to the northeast of the area) *Pholoe minuta, Goniada maculata, Urothoe elegans Nucula tenuis Dosinia lupinus* and *Acrocnida brachiata* were absent although they were otherwise widely distributed. *Myriochele* sp., *Eudorella truncatula* and *Thyasira flexuosa* were restricted to the deeper sediments in the west of the survey area and *Gari fervensis*, *Abra prismatica* and *Tellina fabula* were less abundant or absent in the shallower northeast and deeper west of the survey area.

It was considered possible to interpret the benthic community data as conforming with the 'classical' communities such as those described by Petersen (the *Venus* community), Stephen (the clean sand faunal complex of the coastal zone), Jones (the boreal offshore sand association) or Thorson (the *Venus gallina* (Boreo-Mediterranean *Venus* community). However the authors decided that based on the complexity of the communities present and the results of the classification analyses they conducted it was an oversimplification to consider this as a single ecological unit. The stations that had less than 5% fines in the sediments were considered to represent an intermediate community between Glémarec's infralittoral and coastal fine sand communities, containing, in abundance, both the infralittoral *Tellina (*now *Fabulina) fabula* and the coastal *Dosinia lupinus.*

Interpreting the data through classification analysis, the authors identified a number of community types present in the area. Stations to the south and west (defined as groups D, E and F) are believed to represent the same fine sand grouping, but the fauna in the deeper, more muddy, areas reflected the presence of finer material with species such as *Thyasira flexuosa, Virgularia mirabilis, Aricidea catherinae* and *Eudorella truncatula.* This suggests a transition into the muddy sand community. Again the joint occurrence of species such as *Nucula nitidosa* (formerly *turgida*) and *Acrocnida (*now *Amphiura) brachiata* with *Nucula tenuis* and *Amphiura filiformis* indicates the interface between the infralittoral and coastal provinces respectively. Groups B and C had sediments that were slightly coarser with a lower fines content and were characterised by the occurrence in abundance of *Ophelia borealis, Travisia forbesii, Crenella decussata* and *Tellina pygmaea* and greatly reduced densities of *Urothoe elegans*. This corresponds to the *Ophelia borealis* facies of medium sands of the *Echinocyamus pusillus – Tellina pygmaea* community of Glémarec's coastal province coarse sands. Group A was associated with coarse sediments (>5% gravel) and was mainly located on the Smith Bank. This grouping was characterised by some taxa being absent or at reduced density, e.g., *Pholoe minuta, Owenia fusiformis, Eudorellopsis deformis* and *Tellina fabula* and other widely distributed species being present in unusually high abundances (*Scoloplos armiger, Lumbrineris gracilis* and *Polycirrus* sp.) The distinctive fauna associated with the shell gravel was regarded as a local variant of the fine sand community.

In general, the fauna showed reasonable qualitative and quantitative persistence in the short term, despite several taxa showing significant changes over time. Comparison with the earlier data published by McIntyre suggested that the fauna also exhibited considerable persistence in the medium term.

After the Beatrice Oilfield had been in operation for some time Addy et al. (1984) conducted a series of surveys close to the platform which had, by then, drilled 13 wells using water-based mud and 6 using a low-toxicity oil-based mud. In the area influenced by the discharge of cuttings and attached mud, biological effects were weak at 250m from the platform, even weaker at 500m and undetectable at 750m when water-based mud was used. When oil-based mud was discharged, marked changes in the community structure were detected close to the platform, with *Capitella capitata* the classical opportunist attaining densities of more than 5000.m^{-2}.

The community generally reflected the response expected in organic enrichment situations identified by Pearson and Rosenberg (1978).

The NMP stations in the Moray Firth showed the fauna was dominated by polychaetes accounting for more than 57% of the individuals present, with the top 10 species being made up of 67% of the individuals. The brittle star (an echinoderm) *Amphiura chiajei* was also common in this area.

Localised surveys have been carried out by the oil industry in areas suspected of supporting herring spawning. Blocks 11/24 off the Wick coast (Premier Oil plc, 1996) and 12/22 at the Remus prospect were surveyed using acoustic techniques and photographic assessment of the sea bed was also undertaken. Interpretation of the data yielded by the different survey methods showed that there were significant areas of potential herring spawning ground in the vicinity of the proposed drilling location, with seabed sediments in 11/24 being defined as stable with characteristics of a relatively high energy environment. On a north to south gradient, stones and cobbles colonised by soft corals (*Alcyonium digitatum*), tunicates and hydroids, bryozoans and sponges gave way to coarse grained, gravelly sediments with the brittle stars *Ophiothrix fragilis* and *Ophiocomina nigra* before encountering sands, supporting no prominent epifaunal species but showing indications of infaunal polychaetes, burrowing crabs and molluscs. In 12/22 there were no areas with significant potential to support herring spawning and no epifauna of note were identified from the photographic survey.

6.1.5.4 The Inner Firths and Inlets

Although not strictly a firth as commonly defined, Loch Fleet is the most northerly inlet on the north coast of the Moray Firth. It is formed by the estuary of the River Fleet, has mainly sedimentary shores and sublittoral sediments which are muddy sands. Clean sands were reported from the loch mouth and on a large sandbank. Wells and Boyle (1975) reported that the most common species recorded were oligochaetes, the polychaetes *Arenicola marina*, *Fabricia sabella*, *Nephtys* spp., *Nereis diversicolor*, *Pygospio elegans* and *Scoloplos armiger*, the amphipods *Bathyporeia* spp., and *Corophium volutator*, the snail *Hydrobia ulvae* and the bivalves *Cerastoderma edule*, *Mytilus edulis* and *Macoma balthica*. The opisthobranch molluscs *Akera bullata,* not reported from elsewhere on the east coast of Scotland*,* formed part of an interesting molluscan fauna (McKay & Smith 1979; Smith 1984)

The Cromarty, Dornoch and Inverness/Beauly Firths form the western extremity of the Moray Firth and are the only enclosed firths on the east coast of Scotland north of the Tay (Hunter and Rendall, 1986). The Dornoch Firth is shallow, sandy and brackish whereas the Cromarty is deep and saline with the Inverness/Beauly Firth being intermediate between these two extremes.

During the early years of the 1980s Hunter and Rendall sampled the three firths (Dornoch, Cromarty, and Inverness/Beauly) using an axial pattern of stations from the inner estuarine areas to the fully saline beyond the limits of the respective firth and within the Moray Firth proper. At each station five samples were obtained for conventional community analysis. In addition material was collected for sediment particle size analysis.

The Dornoch Firth, about 23km in length from Bonar Bridge to the mouth of the firth has strong tides in several areas, particularly at Meikle Ferry, resulting mainly in mobile, sandy sediments. Salinity conditions in the firth have only rarely been assessed. Brackish water species such *Fabricia sabella, Nereis diversicolor,* *Pygospio elegans,* tubificids and Nemertea were present at the most landward station (Newton). The composition of the benthic community suggests an increasing salinity down the firth with *Mytilus* beds in the middle reaches and these had an associated fauna which included their predator (*Nucella* sp.) and epifaunal polychaetes. Species common to all three firths tended to be displaced towards the seaward end of the Dornoch Firth. Species preferring coarse or sandy sediments were prominent in the Dornoch Firth, including *Nephtys cirrosa, Tellina tenuis, Chaetozone setosa, Venus striatula, Glycera capitata* and *Corophium crassicorne.* The mobile nature of the sediments meant that certain species such as the Caprellids and pycnoginids were absent from the communities. The capitellid polychaete *Mediomastus fragilis* was very common in the Firth and this record was one of the first for the UK. On the basis of its biological features the Dornoch Firth has been designated as a Site of Special Scientific Interest (SSSI), the main features being dune vegetation succession and its status as a nationally important site for waders and wildfowl.

The Cromarty Firth is about 28km in length and was the deepest of the three firths in the study. Landward of Invergordon estuarine conditions prevail but the area to the seaward of this has a high and stable salinity. The more variable inner sediments (in 1981 it was sandy) supported a fauna which included the bivalve molluscs *Tellina fabula* and *Gari fervensis*. Deeper stations near Nigg had a more muddy bottom with relics of scattered clinker from the Grand Fleet of about 1914. A richer fauna was found there, characterised by *Abra alba* with species of *Nucula, Scalibragma, Notomastus Goniada* and *Corophium* sp. Between the Sutors, the sediments had a reduced mud content and species of sand dwellers such as *Ophelia borealis* appeared and a small sub-community comprising *Aonides oxycephala, Glycera capitata* and *Prionospio cirrifera* in varying combinations occurred. The open Moray Firth station demonstrated a finer sediment and a lower diversity but included additional species such as *Chaetaderma nitidulum, Echinocardium cordatum, Spiophanes kroyeri, Magelona alleni* and *Corophium affine.*

Parts of the Cromarty Firth around Nigg and Udale Bays contain areas of conservation importance. Despite this, much of the coastline around Nigg Bay has been the subject of land reclamation and developed for use as a naval base, an oilrig construction yard and an oil terminal serving the needs of the Beatrice oilfield. The shoreline also has a distillery and was formerly the site of an aluminium smelter. The sediments in the bay are fine sands with a tongue of coarser material running from the eastern shore (Raffaelli & Boyle 1986). Most of the polychaetes taken in the survey were widely distributed with *Scoloplos armiger* being the most frequently encountered. *Fabricia sabella* and *Pygospio elegans* and the oligochaetes *Tubificoides benedini* (sic) and *Aktedrilus monosperme* were associated mainly with higher reaches of the beach at the head of the bay, and the tubicolous *Arenicola marina* was abundant over most of the bay. The gastropod mollusc *Hydrobia ulvae* and the bivalve *Macoma balthica* had extensive populations over the bay whilst the cockle *Cerastaderma edule* was restricted to intermediate shore levels, apparently in association with the coarser sediments in that area. The bay also supports extensive mussel banks, particularly in the western sector. Anderson (1971) had previously surveyed the area prior to much of the development on the bay. Although comparison of the data between the years was difficult due to changes in methodologies, timing of sampling and natural temporal variation, Raffaelli and Boyle concluded that it was not possible to say if changes in the fauna had been induced by onshore developments.

As mentioned above, the Cromarty Firth is a recognised Special Area of Protection (SPA) on the basis of containing a range of high-quality coastal habitats including mud-flats, shingle, reed beds and saltmarsh (Henderson, 2002). In support of this designation, the Cromarty Action Plan gives details of the policies and actions deemed necessary to fulfill the Cromarty Firth Management Strategy devised by the Cromarty Firth Liaison Group.

The Inverness and Beauly Firth system is similarly about 23km in length but has characteristics which are intermediate between the Dornoch and Cromarty Firths, having shallow areas and sub-tidal sand-banks like the Dornoch but also some deeper muddy areas like the Cromarty. At the navigable limit of the Beauly Firth there was a surprisingly rich fauna considering there must have been some fresh water influence, while at the confluence of the River Ness the fauna was severely impoverished, with sediments described as '… oily, black and anoxic and some sewage solids appeared in grab samples'. Large numbers of tubificids, capitellids and nematodes suggested that pollution (enrichment) was the main cause of the impoverished state of the community. Between Kessock and Meikle Mee the seabed is stony but the nonetheless there was an increased level of organic content at Kessock which the authors attributed to a sewage outfall at Longman. The stony bottom supported a distinctive community containing a high proportion of carnivorous polychaetes such as *Lepidonotus squamatus,* and *Harmothoe* spp.. *Lepidonotus clava,* previously unrecorded from the east coast of Scotland was also found here. *Dynamena pumila*, a hydroid, and various bryozoans were also present, accompanied by the bivalve mollusc *Musculus discors.* The sewage input apparently exerted no influence on the community structure, possible due to its being held in the freshwater surface layers until well diluted. Alturlie Deep resembled the middle of the Cromarty Firth with an *Abra alba- Nucula* community including other mud-dwelling species such as *Terebellides stroemi* and *Nephtys hombergi*. This Deep also represents a transition area between the estuarine species such as *Pygospio* and *Macoma* to the more marine species such as *Abra alba* and *Harpinia antennaria.* At the Munlochy Buoy the proportion of sand-dwelling species such as the amphipod *Corophium crassicorne* increased, as well as the tube-building polychaetes *Myriochele oculata* and *Lanice conchylega.* Th firm sandy bottom at the narrows near the Chanonry and Fort George exhibited some areas devoid of fauna although the Chanonry site itself had 114 species with *Aonides oxycephala, Glycera capitata, Microphthalmus similis* and *Prionospio* spp occurring sporadically. Fort George was dominated by the bivalve *Spisula solida* and also had populations of *Glycera capitata* and *Microphthalums simils* present.

The Inner Moray Firth (Inverness and Beauly Firths) was designated as an SPA on the basis that it contains extensive intertidal mud flats with smaller areas of saltmarsh. It is the most northerly major wintering area for wildfowl and waders in Europe.

Findhorn Bay on the south coast of the Firth has sediments that range from clean medium sand to muddy sand with areas of scalp in places (Harding-Hill 1993). The invertebrate community was representative of a sheltered muddy sand with a reduced salinity (Bartrop et al. 1980) with abundant *Corophium volutator* and with the polychaetes *Nereis (Hedistes) diversicolor* and *Arenicola marina* and the bivalve *Macoma balthica* being common. Wells and Boyle (1975) also recorded the presence of *Pygospio elegans* and *Fabricia sabella* and, in an area where two drainage channels met, coarser sediments supported *Tellina tenuis*, *Arenicola marina* and *Nephtys cirrosa*. Stephen (1929) stated that, intertidally, "… although several squares were sieved at various levels " he found no molluscs or polychaetes in the sediments.

6.1.6. The Firth of Tay

6.1.6.1 Introduction

The Firth of Tay lies to the north of the Firth of Forth and meets the sea between two sandy peninsulas at Buddon Ness on the north bank and Tentsmuir on the south. The Tay has the seventh largest drainage basin in the UK and contains seventy freshwater lochs making it the foremost British river in terms of its discharge (McManus 1968). The dynamic nature of the local hydrography leads to a very complex sedimentary regime within the firth. Above the Bridges there is a wide sheet of mobile sands forming banks. Close to the bridges there is evidence of scouring. Diver observations led Buller and McManus to conclude that sediments in the area are derived from marine rather then riverine sources. To the north and west of the sandbanks lies the Kingoodie mud flat. Below the bridges the sedimentary regime is subject to both depositional and erosional processes, resulting in a wide range of sediment types (McManus, Buller and Green, 1980). The north shore sediments are predominantly fine sediments and the south sands and gravels. There are coarse sand and gravel shoals offshore of the south bank. The channel bed is mainly composed of coarse and medium sand. In the middle part of the estuary, west of Broughty Ferry shell material deposited from the mussel beds lines the southern margin of the channel. Fine material derived from faeces and pseudofaeces is mixed with this shell gravel in significant proportions. East of Broughty Ferry the seabed is floored with patchy assemblages of sediments, pebbles, sands, mussels and stands of Fucus and Laminaria, leading down to the fine and medium sands of Buddon Ness and the Gaa sands. The Abertay sands on the south shore have similar sediments. Gravels and substantial mussel colonies are to be found in the main channel, giving way to medium and fine sands at the river 'bar'.

Until the 1970s, no benthic studies had been conducted in the Tay since the work of Alexander (1931).

6.1.6.2 The Littoral Zone

From the point of view of descriptions of the fauna the Tay can be divided into three areas, the inner, middle and outer estuaries (Khayrallah & Jones 1975)(Figure 7). The outer estuary, from Broughty Ferry Castle seawards to Buddon Ness, supported a considerable diversity and density of faunal species but there were few attachment points for algae which resulted in a very localised distribution. The majority of the substrates in the area were of fine or medium sands containing typical littoral communities. The north shore was composed entirely of sand with two large mussel beds *(Mytilus edulis)* near low water Mussel beds were also found on the south shore together with a small area of *Zostera marina.* Algae and littorinids were associated with the mussel beds on both shores, these beds forming suitable substrates. The south shore comprised sandy sediments with an area of mud and fine sand east of Tayport which supported a dense population of the oligochaete *Peloscolex benedeni* (up to 8000/m^2).

The middle estuary, extending westwards from Broughty Ferry Castle to Invergowrie, is the zone of maximum salinity fluctuation. In this portion of the firth hard substrates dominated the littoral area on both banks, the northern bank being mainly man-made (quays, flood defences etc) and the south bank naturally rocky. The barnacle *Balanus balanoides*, colonised most of these hard substrates along with euryhaline algae. The north shore was more polluted than the south due to the harbour infrastructure of Dundee port, and the presence, at the time of the study, of more than 30 outfalls (these outfalls have now been replaced by a new interceptor system with a single discharge in the area of the Dighty Burn). The beaches in this middle estuary were populated by *Mytilus edulis* together with numbers of the gastropod *Littorina littorea* and the barnacle *Balanus balanoides.*

The inner estuary, from Invergowrie to Errol, was penetrated by only the most euryhaline species. The north bank, composed of soft sediments had euryhaline annelids and crustaceans as the dominant elements. Those areas of mud above mean tide level contained large numbers of oligochaetes *(Tubifex* sp.), while the lower sandy areas contained considerable populations of *Nereis diversicolor* and *Nerine cirratulus* together with very dense populations of *Corophium volutator.* Populations of *C. volutator* were found in muddy sediments just above Newburgh, where the maximum salinity recorded was 0.26%,. The observations of McLusky (1968) in the Ythan estuary suggested that *C. volutator* has a critical lower salinity (2%), and the population at Newburgh, therefore, represented an unusually euryhaline group. More sandy sediments support populations of *Bathyporeia pilosa* and *Neomysis integer,* the former population also having penetrated beyond its normal range of salinity. Freshwater chironomids were found in the muds and sandy muds near Newburgh, indicating that this point represented the region of overlap of freshwater and estuarine faunas. Hard areas of the south shore supported algae such as *Enteromorpha* sp. as well as animals such as *Balanus balanoides*, enabling them to penetrate as far as this point in the estuary.

Invergowrie was also the location at which dense populations of a spionid polychaete, *Marenzellaria viridis* were discovered. This represented one of the first records of the species outside of North America. Atkins et al. (1987) speculated that its presence in the Tay might be the result of a transfer of larval forms in water ballast from the east coast of the United States, although the possibility of a transfer of a similar species from the European Arctic was not discounted.

In his study of the sedimentation in the outer parts of the Tay (Tayport to Tentsmuir), Green (1975) demonstrated that the higher beach areas, in common with many other beaches were dominated by amphipod crustaceans, in particular *Talitrus* sp. On lower-lying parts of the beach at Tayport, where muddy sands dominated, the molluscs *Hydrobia* sp. and *Macoma balthica*, the crustaceans *Corophium* sp. and *Bathyporeia* sp. and the polychaetes *Lanice* sp., *Arenicola* sp. and the oligochaete *Peloscolex* (now Tubificoides) sp. were present. Where the sediments were sandier, *Cardium* sp. and *Tellina* sp. were added to the species complement. At the lowest point of the beach mussel beds could be found. At Tentsmuir the intertidal sand flats supported populations of *Talitrus* sp., but the area was notable for the range of dead shells of the molluscs which were present. In addition to the previously- mentioned species, *Ensis* sp., *Lutraria* sp. and *Mytilus* sp. were present in large numbers. According to Green, the sand beach at Tentsmuir supported no fauna, but Eleftheriou and Robertson (1988) found a total of 35 species on Tentsmuir. The majority of the fauna was found around the mid-tide level and below, but crustaceans (*Haustorius arenarius, Bathyporeia pilosa, Talitrus saltator and Eurydice pulchra*) dominated the upper foreshore. *Tellina tenuis* and *T. fabula* occupied the area from mid tide down to the MLWS; polychaete species found in appreciable densities were *Scolelepis squamata, Spio* sp., *Paraonis fulgens* and *Nephtys cirrosa*. Cumaceans (*Cumopsis goodsiri, Cumopsis longipes* and *Pseudocuma gilsoni*) were found between the mid tide level and MLWN. The high number of species taken at the low water mark was interpreted as being indicative of a strong subtidal faunal influence. There is no explanation for the apparent discrepancy between Green's results and those of Eleftheriou and Robertson.

The only other intertidal studies are those of Khayrallah and Jones (1980) who conducted an autecological study on the haustorid amphipod *Bathyporeia pilosa* on Tayport and Tentsmuir beaches, and concluded that stable sedimentary conditions determine the distribution of this species.

6.1.6.3 The Sublittoral Zone

The more southerly part of the sublittoral zone contained a large mussel bed with densities up to 13000 individuals per m^2, together with significant numbers of *Asterias rubens* (up to 444/m^2). In the north, towards Monifieth there was a bed of *Laminaria saccharina* which supported a considerable epifauna. Other epifaunal species identified from the area were *Buccinum undatum* and *Eupagurus bernhardus*. The marine nature of the outer estuary fauna and flora reflected the relatively constant salinity found in the area.

In the middle estuary a great deal of organic matter and silt was found in the lower littoral zone and the gravelly substrate had a very pronounced anaerobic layer immediately below the surface. The less polluted southern shore showed a higher diversity than the northern shore. The sublittoral areas contained little infauna due to the coarse and unstable nature of the sediments. The predominant populations were again those of *Mytilus edulis*.

Mussel beds in the middle and outer estuary played an important role in sedimentary processes of the estuary. Many of these beds appeared to be dominated by a single year class and the authors suggested that a study of growth and recruitment in these populations should prove interesting.

The sublittoral area in the upper estuary is subject only to freshwater influence with no marine species being present in the sediments.

The NMP estuarine samples from the Tay showed very impoverished faunas with means of less than 5 taxa per sample, and a maximum of only 12 taxa per station, reflecting the stressed nature of the environment. The Tay samples included the polychaete annelid *Marenzellaria viridis* amongst its dominants

6.1.6.4 General Remarks

At the time of Khayrallah and Jones' survey, the north shore of the Tay had significant numbers of outfalls draining into it. The Tay has the largest flow of water of any estuary in the British Isles and this results in short flushing times which have maintained most of the estuary in an unpolluted condition. In an effort to reduce contamination in those areas which had been impacted, these outfalls have recently been collected into a much smaller number of discharges. In support of this move, and in continuation of similar initiatives in the 1990s, a significant number of environmental surveys were undertaken to allow environmental impact assessments of the likely effects of these major works to be carried out (McManus et al. 1985; Jones, McManus & Herbert 1986; Jones, Herbert & McManus 1989, 1990) There was also considerable land reclamation to the west of Dundee which also required a number of environmental assessments to be carried out (Jones, Atkins & Caudwell 1992). These showed that the western half of Invergowrie Bay reflected localised sewage inputs by having a much richer faunal complement than an area to the east, south of Dundee Airport.

6.1.7 Firth of Forth

6.1.7.1 Introduction

The Firth of Forth is the most southerly Firth on the Scottish east coast. The area seaward of the bridges is considered to be an inlet of the sea, rather than an estuary (McLusky 1987). The Firth is important in terms of navigation and commerce, much of it associated with the petrochemical and oil-refining industries; it has even been suggested that this is the most intensively used sea area around Scotland. To simplify discussion, we have subdivided the Firth and adopted the boundaries as laid down by McLusky in his introduction to the Royal Society of Edinburgh's Symposium on the Forth in 1987. He defined the inner firth as extending from the Forth Bridges to a line drawn between Leith to Pettycur. The middle firth extended seaward from this defined limit to another line of demarcation drawn between Gullane and Earlsferry. The outer limits of the Firth were defined by a line from Fifeness to Cockburnspath, passing through the Isle of May. The estuary lying to the west of the Forth Bridges is not considered in this review, other than in its role of providing an input source to the Firth, although it is acknowledged that in Grangemouth and its surrounding area there is significant oil-related infrastructure.

Water circulation in the Firth is generally accepted to be westerly along the northern coast and easterly along the southern coast. However flows within the Firth are also recognised to be weak (typically $0.5 m.s^{-1}$) and studies undertaken to date are considered to be unsatisfactory as far as the outer firth is concerned (Dyke 1987). Because river flows to the estuary and hence to the firth are much less than might be considered typical for such a large water body, they do not exert much influence on the current regime which is dominated by tidal and wind-driven movements. It has been suggested that as the River Teith contributes more than 60% of the freshwater input to the Forth system the nomenclature should be Firth of Teith, " but there is a limit to which rational definition can be extended"! (McLusky, 1987).

Bennett and McLeod (1998) described the coastline of the Firth of Forth as being a series of indentations of sandy bays and rocky headlands with some more extensive cliffed rocky shores. In general the outer parts of the firth have rocky shores. The sublittoral environment is predominantly sedimentary with a few island features being present. The shallow sublittoral is dominated by sand and the majority of the sediments in the middle and outer firth are either muddy sand or sandy mud. Gravel based sediments occupy a large part of the inner firth (Figure 8).

The seascape of the firth is enhanced by islands such as Bass Rock, Isle of May, Inchkeith and Inchmickery. The distinctive and varied features of these islands provide a range of nesting habitats allowing a rich diversity of seabirds to breed within the Firth, which is one of the few areas in Britain where breeding takes place in close proximity to human activities. (Harris, Wanless & Smith 1987).

Studies of the marine ecology of the estuary and the Firth of Forth have benefited from the presence in the vicinity of the Universities of Stirling and Heriot Watt, Napier College (now Napier University) and the Forth River Purification Board (FRPB, now incorporated into SEPA). Research interest in the benthos of the Forth commenced in the 1970s and these organisations continue their studies to the present day, although the greatest effort took place in the late 70s and early 80s. (Bennett & McLeod 1998).

6.1.7.2 The Littoral Zone

Nevertheless, the earliest reference in the published literature utilising a modern approach to shoreline ecology, came from a researcher from Paisley Polytechnic. Smyth (1968) examined in detail a series of rocky outcrops to the west of Granton Harbour and made comments on the intervening sandy and muddy substrates. His results, reported in a semi-quantitative manner, demonstrated that although the area had a poor species complement there was an abundance of animals. The area was subject to inputs from two sewage pipes, believed by this author to make an observable contribution to the onshore movement of effluents during flood tides, which made it noticeably dirtier than the surrounding areas. His investigations revealed that the algal vegetation was relatively poor in the area close to Granton while a full series of the fucoid algae was found at Cramond Island. *Gigartina stellata, Fucus* showed a patchy distribution while *Porphyra umbilicalis* was common, *Ulva lactuca* and *Enteromorpha* spp (green algae) were more evident in areas affected by sewage. In some areas *Fucus* sp, *Rhodochorton rothii* and *Enteromorpha* sp. provided niches for small invertebrates.

The shore fauna was dominated by *Mytilus edulis* (occurring in beds*), Balanus balanoides,* with occasional patches of *Elminius modestus,* and *B. crenatus* and the spionid worm *Polydora ciliata.* Large numbers of *Littorina littorea* were found everywhere except where *Polydora wa*s dominant or where fucoids growth was densest. *Polydora ciliata* formed dense mats on low-level rocks. The intervening mud and sand was populated by what is now recognised as a typical opportunistic fauna which had very high numbers of nematodes and the spionid polychaete *Scolelepis fuliginosa.* Towards Cramond Island the community became more diverse but less abundant with the typical sandy shore species *Tellina tenuis* and *T fabula, Nephtys hombergi* and *Spio filicornis* and the muddier sediments supporting populations of *Cerastoderma edule, Macoma balthica* and *Pygospio elegans.* Smyth (1968) commented on the presence in the area of biogenic mats formed by the tube-building polychaete *Polydora ciliata* and which provided a matrix that supported a community including the oligochaete *Clitellio arenarius* and nematodes. *Phyllodoce maculata* and *Eteone longa* were also present with amphipods poorly represented. He attributed the presence of the mats to the sewage contamination of the shore. Moreover, while recognising that the exclusion of species from the area which were very common on the adjacent shores (such as *Pomatoceros triqueter, Patella vulgata* and *Thais lapillus*) had some significance, he did not provide an explanation for this salient feature.

Researchers at the then Napier College conducted a study the objective of which was "… to investigate the ecology of Edinburgh coastal zone by means of study of the littoral and sub-littoral benthos and to determine the reasons for any changes detected." (Read, Anderson, Matthews & Watson 1981; Read, 1987).

The study reported on work done between 1974 and 1980 and included sandy shore and rocky shore benthos and sublittoral benthos. Some meiobenthos (on the sandy shores) and algal studies (on the rocky shores) were also reported and are detailed below. The sublittoral section dealt only with the macrobenthos and covered an area of the seabed around the end of the Seafield long outfall that was studied between March 1978, just before the sewage works became operational, and September 1980.

The sandy shore benthos was studied at four locations, Cramond, Seafield, Portbello and Seton Sands. The sands were predominantly fine to medium grained sands. Deposits of mud were present at Cramond near MHWS but in general the sediments were coarse in the upper beaches and became progressively finer down the tidal range. The macrobenthos of the four beaches fitted broadly into the usual pattern of communities associated with different sediment types and depths (Read, 1987) although where gross sewage pollution was in evidence the community structure was significantly modified. A well-developed *Tellina* community was present at Seton Sands and Cramond Beach although the absence of *Donax vittatus* was noted. A *Macoma* community was present on parts of Cramond which was generally poorer in species and richer in individuals than the *Tellina* community of the sandy regions. Modified *Tellina* communities were found at Portobello and Seafield and a community with extremely reduced diversity dominated by *Scolelepis fuliginosa* and *Capitella capitata* at Seafield West.

After sewage discharges were stopped, the changes in the fauna of the Seton Sands and Cramond beaches were negligible. However, the Portobello community showed moderate change, and at Seafield there was a significant reduction in numbers of individuals (mainly due to changes in the abundances of the opportunistic populations of *Capitella capitata and Scolelepis fuliginosa)* accompanied by an increase in numbers of species.

Read (1987), in referring to surveys of Belhaven Bay conducted separately by the (then) Marine Laboratory, Aberdeen and the Forth River Purification Board (FRPB) concluded that the intertidal Belhaven Bay was a high wave energy area, and was biologically poor with very little input to the sediment of organic matter from any source. In their later report (1988) Eleftheriou and Robertson noted the existence on the beach of a species-poor fauna, dominated by amphipods such as *Bathyporeia pelagica*, *Haustorius arenarius*, *Pontocrates arenarius* and the isopod *Eurydice pulchra*, while molluscs and polychaetes were virtually absent.

However at Gullane, a small sandy beach at the northern margin of Aberlady Bay a much richer community was present (Eleftheriou & Robertson 1988). In addition to the same dominant amphipod species as found at Belhaven, a healthy polychaete community was found including *Nephtys cirrosa*, *Spio filicornis* and *Paraonis fulgens* on the lower foreshore and *Scolelepis squamata* and *Ophelia rathkei* in the area between MHWN and MTL. The only bivalve with a significant population *was Tellina tenuis*. When Stephen (1929) visited this beach he reported a much poorer fauna, with *Tellina tenuis* and *Nephtys caeca* the dominant species. Eleftheriou and Robertson ascribed these disparities to the use of different sampling techniques.

The results from several surveys of the beach at Dunbar (FRPB, 1981) showed that the fauna was predominantly polychaetes and that most of the species were typically mobile in unstable sediments. There were large populations of *Tellina fabula* (700m^{-2}), with crustaceans being represented by amphipods and cumaceans including many mobile, sediment-dwelling species. Since, in addition, diversity and evenness indices were high for most areas, the conclusion reached was that the area represented a clean unpolluted environment.

On the north side of the Forth, IOE conducted a survey of the Braefoot Bay area with four traverses covering three beaches (IOE, 1984). The community was shown to be relatively diverse with species distributions conforming to the classical pattern of sedimentary shores. The most abundant species, common to all beaches was the polychaete *Pygospio elegans;* otherwise, the fauna was unremarkable apart from a population of the bivalve *Abra alba* on a single beach.

From a survey carried out around Burntisland by FRPB (FRPB, 1983) it was concluded that, mainly as a result of the sedimentary and hydrographic characteristics of the area, the fauna of the intertidal sands was poor; it did not seem that the existing discharges had a catastrophic effect on the communities.

In contrast, Inverkeithing Bay had, over a period of some years received paper-mill effluent which had caused a build-up of organic matter, mainly cellulose. A survey carried out by FRMB (1984) revealed a fauna impoverished in diversity, with high numbers of annelid worms, notably capitellid polychaetes and tubificid oligochaetes, resulting in an increased biological production in the area. The authors concluded that as might be expected, the bay contained a benthic community under a high degree of stress.

Though there are no records of recent beach surveys, it is interesting to discover that there is some evidence for stability of the faunal communities of the Edinburgh beaches gleaned from third party studies. For instance, in the course of reporting their experimental studies on patchiness of tube-building polychaetes, Bolam and Fernandes (2002) confirmed that in the late 1990s the polychaete *Pygospio elegans* had remained as one of the dominants in the area where Smyth (1968) had carried out his original studies. Furthermore, from the undisturbed areas amongst the primary colonisers they identified *Cerastoderma edule* and *Macoma balthica* as being consistently present. From this it may be inferred that populations of these species are still present and thriving in the area.

Rocky shore surveys were carried out at West and East Granton, Joppa, close to Edinburgh, and at Ferny Ness, 15km to the east (Read, Anderson, Matthews & Watson 1981). The latter was included to act as a control. It was established that following the introduction of sewage treatment no changes ascribable to contamination changes were detected there, the area being covered with *Balanus* sp. and *Littorina* sp. and supporting beds of *Mytilus edulis* and patches of Fucoids and *Ascophyllum nodosum* at mid tide level. Species which did not appear at the more westerly locations included the molluscs *Leptochitona cinereus*, *Nucella lapillus*, the polychaetes *Harmothoe impar*, *Pomatoceros triqueter* and the algae *Chaetomorpha* spp., *Dictyosiphon foeniculaceus*, *Halidrys siliquosa*, *Pelvetia canaliculata, Bangia fusco-purpurea*, *Corallina officinalis*, *Lithothamnion* sp., *Lithophyllum incrustans* and *Polysiphonia* sp.. At East Granton and Joppa few of the recorded species disappeared following the opening of the sewage treatment plants, but on the contrary, species diversity increased with the addition of 'new' records for the areas including the crabs *Cancer pagurus* and *Eupagurus bernhardus*, the coelenterates *Obelia dichotoma* and *O. geniculata*, and the tunicates *Botryllus schlosseri* and *Dendrodoa grossularia*. Red algae also increased in diversity with the addition of *Rhodymenia palmata*, *Griffithsia flucolosa* and *Corallina officinalis* and *Fucus ceranoides, Laminaria digitata* and *L.saccharina* contributed to an increase in the brown algae (Phaeophyta). At West Granton there was little change in the diversity, but dramatic changes in the abundance of certain individuals were noted. The mat-like growths of *Polydora ciliata* and *Fabricia sabella* (a phenomenon also noted by Smyth, 1968) had disappeared along with the organisms associated with the matrix provided by the mat, such as *Rhizoclonium riparium*, *Stichococcus* sp. and *Urospora* sp. New records for the area included the invertebrates *Pomatoceros triqueter*, *Actinia equina* , *Carcinus maenas, Idotea pelagica* and *Nucella lapillus* and the algae *Punctaria plantaginea*, *Chondria dasyphylla*, *Laminaria digitatum* and *Laminaria saccharina.* The fucoids, including *Fucus ceranoides* were no longer recorded as being stunted.

In his report on the Beaches of Fife, Ritchie (1979) identified the beaches which lay along the north coast of the Firth from Balcomie to Inchcolm. The report was one of a series of five on the beaches of Lowland Scotland commissioned by the

Countryside Commission for Scotland and was essentially a systematic description of the physical characteristics of the beaches dunes, links and associated surfaces." Although Ritchie identified a variety of habitat type associated with the various beaches he did not seek to describe the biotic environment in the kind of detail required for the present synthesis report. However his descriptions of the various locations can be used to amplify the somewhat meagre biological data that do exist for these beaches.

Over 130 species of molluscs have been reported as living or having been cast up alive on the shores of the Firth of Forth with about 100 of these living on rocky shores (Berry & Smith 1987). Some 50 of these were considered to be common; however, only six are present continuously on rocky shores over the whole area from Queensferry to the eastern boundary of the Firth. They were *Patella vulgata, Littorina littorea L. saxatilis, L. obtusata, Nucella lapillus* and *Mytilus edulis.* All were common or abundant except *L. obtusata ,* the distribution of which is dependent on seaweed cover.

Around the East Neuk on the north shore, a total of 45 species was recorded in all with rocky shore numbers diminishing further the west, with a minimum of 9 at Buckhaven. However Aberdour showed an exceptional diversity with 45 species being present.

On the south shore, with fewer rocky sites and significant levels of siltation and turbidity only 30 species were reported from around Joppa. However the number of species did increase beyond Seton Sands with over a hundred species noted at Dunbar, most of which were found on the rocky shores between Tyninghame and Belhaven. Increasing diversity was ascribed to superior water quality which allowed more indigenous species to flourish and, in addition, the input of planktonic larva from further north permitted the settlement of adventitious species generally uncommon in the east of Scotland.

Moore (1987) reported that there was very little published information on the intertidal meiofauna of the estuary of the Forth but it was recognised that work was ongoing, mainly in relation to the extensive mudflats. Likewise there was very little information regarding the subtidal fauna. The author reported results from 12 stations between Queensferry and Grangemouth. The mean abundances found were similar to those found intertidally during the summer period. The community was dominated by nematodes with Copepods being second in abundance. Other taxa were present in insignificant numbers.

The reports from the Firth of Forth concern mainly the beaches around Edinburgh and changes resulting from the commissioning of the sewage works in 1978. Before the start of the scheme meiofaunal copepod populations at Cramond and at Dunbar showed characteristics similar to those of clean marine beaches remote from the Forth. Between these two locations, the beaches around Edinburgh appeared to be impoverished, with numerous nematodes, two gastrotrichs *Turbanella hyalina* and *Neodasys chaetonotoides* and few species of copepods, particularly interstitial forms. Following the introduction of the new sewage system, copepod diversity increased at Seafield with the addition of interstitial species such as *Paraleptastacus espinulatus* and *Arenosetella tenuisima*, where they were previously unrecorded. The appearance of epibenthic and burrowing species near the old sewage outfall was also noted and included the addition of the gastrotichs *Xenotrichula intermedia* and *Macrodasys caudatus* at Portobello and *Thiodasys* sp. at Seafield East (Anderson et al, 1981).

6.1.7.3 The SubLittoral Zone

The Napier College study on the ecology of the Firth of Forth included a series of sublittoral surveys. The sublittoral benthos was studied at the location of the discharge pipe from the 'new' Seafield sewage treatment works (Read, Anderson, Matthews and Watson, 1981). The pipe was 2800m in length and over the last 800m a series of eight diffuser heads were located. The benthic community was considered to be a variation of the *Abra* community described by Thorson (1957) which is typically found on muddy sand bottoms rich in organic material and generally in sheltered estuarine conditions. The characterising species of Thorson's classification, the bivalves *Abra* (formerly *Syndosmya*), *Cultellus*, *Corbula*, and *Nucula* and the polychaetes *Nephtys* and *Pectinaria* (as *Lagis* in this report) are all present in the sublittoral samples. Over the study period the basic community statistics (number of species, abundance and biomass) of the benthos showed a consistent increase. The authors concluded that there was no evidence of deleterious effects caused by "… the new effluent input, although there does appear to be some enhancement of the fauna in the area." They did recognise that three years was a relatively short period of time to observe faunal fluctuations and during part of that period the system was not operating at full capacity.

Mainly on the basis of a major sampling exercise in 1979 Elliott and Kingston (1987) classified the macrofaunal associations within both the estuary and the Firth of Forth. Many of the groups in the firth (east of the bridges) corresponded to Petersen's classical community types when the data were examined in the light of the criteria of Thorson (1957). The estuary's fauna fell into a classification that was described by its basic characteristics, but as the estuary is outwith the geography of this report it is not detailed here.

Four clear associations, accounting for six groups were described from the Firth of Forth. The *Abra* community (and two variants) formed the largest group, an *Echinocardium-filiformis* group (Petersen, 1914) was found in a broad band curving from Inchkeith into Largo Bay, a *Venus* community formed bands off the north and south coasts of the firth near Largo and Aberlady Bays and a *Crenella* association (characterised by the bivalves *Crenella decussata* and *Venus ovata*, and the amphipod *Metaphoxus fultoni)* occurred in two small areas on the northern and southern sides of the firth, close to its outer limit. One station, to the west near the bridges, supported a classical *Modiolus* association with a local but substantial population of adult horse mussels. The community here also contained the bivalve *Venerupis rhomboides*, the crab *Porcellana longicornis* and the brittle star *Amphipholis squamata.*

In the estuary the supra-estuarine association actually extended into the firth, covering the central southern part of the estuary starting at Bo'ness and following the main channel to Inchcolm. The group was characterised by marine species such as the cirratulid *Dodecaceria concharum*, the terebellid *Neoamphitrite figulus* and the bivalve *Abra alba*. The north central part of the estuary, east of Bo'ness was occupied by an impoverished supra-estuarine association. A group regarded as the stressed transition area showed an extremely impoverished community, predominantly represented by the polychaetes *Nephtys hombergii* and Eteone *longa* which were present in very low numbers. A *Polydora*-oligochaete association, characterised by the spionids *Polydora ligni/ciliata* and *Marenzellaria wireni* and the oligochaete *Tubificoides* spp. occupied the area to the west of Kinneil, the fauna approaching that found at the freshwater brackish water interface.

The faunistically richer areas of the firth form an arc from the central Fife coast to Inchkeith to Edinburgh's shore and the eastwards to Aberlady Bay. This latter portion coincided with an area that was considered to be nutrient-enriched at the time. Changes brought about by the diversion of Edinburgh's sewage may have resulted in changes to the distribution patterns since these data were published.

The communities were considered to be controlled by physical variables with the deeper muddier basins being poorer than the surrounding areas. Although there are many anthropogenic threats to the benthos of the Forth, in the firth the major part of the benthos does not show signs of stress. In several coastal areas the benthos has been modified leading to the conclusion that, "… in general, the benthos of the coastal areas has a greater variability dependent on anthropogenic stresses superimposed on sedimentary effects.(Elliott & Kingston, 1987)".

Like the Tay, the NMP estuarine samples from the Forth showed very impoverished faunas with means of less than 5 taxa per sample, and a maximum of only 12 taxa per station, reflecting the stressed nature of the environment. A brackish water oligochaete, *Limnodrilus hoffmeisteri,* dominated the estuarine communities. The intermediate site in the Firth of Forth (Kingston Hudds) had a very varied fauna with polychaetes and molluscs dominating. *Rhodine gracilior, Prionospio fallax, Lumbrineris gracilis, Heteromastus filiformis, Nephtys incisa and Scalibregma inflatum* co-dominated the polychaetes while the gastropod *Turitella communis* and the bivalve *Mysella bidentata* were the commonest of the molluscs.

Published information on subtidal meiofauna from the Firth is confined to Scott's records from 1906. Thomas Scott published a number of papers on the Crustacea of the Firth of Forth listing 170 species of harpacticoids and 132 species of ostracods along with notes on their distribution and abundance. An unpublished report (SJ Anderson reported in Moore, 1986) described impacts of a sewage discharge on meiofaunal communities in Largo Bay. Strongly reduced conditions in the fine sand sediments led to a low-diversity, high-abundance community dominated by the nematodes *Sabatieria pulchra*, *Daptonema* sp and *Pontonema* sp., the copepods *Bulbamphiascus imus* and *Paramphiascopis longirostris* and the polychaetes *Capitella capitata* and *Malacoceros vulgaris*.

6.1.7.4 General comments

Though the Firth of Forth is not a recognised oil production area, it receives effluent from Scotland's major petrochemical and oil-refining industries in addition to the more usual hydrocarbon inputs expected in a major water body (occasional spillages, storm-water run-off and municipal discharges). Sources of petrogenic inputs include the petrochemicals complex at Grangemouth (BP), the BP refinery, production waters from oilfields (from the Kinneil outfall), treated ballast waters from the Hound Point terminal and some limited discharges from the Braefoot Bay terminal. Pyrolytic inputs, generally from domestic and industrial inputs, but more specifically from the fossil fuel fired generating stations at Kincardine, Longannet, Methil and Cockenzie also contribute to the inputs to the Firth (Elliott & Griffiths 1987).

There is evidence of increased levels of hydrocarbon contamination in the various components of the biota within the Firth. The common mussel was used to monitor hydrocarbon contamination in the Forth, but its value as an indicator of petrogenic hydrocarbon differs with particular hydrocarbons (Mackie et al.1980). In general concentrations of aliphatic and aromatic burdens in mussels decreased down the Forth although certain areas deviated from this pattern.

Oil contamination from the estuary intertidal petrochemical discharges has resulted in changes in the benthic microalgal community structure in these areas, producing dense beds of filamentous blue-green algae (Cyanophycae). Mills (1985) reported that this had resulted in an increase in the standing crop and production close to the effluent channels when compared to other areas in the estuary. Refinery discharges had reduced the epilithic algal community at Kinneil and though rocky-shore floral communities were also reduced, they recovered with distance from the discharge. Invertebrate faunal patterns have been changed by the petrochemical discharges, the spatial response mimicking the effect of organic enrichment. However the response varied seasonally due possibly to changes in sedimentary-reducing conditions. Both subtidal and intertidal benthos in the estuary have been affected by the discharges and the hydrocarbon contamination.

The Elliott and Griffiths (1987) study concluded that in the Forth "…petrochemical effluents have very near-field toxic effects but the predominant effects are related to sediment organic enrichment which produces anaerobic conditions that control the floral and faunal communities".

6.1.8 Other significant inlets on the East Coast

6.1.8.1 The Ythan Estuary

The Ythan estuary is a small meso-tidal bar-built estuary (Davidson et al. 1991) lying approximately half way between Peterhead and Aberdeen on the east coast of Scotland. It is a well-understood small-scale ecosystem (Raffaelli 1992) and has been the subject of many studies based at the Culterty Field Station of the University of Aberdeen. The scale of the estuary is such that most of the trophic links in the food web for the estuary have been discovered (Gorman & Raffaelli, 1993).

At the mouth of the Ythan the sediments are sandy with stones and mussel beds and with occasional patches of muddy sand. In the middle reaches of the estuary the sediments are muddy sand becoming finer further into the inner estuary (Baird & Milne, 1981). Nutrient inputs to the estuary are at such a level that the then Scottish Office (now the Scottish Executive) proposed its designation as Scotland's first Nitrate Vulnerable Zone in 1994.

The faunal community is well studied, the amphipod *Corophium volutator*, with the gastropod mollusc *Hydrobia ulvae*, the polychaete *Nereis* (now *Hediste*) *diversicolor* and the bivalve *Macoma balthica* being widely distributed. Species such as the cockle *Cerastoderma edule*, the gastropod *Littorina littorea*, the shore crab *Carcinus maenas* and the mussel, *Mytilus edulis* exhibit more localised distributions (Bennett & McLeod 1998). Increasing weed cover (*Enteromorpha intestinalis*) led to increases in the opportunistic polychaete species *Capitella capitata* in the 1980s.

6.1.8.2 The Montrose Basin

Montrose Basin (the estuary of the River South Esk and a Ramsar site, wetland of international importance and a Special Protection Area (SPA) for birds) forms a broad, muddy, predominantly intertidal basin, much of which remains largely unmodified by pollution and land-claim, except around its mouth. It has the highest density of saltmarsh breeding waders in Britain (Davidson et al. 1991). Although there is significant industrialisation around the mouth, there are rural and undeveloped areas, with natural shorelines in the inner part of the Basin.

The wide mudflats of the Basin supported a rich estuarine fauna, dominated by the gastropod mollusc *Hydrobia ulvae*, the amphipod *Corophium volutator*, the bivalves *Cerastoderma edule*, and *Macoma balthica* and the polychaetes *Manayunkia* spp. and *Fabricia sabella* (McLusky & Roddie 1982). There were extensive mussel (*Mytilus edulis)* beds present, particularly on banks at the eastern end of the basin and along the main drainage channels (Atkins et al. 1992). Dwarf eelgrass *Zostera noltii* and narrow-leaved eelgrass *Z. angustifolia* were found within the basin, although Atkins and his co-workers noted a marked decline in cover within the basin between 1982 and 1991.

6.2 Offshore areas

6.2.1 Introduction

In spite of the fact that the North Sea is one of the most studied marine environments in the world, most investigations concerned fish populations and as a result, there is still relatively little information available about the benthic fauna. The North Sea Conference (Goldberg, 1973) pointed up the relative lack of benthic faunal data, particularly with regard to the northern North Sea. Since then intensive small-scale surveys have been a necessary requirement of the oil and gas explorations which have taken place. Wide-ranging surveys (Basford & Eleftheriou 1988; Eleftheriou & Basford 1989; Basford et al. 1989, 1990 & 1993; Kunitzer et al. 1992), as well as epifaunal surveys (Dyer et al. 1982, 1983; Jennings et al. 1999; Zulhke 2001) have been undertaken.

As previously mentioned in this report there are major hydrographic divisions between the northern and central North Sea. The north Atlantic inflow is the main influence in the northern part, while currents in the central area are wind-driven (Dooley 1974). Another division reported by many authors runs east-west just north of the Dogger Bank. As a result, different authors using different criteria have given different names to the same areas, e.g., the open sea, coastal and infralittoral étages noted by Glémarec (1973), and the offshore northern, offshore central and offshore southern areas by Adams (1987). As the latter subdivisions appear to be both long-lasting and relate to both the benthos and the plankton, this section of the SEA 5 Report follows these categories and the relevant areas entitled 'northern' 'central' and 'southern'.

In their review of the North Sea level bottom communities Kingston and Rachor (1982) indicate the areas in which major studies of the North Sea benthos have been carried out in recent years and use this information to project the locations of the major communities. From the available data they were unable to distinguish the geographic extent of the communities, mainly because the early samples were collected along transects or related to specific area of economic interest (generally oil or gas investigations). Nor did the subdivision between the northern and central North Sea appear to be particularly relevant to the infaunal communities. They noted that some form of *Amphiura* community extended over the whole of the central and most of the northern North Sea. The division between the central and southern North Sea was better delineated (probably as a result of the increased level of sampling) and was recorded as the northerly extent of the *Amphiura* community which includes *Echinocardium filiformis* and *Brissopsis chiajei* communities (Kingston & Rachor 1982). They concluded that there was an urgent need for further investigations covering the northern and central areas since they considered that, at that time, quantitative bottom community data were not available. Thereafter Kunitzer et al. (1992) reporting in a large ICES North Sea survey were able to resolve the difference between the central and northern areas and to go further in proposing a Scottish inshore subdivision in the northern area and four subdivisions of the southern area.

Where authors have applied cluster analysis to the epifaunal stations, they noted groups corresponding approximately to the northern, central, and southern North Sea (Jennings et al. 1999; Dyer et al.. 1983)). Dyer et al. (1983) were able to subdivide the northern area into two clusters (N1 and N2). However, their third cluster, (N3), conforms to the central area described by other authors (Glémarec 1973; Lee 1980; Adams 1987), and includes one sample from the Moray Firth. Dyer et al. (1983) also subdivided the southern area into three areas. Frauenheim et al. (1989) subdivided the North Sea seasonally: in the summer, there was a north/south divide (north and south of the Dogger Bank and in the winter there was a west / east divide. The division north of the Dogger Bank designated by Frauenheim et al. conforms therefore to the northern and central areas designated by the previous authors which allows us to infer that the major North Sea division may be between the central and southern areas rather than between the northern and central areas. Basford et al. (1989), sampling more intensively, and mainly in the northern area were able to distinguish four subgroups, but since their survey did not cover the central and southern North Sea it is not possible to comment on the major divisions as described above.

From the few publications on the meiofauna of the North Sea however Huys et al. (1990, 1992) described the harpacticoid copepod communities from central and southern North Sea samples, again noting a sub-division between his areas III and IV, which approximately corresponds to that of the previous authors. Within SEA 5 area Huys et al. (1990) recorded a coastal community closely reflecting the infaunal coastal grouping noted by Basford et al. (1990).

6.2.2 Northern Area (North of 57° 30'N)

6.2.2.1 Introduction

The benthic infauna of the offshore northern North Sea in general is characterised by its tendency towards higher diversities than the central or southern areas (Kunitzer et al. 1992)). While these results may be attributable, in part, to the use of finer sieves (0.5mm in the northern area as opposed to 1mm elsewhere), the gradual increase in diversity northward through the southern and central areas would suggest that this gradient does exist. There may be a relationship between this increase and changes in depth and productivity in the area, but the variability of the data makes it difficult to discern clear divisions on smaller scales.

Much of the productivity in the northern North Sea is associated with the input of high nutrient water from the North Atlantic and this has an effect on the assemblages of the benthic community in this northern portion of the SEA 5 area.

6.2.2.2 The Epifauna

The main historical thrust of North Sea investigations concerned fish populations and benthos studies were marginal. It should be noted that all previous work (Petersen & Boysen Jensen 1911; Petersen 1914, 1915; Blegvad 1922; Davis 1923, 1925; Stephen 1923, 1933,1934; Ursin 1960) appears to have centred on the grab-sampled infauna which is less readily available to fish than the surface-dwelling epifauna. However, direct observation of the benthic epifauna recovered in the fishing trawl might well have served to give an initial insight into the benthic communities. Dyer et al. (1982, 1983) and Cranmer et al. (1984) took this approach, describing for the first time the wide-scale epibenthic communities from the fauna caught in the trawl used on the annual MAFF ground fish surveys of 1977-1983.

These authors went one step further by using a camera attached to the headline of the demersal trawl from 1978 – 1982. They photographed the bottom at between one and three frames per minute during each one-hour trawl (6km average) carried out at 49 stations in SEA area 5 north of Peterhead. The animals in each trawl were collected and correctly identified, but the resolution of the photographs was often poor. Only 23 stations were adequately surveyed with the camera by Dyer and his co-workers (1982) though Cranmer et al. (1984) later surveyed 95 stations. In addition, Dyer et al. (1982) acknowledged that animals which normally bury or conceal themselves cannot be accurately assessed by remote photography. Several authors have also noted the low efficiency of dredges and trawls in collecting epibenthic fauna (Eleftheriou & Basford 1984; Dyer et al. 1982; Dickie 1955; Richards & Riley 1967)). Dyer et al. (1982) mapped the abundances of the most common or locally abundant species in their trawls or their photographs Seven of these occurred in the SEA 5 area, the echinoderms *Echinus acutus* and *Asterias rubens*, the polychaete *Hyalinoecia tubicola*, the red sea pen *Pennatula phosporea*, Dead Men's Fingers *Alcyonium digitatum*, the Norway Lobster *Nephrops norvegicus* and the bryozoan, *Flustra foliacea*.

Dyer et al. (1983) used only the epifaunal data from the trawl to describe the faunal assemblages. Six of the trawl stations fell within this subdivision of SEA 5. One station fell into Dyer's Central North Sea grouping and was dominated by the sea urchin *Echinus acutus* and the scallop *Pecten maximus*. Three stations fell within the Fladen Ground group dominated by the anemone *Hormanthia digitata,* the gastropod *Colus gracilis* and the ascidians *Ascidia oblique* and *Phakellia sp*. A single station fell into the Northern North Sea group where the starfishes *Hippasteria phrygiana* and *Asterias rubens* were the most commonly encountered species, and the final station was unallocated being highly diverse but low in abundance, with only the starfish *Hippasteria phrygiana* being present in numbers greater than 10 individuals per trawl.

Dyer and his co-authors do not indicate which organisms characterise individual areas, preferring to describe, in more general terms, those organisms that were common in the wider geographical northern or southern regions. Thus they noted that the northern species included the asteroid starfishes *Hippasteria phrygiana*, *Strichastella rosea, Henricia sp* and *Solaster endeca*, the sponges *Tetilla spp* and *Phakellia spp*; the anthozoan *Adamsia palliata*; the polychaete *Hyalinoecia tubicola*, the colonial tunicate *Synoicum pulmonaria* and the pycnogonid *Nymphon stromi*. They observed that the sea urchin *Echinus acutus* was common throughout the northern North Sea except in the Fladen Grounds.

They also concluded that substrate type, water masses and the associated plankton, depth, temperature range and water circulation patterns, are likely to be among the factors governing the assemblages. The effects of these factors are likely to be interactive and complex, with the relative importance of any single factor likely to vary from area to area.

The distribution of the regular echinoids from the above surveys were described by Cranmer (1985) and follows the major work by Ursin (1960) which mapped the distribution of this group in waters of less than 100 metres.

Basford et al. (1989, 1990) undertook a more intensive epibenthic survey using a 2m Agassiz trawl, towed for an average distance of 920m at the 38 stations in SEA area 5 north of Peterhead. The authors found uniformly low densities (<200 per 1000m^2) and low species richness (10 - 20 species per trawl) over most of the North Sea. The number of species increased to over 20 species per trawl in an extensive area extending to the south east of Shetland and fell below 10 towards the Buchan coast off Peterhead. This increase in species richness to the east of Shetland was not apparent in the data presented by Dyer et al., who generally recorded much greater diversity (average of 41 species per trawl within this sub-area) and may therefore reflect the different sampling techniques used by the different authors.

Basford et al. (1989, 1990) used statistical techniques to investigate community assemblages and link them to the environmental parameters. Initially the data showed two groups of stations:

a) fauna inhabiting moderately sorted, coarse sediments with relatively low silt and organic carbon levels characterised by Porifera, the bryozoan, *Flustra foliacea*, the anemone *Bolocera tuediae*, and the crab, *Hyas coarctatus,* typically in the sandy areas extending south of Fair Isle to off Peterhead and

b) the deeper, finer sediments, of the Fladen Ground and its northern extensions where the fauna was typified by the echinoids; *Asterias rubens, Astropecten irregularis*, and *Bryssopsis lyrifera*.

The latter group was further subdivided giving a deeper mud-dwelling group in the Fladen area characterised by the seapen, *Pennatula phosphorea* and a shallower group typified by the hermit crab, *Pagurus bernhardus, the brown shrimp, Crangon allmanni, the purple heart urchin, Spatangus purpureus* and the gastropod, *Colus gracilis* in the surrounding area. Similarly, further divisions of group a), gave a shallower (70m) and coarser sediment group inhabiting the sediments between Orkney and Shetland and off the Buchan coast typified by the presence of Porifera, and a deeper (100m), finer sediment, group typified by Tunicates, and the shrimp *Spirontocaris lilljeborgi* covering the intermediate flat offshore area.

Jennings et al. (1999) undertook a large-scale survey taking 5-minute trawls with a 2-m beam trawl from over the whole North Sea. The authors differentiated the fauna into free-living and attached epibenthos. The authors used ICES data (mean bottom temperatures from winter and summer, the difference between these representing a measure of thermal stability and the maximum spring tidal current speed) to identify environmental influences. Their data generally reinforced the divisions of Dyer et al. (1983).

Five stations from their survey fall into the northern subdivision of SEA 5. The mean diversity of attached fauna for these stations was 13 species; and a mean of 18 species of free-living organisms was found. The grouping derived from the free-living epibenthos was typified by the presence of *Asterias rubens, Crangon allmanni, Pagurus bernhardus, Hyas coarctatus, Astropecten irregularis* and *Anapagurus laevis.* The attached species grouping was characterised by *Flustra foliacea, Hydrallmania falcate, Lafoea dumosa, Suberites ficus, Ciona intestinalis* and *Alcyonium diaphanum.* They concluded that temperature variation and depth were better descriptors of the environmental drivers of the community than was temperature alone.

Zuhlke (2001) surveyed the whole North Sea using a 2m steel beam trawl towed at 1knot for 5 minutes (average distance 270m. Like Jennings et al. (1999) she separated the sessile and free-living species in her analysis but included both in a further total epibenthic analysis. Though her data clearly indicated the division between the central and southern North Sea in all three analyses (she describes this at 50m depth while other authors used 60m) the division between the northern and central North Sea was noted only in the sessile and total fauna analysis. The maximum species richness in the northern North Sea was due to large numbers of sea urchins, *Echinus* spp. This species, along with hermit crabs, accounted for the maximum biomass in the northern area.

6.2.2.3 The Infauna

Stephen in his early work in the North Sea (Stephen 1922) carried out sampling along two transects across the North Sea and one around Shetland as well as taking many inshore samples. In his grab survey he described a pure *Ditrupa* community around the north of Shetland, then *Ophiura affinis* and *Echinocyamus pusillus*, and, *Ditrupa* without *Ophiura affinis*, to the east and south of Shetland. In the outer Moray Firth the fauna was characterised by *Amphiura chiajei* and *A. filiformis* communities. He also recorded a Foraminifera community in the deeper areas to the north of the Fladen ground. He further noted that the offshore fauna was less dense and more uniform than that found inshore. Stephen emphasised that more intensive sampling might improve the accuracy of his proposed communities and might permit sub-communities to be mapped.

Stephen's large-scale survey was not followed up until the North Sea surveys undertaken by Eleftheriou and Basford which were continued by the ICES investigations in the early 1980s. However, in the meantime, though numerous localised surveys have been undertaken, mainly in relation to oil explorations, few of these fall within SEA5 (see Figure 4) and fewer still contain faunal data.

From 1980 –1985 Eleftheriou and Basford took samples every 15 miles in a grid extending across the North Sea from just north of Shetland to the Firth of Forth. The physio-chemical environment is described in detail in Basford & Eleftheriou (1988): to summarise their findings, the seabed was generally smooth, the shallower western boundary had coarse grades and the deeper eastern area was silty, with much of the intervening area covered with fine sand.

The abundance varied from 500 individuals per square metre inshore to the east of Shetland to 9,600 towards the more silty deeper offshore area, with mean abundance for all 32 stations being 3,300. Polychaetes predominated throughout, regularly making up 50% of the abundance and generally being between 2 to 5 times as numerous as the molluscs or echinoderms. The number of species varied from 26 at the most northerly station off Shetland, to 80 in deeper silty stations north of the Fladen Ground; the mean species diversity was 54 species per station.

Eleftheriou and Basford (1989) also allocated feeding guilds to the five predominant species. Carnivores predominated in the coarse northerly stations off Shetland with subsurface deposit feeders being more common over most of the area, with small areas where subsurface deposit feeders occurred. The latter were often associated with the deeper depressions where finer sediments were found.

Analysis of benthic data in conjunction with the sediments produced two distinct groups according to the amount of silt present in the sediments.

The group of stations containing less than 20% silt was sub-divided into a fine sand group, inhabited by *Abra prismatica, Ophelina neglecta, Travisia forbesi, Bathyporeia elegans* and *Eudorellopsis deformis,* an inshore, coarser sandy sediment group (Shetland) where *Hesionura elongata, Dorvillea kefersteini, Protomystides bidentata* and *Tellina pygmea* were present, and a finer (medium to very fine sand) group, which was characterised by *Spiophanes kroyeri, Myriochele heeri, Harpinia antennaria* and *Aricidea wassi*. The group of stations defined by containing more than 20% silt was geographically located in the Fladen Ground and is outwith the SEA5 area.

Basford et al. (1990) reported on an additional sampling from the above survey extending from off Orkney to the inner Moray Firth. These samples indicate an increased infaunal density from less than 3,000 individuals per m^2 offshore increasing up to 6,000 in the outer Moray Firth. Species richness varied from 30 –60 species per station with no detectable pattern. The initial division shown in the analysis of the data revealed an inshore group and an offshore group. These groups were subdivided into a siltier group characterised by the polychaete, *Pisione remota*, and a coarser silt group typified by the lamellibranch, *Nucula tenuis*. The offshore group was further subdivided with the polychaete, *Spiophanes bombyx* representative of the shallower, less silty group and the amphipod, *Eriopisa elongata*, lamellibranchs, *Thyasira spp* and the polychaetes, *Lumbrineris gracilis* and *Ceratocephale loveni* representative of the deeper siltier samples.

Kunitzer et al. (1992) analysed the data from their ICES North Sea Benthos Survey of which the above samples were a subset, and again found an offshore / inshore group division with relatively similar boundaries. The sediments again appeared to govern the subdivisions with the fauna of the finer sediment group characterised by the polychaetes *Minuspio cirrifera, Aricidea cathrinae* and *Exogone verugera* and the lamellibranch *Thyasira* spp. The coarser sediments were inhabited by the polychaetes *Ophelia borealis, Exogone hebes, Spiophanes bombyx and Polycirrus* sp. It is interesting that different indicator species can be shown by the same data set if additional samples are added. This tends to lend strength to Stephen's proposition that with more intensive sampling sub-communities may be revealed. This sub-area of SEA 5 extends through the 'offshore zone' described by Stephen (1933) as having low numbers of lamellibranchs but with a wide distribution of *Dentalium entalis* and locally common, to the deeper '*Thyasira* - Foraminifera zone' where *Thyasira* spp accounted for most of the population. The indicator species found by Eleftheriou and Basford (1989) were, in the main, polychaetes which were overlooked by Stephen as they were too small to be retained on the 1.5mm square mesh which he used.

Basford et al. (1996) also reported on a 5-station transect across the North Atlantic inflow. The stations were sampled in the spring and autumn between 1980-1984 in an attempt to relate any changes that might have occurred in the infauna to changes in the hydrography. The authors found no obvious signals or long-term trends, noting that a longer timescale study, and ideally a grid of stations downstream of the inflow, would be more likely to show whether any changes had occurred.

6.2.2.4 The Meiofauna

No meiofauna studies have been conducted in the offshore area covered by SEA5, although there are some areas on the periphery that have been surveyed (McIntyre, 1964; Faubel et al. 1983).

6.2.3 South of 57◦30'N

6.2.3.1 Introduction

Many authors (Glémarec, 1973; Adams 1987) have used the 100m contour which crosses the North Sea at the approximate latitude of Peterhead, to define a major ecological division of the North Sea. This arbitrary sub-division of SEA 5, south of the effects of the Fair Isle current, is hydrographically more stable than the northern area. Few benthic surveys traverse this area; however those that do, seem to indicate that there is also a benthic community change at this latitude (Kunitzer et al.1992). The infaunal species diversity in the central North Sea was similar to the northern area (each having 48 species), and higher than the southern North Sea with 33 species. However the higher biomass in the central and southern areas (Kunitzer et al. 1992) was probably due to the higher production in the shallower water.

6.2.3.2 The Epifauna

The maps produced by Dyer et al. (1982) reveal considerable variability between trawl catches and photography. For instance, the starfish, *Asterias rubens* was trawled at 17 stations but seen by the camera only at two stations with a maximum density of 3 per 100 m^2. Similarly the urchin *Echinus acutus* was trawled at 18 stations but was photographed only once. The echinoids; *Echinus acutus* , *Asterias rubens*, the cnidarian *Alcyonium digitatum* and the polyzoan *Flustra foliacea* were commonly trawled within this sub-division of SEA 5. *Alcyonium digitatum* and *Flustra foliacea* also occurred at four of the photographic stations The anthozoan *Bolocera tuediae,* recorded at five stations from the west of this sub-division, was added to these species from the supplementary photographic surveys of 1981-1982 (Cranmer et al. 1984).

Three stations described by Dyer et al. (1983) fall within this subdivision of SEA 5, grouping them with other stations extending from the Moray Firth across the North Sea south of the 100m contour.

The data indicated a small increase in both diversity and faunal abundance as the stations extend offshore. The most common organisms at the deepest station (80 – 100m) were *Alcyonium digitatum* and *Flustra foliacea*. The hermit crab, *Suberites domuncula* and the cnidarian, *Actinostola callossa* were the most common organisms in the nearest inshore station (60 –80m).

Basford et al. (1989, 1990) surveyed the epifauna from 28 locations within the SEA 5 area. The numbers of species trawled was generally low: the northern half of the area had fewer than 10 species per trawl and the southern half had 10 –20. Densities of less than 200 individuals per trawl were recorded throughout the area. TWINSPAN analysis grouped the majority of the stations together based on the presence of Porifera, Tunicates, *Spirontocaris lilljeborgi* and the hermit crab *Pagurus bernhardus*.

Environmental data were collected simultaneously at these stations in order to establish relationships between the faunal assemblages and the sedimentary characteristics. Although the authors noted that depth was the major determinand of community structure, their data tended to confirm the view taken by Dyer et al. (1983) that the epibenthic communities are governed by a range of associated factors including particle size, sorting, and organic carbon.

The studies of Jennings et al. (1999) on the epifauna of the whole of the North Sea. included four stations within this sub-division of SEA 5. They showed a mean diversity of 25 species per trawl. The authors divide the epifauna into two categories: free-living and attached. Like Dyer et al (1983) they could not directly test the complex relationship governing the faunal distributions. However, by analysing the free-living epibenthic species separately they were able to identify groups within the North Sea as a whole which conformed well with the major subdivisions suggested by previous authors, e.g., the étages suggested by Glémarec (1973).

The stations within this sub-division of SEA 5 were represented by two faunal communities by Jennings et al. (1999), one group being characterised by *Flustra foliacea, Hydrallmania falcata, Lafoea dumosa, Subarites fictus, Ciona intestinalis* and *Alcyonidium diaphanum*; and the other by *Hydractinia echinata, Subarites fictus, Flustra foliacea, Alcyonidium diaphanum, Alyconium digitatum* and *Epizoanthus papillosus*. A single free-living group was characterised by *Asterias rubens, Crangon allmanni, Pagurus bernhardus, Hyas coarctatus, Astropecten irregularis* and *Anapagurus laevis.*

The work of Frauenheim et al. (1989), investigating seasonal variation found that the stations within SEA 5 fell into the same grouping on both of the occasions when they were sampled, suggesting that any seasonal changes affecting the wider North Sea do not appear to affect the epibenthos within the area.

6.2.3.3 The Infauna

Stephen (1922) reported on a group of inshore samples from around Aberdeen (20 – 40 m depth) and a transect of eight stations extending offshore in a northwesterly direction to the 100m contour. The above stations, along with another fifteen dispersed widely throughout this sub-division of SEA 5, were considered to be from a community characterised by the presence of *Ophiura affinis* and *Echinocyamus pusillus*. Stephen concluded that there was large-scale geographic similarity in the offshore fauna and that it was less abundant than the inshore fauna. However he suggested that a more intensive survey might indicate that subdivisions of the general *Ophiura – Echinocyamus* community could be revealed.

He also noted a sub-community off the north-east coast of Aberdeenshire where large numbers of broken *Sabellaria* tubes, probably originating from the masses growing near Rattray Head, formed a community characterised by the molluscs *Astarte compressa, Cardium fasciatum, Venus ovata* and *Leda (*now *Nuculana) minuta,* and the polychaetes *Glycera lapidum* and *Ophelia limacina*.

Further south, in the shallower sandy sediments off the Forfarshire and Kincardineshire coast and St Andrews Bay, Stephen (1922, 1933) found that a variety of the *Echinocardium cordatum – Tellina fabula* community existed where *Nucula nucleus* occurred locally in very large numbers, with *Tellina fabula* and *Venus gallina* being less common. This sub-community was more diverse (particularly with polychaetes) than the *Amphiura filiformis/ A. chiajii* community found further offshore.

In his follow-up paper describing the distribution of the molluscs Stephen (1933) identified four zones. He noted the dominance of *Nucula nitida* between St Andrews and Aberdeen, while further north, *T. fabula* was more dominant. He found that the offshore fauna was less diverse, more uniform and the dominant species were often associated with specific depth zones. He concluded that the faunas of the southern North Sea and of the Scottish coastal strip might be expected to be similar, and to differ from those of the deeper North Sea. His data supported this, as do the data of many of the later researchers.

At a later date, McIntyre (1958) described the benthos of the east coast fishing grounds with reference to surveys of St Andrews and Aberdeen Bays. He found the fauna to be dominated by lamellibranchs and polychaetes with *Abra alba, Tellina fabula, Nucula turgida* and *Ensis* sp. At both locations, in addition to these lamellibranchs, the polychaetes *Lanice conchilega, Sigalion mathildae, Notomastus latericeus* and *Nephtys* spp were dominant. Aberdeen Bay had a quantitatively richer fauna than St Andrews. The poorer offshore fauna was dominated by *Abra alba* at St Andrews and by *Nucula turgida* in Aberdeen Bay.

The work by Eleftheriou and Basford (1989) in the northern North Sea was followed by the large-scale ICES survey of the North Sea in 1986 (Kunitzer et al. 1992) that added to the work of Eleftheriou and Basford in the northern area. This extensive survey sampled a grid of stations 15 miles apart throughout the central and southern North Sea. 30 stations were taken within this sub-division of SEA 5 and their data were subjected to computer analysis to identify community groupings and to present a list of species which best represented the faunal assemblages. The presence / absence analysis revealed two main groups of stations: an inshore group (<50m) to the north-east and an offshore group (>50m) (Kunitzer et al. 1992). The analysis indicated that the groups were separated mainly by particle size, the finer sediment being in the offshore group. When faunal densities were included in the analysis a similar division occurred. The north eastern group was characterised by the presence of the polychaetes *Minuspio cirrifera, Aricidea catherinae, Exogone hebes, E. verugera, Spiophanes bombyx, Polycirrus* sp. *and Ophelia borealis* and the bivalve *Thyasira* sp. The offshore group had a large faunal diversity, with the data analysis failing to indicate that any species was particularly characteristic (Kunitzer et al. 1992). Heip et al. (1992) reviewed the same data, and once again the authors noted over the North Sea in general an increased diversity and reduction of biomass to the north, with a more localised increase in biomass in the finer sediment stations in the southern North Sea.

Until the late 1970s Edinburgh and its surrounding areas employed a series of relatively short sea outfalls to dispose of its sewage to tidal waters (Moore & Davies, 1987). A new treatment facility at Seafield, inside the Firth of Forth, disposed of liquid effluent via a long sea outfall with wet solids being transported offshore to two disposal sites (named Bell Rock and St Abb's Head) which were used on a rotational basis. These sites were used continuously from 1978 to 1998. A monitoring programme with annual sampling was conducted initially by the Marine Laboratory, Aberdeen and then by subcontractors (IOE, then FRPB which became SEPA) to the licensee for the disposal operation, yielding a significant data series for analysis.

The macrofaunal communities at both sites showed many of the characteristics of the Boreo-Mediterranean *Amphiura* community of Thorson with the polychaete-dominated, low abundance/high diversity structure typical of many natural benthic communities free from pollution impact. The dominant species found during the pre-dumping phase of the monitoring maintained their status throughout most of the years of the survey operation, although slight changes in dominance patterns were observed over time. Amongst the dominants at Bell Rock were the polychaetes *Galathowenia oculata* (originally reported as Myriochele), *Spiophanes bombyx*, *Pholoe inornata* (originally *minuta*) and *Lumbrineris* sp., and the bivalves *Nucula tenuis*. *Mysella bidentata* and *Abra* sp. Only occasionally were opportunistic species encountered, usually the secondary opportunist *Chaetozone setosa*, with even fewer records of *Capitella* sp. St Abb's Head also had populations of *Spiophanes bombyx* and *Galathowenia* but additionally *Diplocirrus glaucus*, *Prionospio malmgreni* (now *P. fallax*), *Levensenia gracilis* (formerly *Paradoneis*) and *Owenia fusiformis* were amongst the dominants. *Thyasira flexuosa* and *Mysella bidentata* represented the bivalves and echinoids and amphipod crustaceans such as *Harpinia* sp. were also recorded.

Reference to the post-cessation monitoring report (SEPA, 2001), completed following termination of the sewage sludge disposal operation in 1998, confirms the general conclusions made by Moore and Davies (1987) that operations at Bell Rock and St Abb's Head did not cause significant changes in the benthic fauna of these areas over *circa* twenty years of controlled disposal.

6.2.3.4 The Meiofauna

There are very few reviews of the meiofaunal communities in the North Sea, none of which fall within the SEA5 area. Huys et al. (1990, 1992) and Heip et al. (1990) reviewed the available North Sea information, indicating the lack of knowledge, there being no large-scale meiobenthic surveys of the central or northern North Sea.

7 ANTHROPOGENIC ACTIVITIES AND IMPACTS

The major users of the sea are the fishing industry and the oil industry, one of which is considered traditional (although the use of modern technology in fish finding and gear design might suggest otherwise) and one of which is seen as transient. However, there are other smaller user groups whose activities cause anthropogenic impacts on the SEA 5 area which, as well as open sea areas, includes the entire east coast of Shetland, Orkney and mainland Scotland. This encompasses areas of virtually no development in the extreme north, through rural and agricultural areas on the Moray and Grampian coasts, to the most heavily industrialised coastline, around Tayside and in the Firth of Forth.

Harvesting of seaweeds for alginate production and of the edible periwinkle *Littorina littorea* on rocky shores in the Orkneys and baitdigging in sedimentary areas of the Moray coast (Loch Fleet, Cromarty and Beauly Firths, Ythan estuary) has been considered as virtually artisanal, and most is now controlled by strict conservation and coast protection legislation eg Nature Conservation Orders (NCOs) prohibit the commercial collecting of invertebrates from areas such as Loch Fleet, Dornoch Firth and Nigg and Udale Bays (Robson, 1996).

Coastal discharges can range from minor domestic effluents to significant long sea outfalls. Small-scale industrial effluents and a considerable number of untreated domestic point source discharges, may result in eutrophication and/or accumulation of organic matter which is responsible for the establishment of a gradient of effects on the biology of the shores with distance away from the effluent. In general there may be a reduction in species diversity near to effluent sources where, in extreme cases, the environment can initially be azoic, leading to a zone of opportunistic polychaetes (such as *Capitella capitata* and some spionids) and nematode worms. This zone is then replaced by a more diverse macrofauna away from the point source discharge following the Pearson and Rosenberg's model (1978). In recent years discharge consents, issued by SEPA through its industrial inspectorate, have reduced industrial and sewage discharges to the marine environment to a very marked extent with the result that the east coast of Scotland now has some of the cleanest beaches around the UK.

Greater interest in conservation matters and increase in leisure time has, ironically, meant that sandy beaches, popular for recreation, suffer from trampling and the destruction of the backshore which can lead to the progressive degradation of the beaches. However, the greatest impacts result from shore constructions such as jetties and wave-breakers which may destabilise the sedimentary shore and cause long-term and potentially irreversible changes in the shore line. Furthermore, on the open coast, sea defences can also affect the stability of the soft sediment beaches and their animal communities (Eleftheriou 2003).

Most coastal developments, no matter of what size, tend to influence only a very localised area around them and even allowing for longshore transport their impacts should be considered as small. The activity that is most likely to cause the greatest impact on sedimentary shores is land reclamation which takes areas out of the natural ecosystem completely and may disturb the dynamic equilibrium of the coastline forces causing substantial erosion.

Radioactive substances in the form of artificial nuclides are occasionally discharged accidentally from the nuclear reprocessing plant at Dounreay on the north coast and these give rise to levels detectable well into the North Sea.

The east coast of Scotland is well supplied with harbours, the characteristics of many of which are such that they require occasional dredging to maintain navigable depths. These dredge spoils are generally disposed of to local sites licensed under the Food and Environment Protection Act (FEPA). Around the Moray Firth there are 19 licensed dredge disposal sites, six of which were used in 2002/3 to dispose of approximately 24000 tonnes of spoil. In the same period 6 sites were used on the east coast of Scotland to deal with 630000 tonnes of spoil; in the River Tay 3 sites accommodated 380000 tonnes and in the Firth of Forth 6 sites were used to dispose of 670000 tonnes of dredged material.

Although there are as many as 28 coastal quarrying sites on the Scottish east coast, there is only a single extraction licence at present in force for recovery of aggregate from below mean sea level. The site in the Middle Bank region of the Firth of Forth has not yet been dredged but plans are in place for a campaign in the late spring of 2004. Licences have occasionally been issued in the past for the extraction of maerl from areas in the Orkneys but these have been on an assessment basis and none is presently in effect.

The Shetlands, and to a lesser extent the Orkneys, support a large aquaculture industry, producing high quality salmon and some shellfish. This industry benefits greatly from the clean waters of the north east Atlantic which bathe the coasts of the islands but the species farmed are vulnerable to environmental contamination, especially by hydrocarbons as was shown in the case of the “Braer” oil spill, (although the effects were short term). High hydrocarbon levels, which lasted for some time, were also found in wild fish and inshore and offshore sediments.

There are relatively few aquaculture endeavours on the east coast of mainland Scotland, mainly situated in the inner firths (Dornoch, Cromarty and Inverness) of the Moray Firth and concentrating on mussels (*Mytilus edulis*) and Pacific oysters, but also with two farms growing salmon.

Aquaculture activities themselves are recognised as having environmental impacts both on the existing natural environment and on natural wild populations. Large inputs of organic matter, therapeutants and other effluents are responsible for changes in the benthic communities and environmental conditions particularly in areas with reduced water movement. Communities typical of organic enrichment follow the Pearson and Rosenberg model and are dominated by *Capitella capitata* and nematodes in certain extreme cases.

“The impacts of fishing on the environment include physical damage to the seabed, destruction of non-target organisms, and, when overfishing occurs, alterations to the balance of the ecosystem by extraction of the large numbers of commercial species” (Royal Society of Edinburgh, 2004). Fishing is very important to the economic wellbeing of many of the coastal communities of the Orkneys and Shetland Islands and also around the Moray Firth Coast. Peterhead and Aberdeen are the most important white fish landing ports on the east coast of the UK. Fishing intensity varies dependent on the target group. Demersal fishing shows the most intensive effort in the far north of the SEA 5 area, reducing in intensity into the Moray Firth and in the more inshore areas off the Tay and Firth of Forth (Coull et al 1998). Offshore of this area shows a moderate intensity. Pelagic effort (for herring, mackerel, sprats) is generally of below average intensity over the whole SEA 5 and is lowest in the Moray Firth, with no effort in the area off the Tay and Forth. The Moray Firth shows a moderate intensity of effort in fishing for Norway Lobster (*Nephrops norvegicus)* and shrimps (unspecified in the report) with a high effort off the Tay and Forth, but a low effort to the north of the SEA5 area. The coastal strip along the east coasts of Orkney, Shetland, the northern part of the Moray Firth and from south of Aberdeen to the southern limit of the area is considered as high in terms of the effort expended in the use of static gears (prawn and lobster pots). This effort appears to be increasing due to the effects of over-fishing offshore and the concomitant cutbacks in the fishing fleet. The status of the fishing industry has recently been the subject of reports by the Royal Society of Edinburgh (2004) and the Prime Ministers Strategy unit (2004). Both recommend that some form of Strategic Environmental Assessment or Environmental Impact Assessment be conducted for fishing activities off the UK coast.

The offshore oil and gas industry is a major economic activity in the North Sea, and has had a considerable impact on the life cycle, physiology and behaviour of benthic species and the ecology of the area. For instance, the compound gas terminal at St. Fergus on the North-east coast of Scotland was a substantial development which initially radically changed the ecological character of the sedimentary coastline. Practical steps were taken to improve the quality of the restoration of the coast following each pipelaying episode, resulting in achieving compatibility with adjacent areas of natural dune and beach (Ritchie & Kingham, 1997). Around production installations, and to a lesser extent around drilling locations, a variety of contaminants is found in the sediments and these can impact the communities living there. Aliphatic hydrocarbons, Polycyclic Aromatic Hydrocarbons (PAH) and metals such as vanadium (derived from crude oil) and barium (from drilling muds), are found in sediments in the vicinity of drilling activity. In effect the animal communities can be subjected to smothering (through the discharge of water based muds), organic enrichment (through the discharge of oil based or organic phase fluids muds (OPF)) and potential toxicity from the contaminants derived from the drilling operations. Numerous reports have been produced by the oil industry on environmental conditions around their installations and which have been amalgamated into a database of the fauna and environmental parameters (Kingston & Harries 1999). This work demonstrated that significant effects could be detected in localised areas of activity with elevated levels of metals and hydrocarbons being detectable within varying sizes of footprint round any installation, the size of the footprint being dependent on local hydrographic conditions and the drilling history of the installation. The benthic community structure followed the classic Pearson & Rosenberg organic enrichment model, the effects of which were sufficient to mask any specific toxicity effects on the fauna. In disturbed sediments contaminated by drill cuttings, a restricted fauna of opportunistic species such as the polychaetes *Capitella capitata* and *Chaetozone setosa* and spionids, was numerically dominant with secondary opportunists such as *Paramphinome jeffreysi*i occupying areas beyond the initial impact. Large densities of the bivalve *Thyasira sarsi* which are considered as an opportunistic species are usually found in oily drill cuttings piles present beneath many older North Sea oil production platforms. Some species of the Thyasirids are known to harbour chemosynthetic autotrophic bacteria in their ctenidia (Dando and Southward, 1986, Oliver & Killeen, 2002) which allows them to occupy this apparently unwholesome niche. In some locations (NW Hutton Field) a species of mussel, *Idas* sp., has also occupied this niche (Hartley et al, submitted). Hartley Anderson (2000) notes that the beneficial effects of the presence of these species can be shown through bioturbation which promote the aerobic and anaerobic degradation of organic contaminants. The database carries only seven locations within the SEA5 area and only the Beatrice field information contains biological data, the others being restricted to sediment chemistry measurements.

The effects on the benthic community are considered to be reversible, at least in part. Legislation controlling the use and discharge of oil-based drilling fluids has reduced the inputs of oil from this source virtually to zero, and it would be expected that the accepted area of impact around most installations will gradually reduce over time. However there are relatively few studies that are suitable to describe this recovery effectively (see section 8). The discharge of non-oil OPFs, also termed synthetic drilling fluids, are likewise banned from discharge unless they are present at less than 1% by weight, in keeping with OSPAR Decision 92/2.

Oil and chemical spills from offshore exploration platforms and accidental releases from tankers may result in oil slicks with potentially severe consequences for plankton, fish eggs and sea birds, as well as for the seafloor biota, as shown from data gathered from shipwrecks in the northern islands. However there has been a significant reduction in the amount of oil spilled over the past few years although the number of reported incidents has actually increased (DTI, 2003). Estimates of oil inputs from other sources have not been subject to regular reporting within OSPAR, although the 1993 Quality Status Review estimated a total oil input of 85,000-209,000 tonnes per year to the North Sea, including oil-based drilling fluids, riverine sources, shipping and natural seepage (NSTF 1993).

Tarballs, small coagulated lumps of oil residue washed ashore onto beaches and rocks, are a common nuisance in some parts of the country, and have unfortunately been found on Shetland and Orkney in recent years. The Atlantic Frontier Environmental Network (AFEN) commissioned the Institute of Offshore Engineering to analyse tarball samples collected by islanders and various organisations, e.g. RSPB, and match the chemical structure to known oils or blends of oils ('fingerprinting'). Significantly, of samples collected during 1996 and 1997, the largest majority (88%) originated from fuel oil discharges, probably from bilge waters of marine traffic.

Recently introduced regulation of chemical use offshore has the objective of reducing both the amounts of chemicals discharged to the marine environment and the general level of toxicity of those being used. The scheme has only been in operations for a short period and returns from the industry to the Environmental Emissions Monitoring System (EEMS) have not yet been fully analysed. Prior to the introduction of the regulations, returns to the EEMS were made on a voluntary basis and therefore may not be comprehensive. Bearing this in mind, since 2000 there has been a decrease in the amount of chemicals discharged to the sea by offshore oil and gas exploration and production activities. The total tonnage discharged in 2003 was approximately 4% less than the total for the year 2000. The fine detail of discharges in 2003 are not yet available but of the total tonnage of chemicals discharged in 2002 around 85% were considered to pose little or no risk (PLONOR) to the marine environment and based on physicochemical properties and toxicity a further 13% are considered to have a low risk (D Sheahan, pers comm). However a few years data will be required before more than general conclusions such as these can be drawn.

Oil and gas installations and their connecting pipelines on the seafloor provide a hard substratum for a variety of fauna and flora to colonise and provide shelter for numerous fish. However, some disturbance of the seafloor and the biota are accompanied at the positioning of such structures and during operations.

In the SEA 5 area three introduced species have been reported (Eno et al, 1997). In Shetland and along the east coast of Scotland the green alga *Codium fragile* subsp *atlanticum* (Irvine et al, 1975; Norton 1985; South & Tittley, 1986) where it displaces the native species *Codium tormentosum* from which it can only be distinguished microscopically. In northern areas including Shetland the barnacle *Elimnius modesta* competes with the native *Semibalanus balanoides* and other species of barnacles resulting in the displacement of these species, some of which become extremely rare (Hiscock et al, 1978; Howson et al, 1994). The spionid polychaete *Marenzellaria viridis* is found in the intertidal mudflats of the Firth of Forth (McLusky et al, 1993) and in Invergowrie Bay in the Tay Estuary (Atkins et al, 1987) where it has been outcompeting the native species such as *Nereis (Hediste) diversicolor* and the amphipod *Corophium volutator* whose abundances were noticeably affected by the presence of *M viridis.*

The Ythan estuary exhibits problems associated with eutrophication. Increases in nitrogen levels in the River Ythan from the 1950s to the 1990s (Balls et al, 1995) was associated with the expansion of algal mats (composed of species of *Enteromorpha, Ulva and Chaetomorpha)* (Raffaelli et al, 1989), blanketing the mud flats and causing declines in the populations of the amphipod *Corophium* sp and reducing the numbers of the larger individuals of the bivalve *Macoma balthica*. However the mats appeared to have little or no effect on the abundances of the snail *Hydrobia ulvae*. These problems were considered sufficiently severe for the estuary to be declared a Nitrate Vulnerable Zone in 1994.

Contamination of the marine environment by a wide range of chemicals can affect the life cycle and survival of marine organisms. Tributyl tin (TBT) widely used as an antifouling paint and of known toxicity accumulates in a wide range of marine organisms from squids to dolphins and causes deformities in oysters and sex changes in marine snails such as the dog-whelk (*Nucella lapillus*) and the periwinkle (*Littorina littorea*). This latter phenomenon, termed imposex, can be used as a quantitive sensor of TBT contamination of the sea (Bailey & Davies, 1988). The long term consequence of this is interference with the physiology of the organisms leading to a decline in the population and eventual decrease in marine biodiversity.

There are records going back to the 1960a of harmful algal blooms (HAB) caused by the dinoflagellate *Alexandrium tamarense* in the Shetland Isles, in Orkney and along the north east coast of mainland Scotland. Paralytic shellfish poisoning (PSP) has been known to occur on the Scottish south-east coast for several centuries. The major outbreak of PSP in 1968 extended from Humber to Forth and hospitalised 85 people who had eaten infected mussels (Tett & Edwards, 2002). Routine monitoring of the levels of toxins in shellfish has resulted in occasional closure of shellfish harvesting. Although there have been suggestions that some forms of eutrophication (usually directed at effects from fish farming operations) can be a factor in the apparent increase in HAB occurrence. Tett & Edwards (2002) concluded that neither the increase in HABs nor the link to fish-farming was supported by the available direct evidence, but they did say the data were incomplete. It is unlikely that offshore operations could have any influence on HABs.

In conclusion it is clear that the many and various anthropogenic activities do make impacts on the environment of the SEA 5 area, with the most noticeable effects being on the coastline. However, these effects are on the whole localised and in most cases reversible, even in the areas of intensive development. This means that a considerable extent of the SEA 5 sector area could be considered to be in a good state of ecological balance but further work is needed in order to identify the very many and poorly known ecosystems, their structure and function.

8 INFORMATION GAPS

The coastal and inshore areas of Shetland and Orkney have been extensively surveyed over a period of several decades. The accumulated information on the biology and ecology of the faunal and plant communities has been compiled and is available in MCNR reports and publications. There are nevertheless still some problems of species identification which remain an important stumbling block in the investigations. These could be alleviated by verification of the existing taxonomy and the production of identification guides for these and new species. Descriptions of the biota and information on the biodiversity of the benthic communities over a large expanse of the littoral and the shallow sublittoral provide an extremely well-documented database which could be invaluable in our assessment of any habitat loss and biodiversity changes in the area.

However, the East Scottish coast, outside the main estuaries (which have been adequately surveyed) has received very little attention. Early naturalistic studies, both sparse and limited in scope, were followed only recently by more comprehensive studies through individual and specific investigations, or the more extensive and coordinated studies presented in the JNCC Reports. Delay has resulted in considerable gaps in our knowledge of the ecology and dynamics of the fauna and flora, as well as of the wider benthic environment of the area.

The offshore areas in SEA5 have been studied to different degrees of intensity and completion, with the majority of the investigations forming part of site-specific studies in support of licence applications or in connection with exploration activities. While studies of the macrobenthic assemblages have concentrated on the infauna and epifauna, information concerning the smaller metazoan and larger protozoan organisms, the meiobenthos of the soft sediments structured and grouped within roughly the same areas as the infaunal and epifaunal assemblages, is totally lacking. It should be noted that the meiofaunal organisms such as harpacticoid copepods and nematodes have already been recognised as sensors of environmental health and used as indicators of early environmental perturbations (Raffaelli, 1987; Boyd et al, 1998). Furthermore they are excellent sensors of climatic changes and respond rapidly to pollution conditions. This lack of information constitutes a definite and major gap in our knowledge, which should be taken into account when exploratory surveys of the geographical distribution of the communities in relation to the environmental parameters are designed and undertaken.

Considering the offshore area in SEA 5 it should be stressed that although there is a considerable amount of information available nevertheless there are also glaring gaps in our knowledge. Most of the better investigated areas lie in the oil exploration blocks of the North Sea or the oil prospecting areas. However the great majority of the offshore expanse is sparsely covered in a network of stations with 15nm resolution (Eleftheriou & Basford, 1989; Kunitzer et al, 1992). It could be said that coverage provides inadequate information as to the benthic organisms and their environment. From this it could be concluded that for any prospecting in such areas it is imperative that comprehensive surveys should be conducted which encompass the whole range of physical and chemical parameters of the ocean floor and the water column in relation to the faunal composition, structure and dynamics of the benthic organisms.

Studies in the biodiversity of the benthos of the SEA 5 area should include not only the number of species but also the remaining and important biotic indices of abundance and biomass which need to be examined in relation to the environmental parameters and the productivity of the area. The links in the food web can provide invaluable information on the structure and functioning of the marine ecosystem.

Similarly, as the fauna is likely to vary both annually and seasonally, we would suggest that sampling should be conducted in the same season each year. Variations or differences observed between surveys are to a large extent due to the unsystematic and uncoordinated design of such investigations. Synchronisation of surveys and the adoption of a harmonised strategy would maximise the compatibility of the resulting data. Adoption of or participation in an approved quality assurance scheme (such as the National Marine Biology Analytical Quality Control scheme (NMBAQC) would also go some way to standardise discrepancies resulting from the process of identification of the various taxa obtained.

In a similar vein, there is growing acceptance that global climate change is a reality. This could potentially have significant effects on those animals of the benthic fauna that are living at or near the geographic limit of their temperature range. It has already been suggested that climate change is responsible, in part, for the reduction in cod stocks in the North Sea (Royal Society of Edinburgh, 2004). Such changes could be reflected in benthic assemblages as species deletion or diversity modification. It is unlikely that the normal level of sampling associated with offshore surveys would be amenable to analysis in respect of climate change. However in order to ensure that any changes detected are not mistakenly attributed to offshore industry activities, it would be recommended that good time series benthic survey data should be collected to defend the industry's position. At present there are significant gaps in the available data.

It should also be added that the majority of the data presented in the report has its roots in the 1970s and 1980s with a consequent time lapse in respect of hard information. There is therefore an urgent need for more coordinated and temporally based studies to be carried out in the future.

It is clear that the mixed sediments and the hard substrata observed in inshore areas and the shelf require a new methodological approach, as traditional equipment is no longer adequate to provide for representative examination of the fauna. Still photography and ROV video are now providing invaluable information concerning the composition, distribution and abundance of the larger fauna on the shelf (BP, 2002; ChevronTexaco & Hartley Anderson, 2003). Suggestions to improve remote collection of specimens by ROV manipulator to ascertain identification of materials is an important addition to the combination of techniques and methods which should be employed in order to have a representative, detailed and useful account of the benthic assemblages and the environment of the shelf area.

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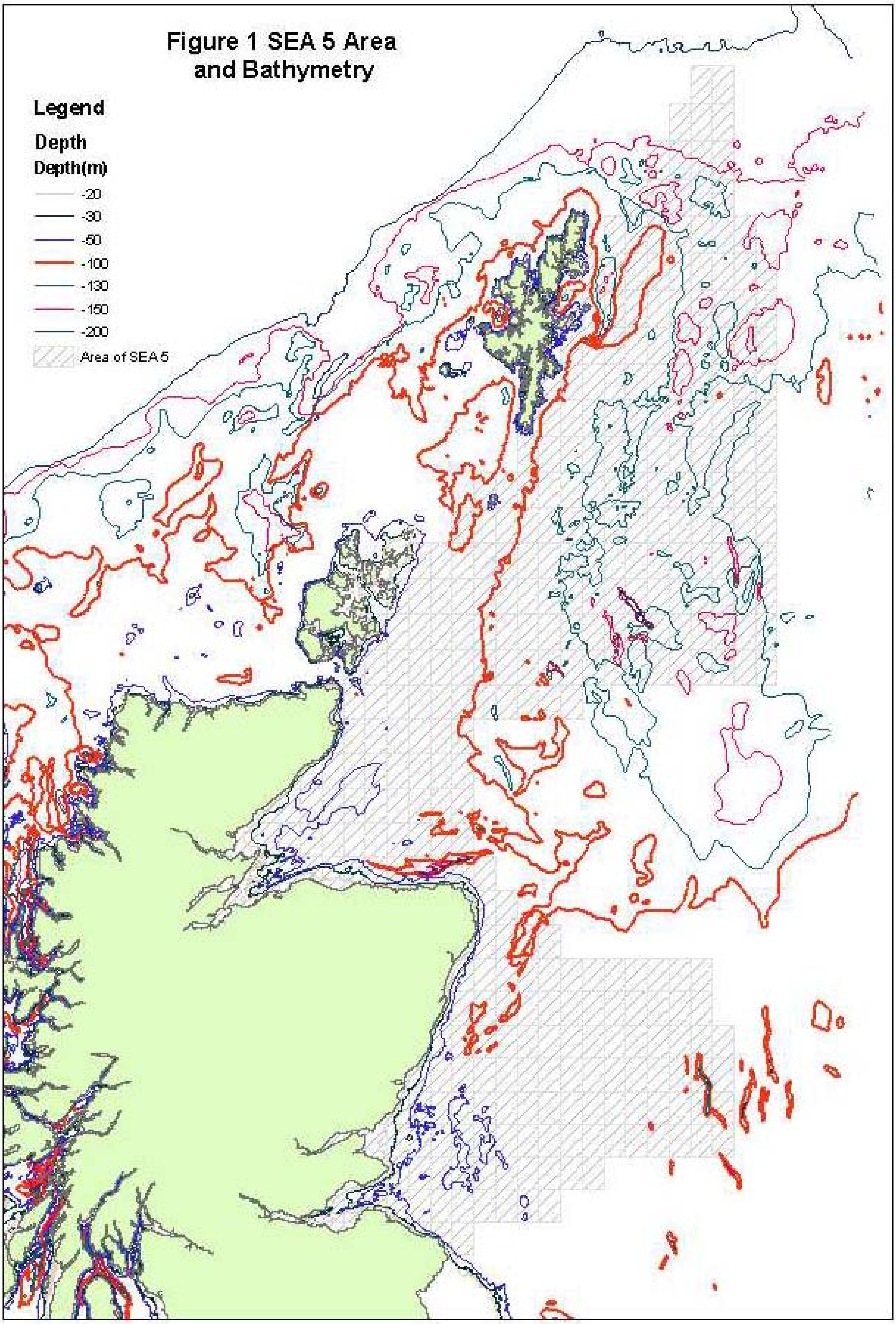


Figure 1 SEA 5 Area
and Bathymetry
Legend
Depth
Depth(m)
-20
-30
-50
-100
-130
-150
-200
Area of SEA 5

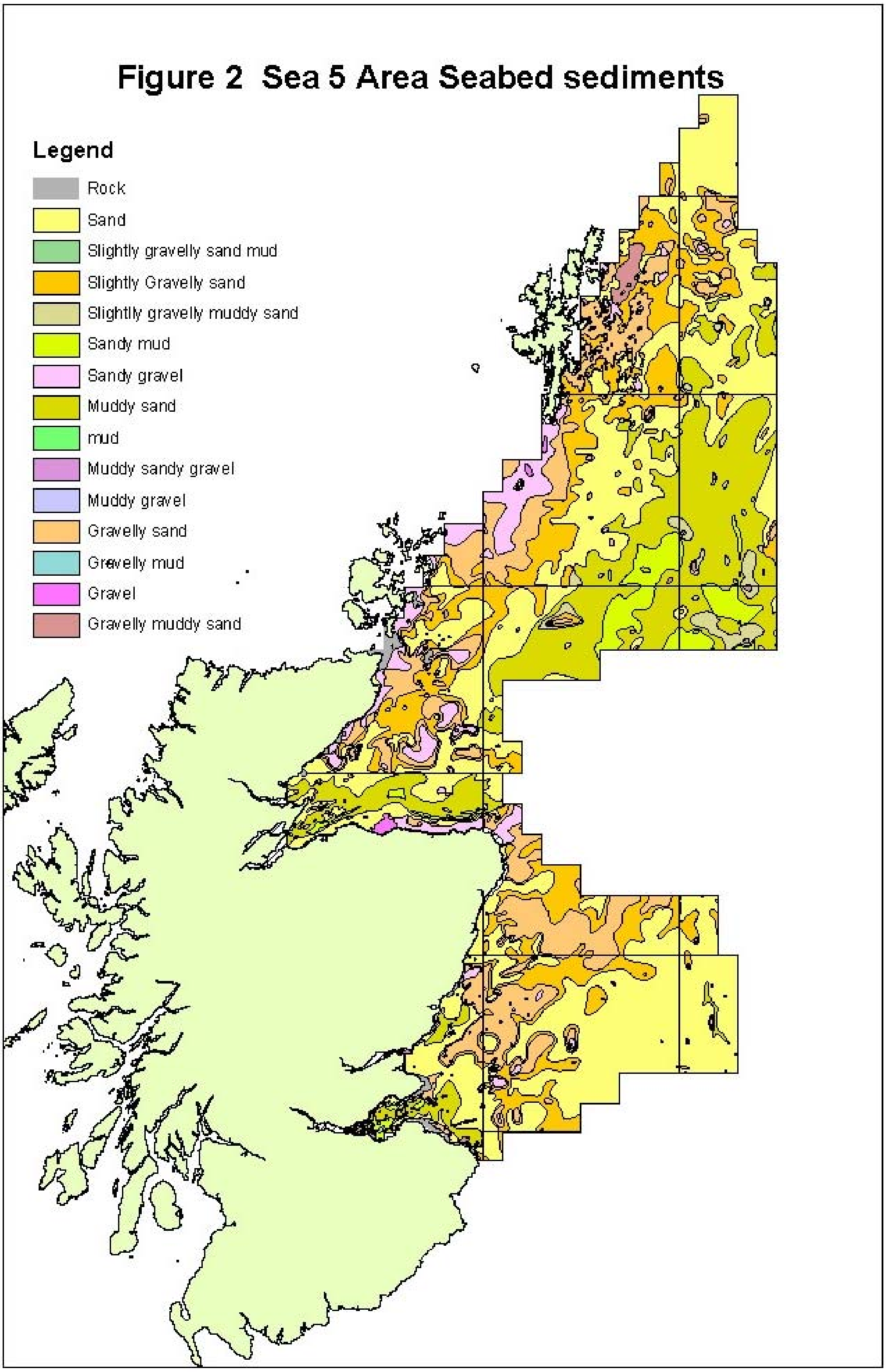
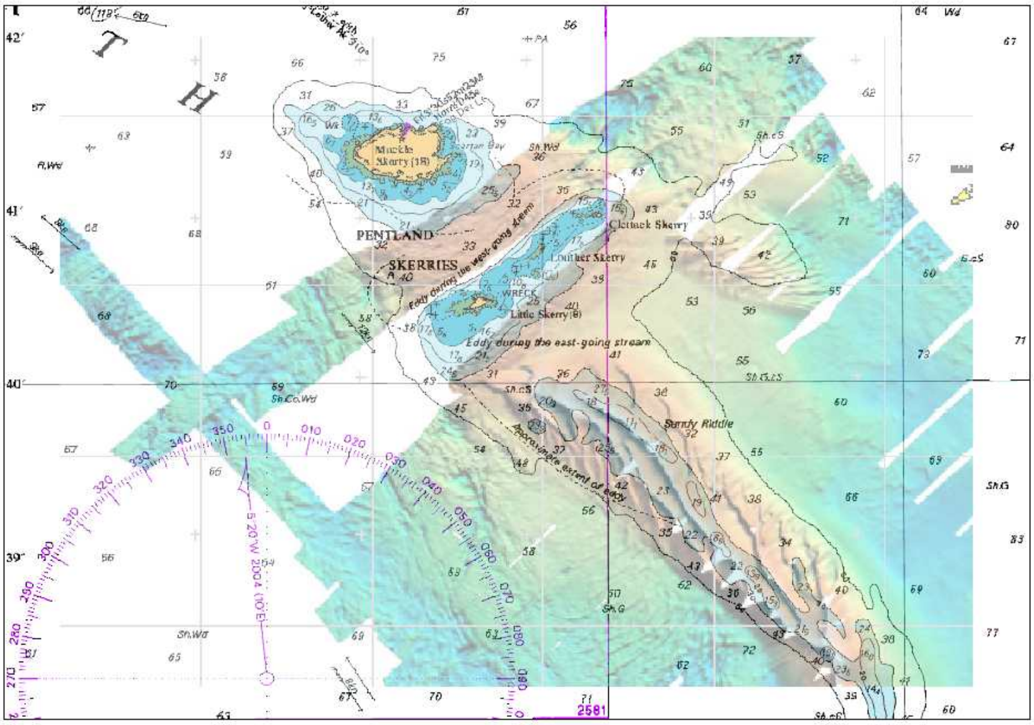


Figure 2 Sea 5 Area Seabed sediments
Legend
Rock
Sand
Slightly gravelly sand mud
Slightly Gravelly sand
Slightlly gravelly muddy sand
Sandy mud
Sandy gravel
Muddy sand
mud
Muddy sandy gravel
Muddy gravel
Gravelly sand
Grevelly mud
Gravel
Gravelly muddy sand


Muckle Skerry (18)
PENTLAND
SKERRIES
Clettack Skerry
Louther Skerry
Little Skerry (8)
WRECK
Eddy during the west-going stream
Eddy during the east-going stream
Sandy Riddle
Approximate extent of eddy
2581

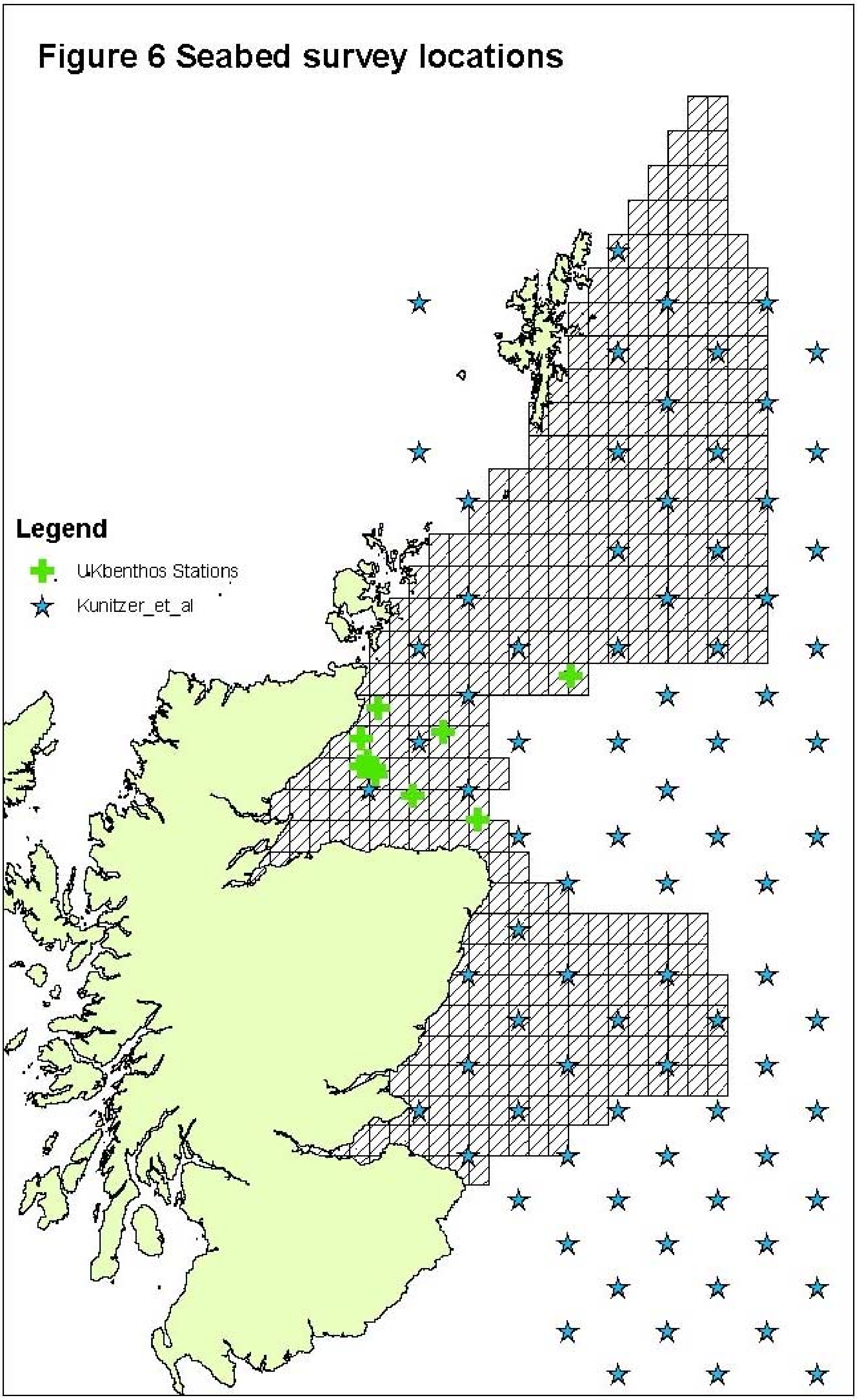


Figure 6 Seabed survey locations
Legend
UKbenthos Stations
Kunitzer_et_al

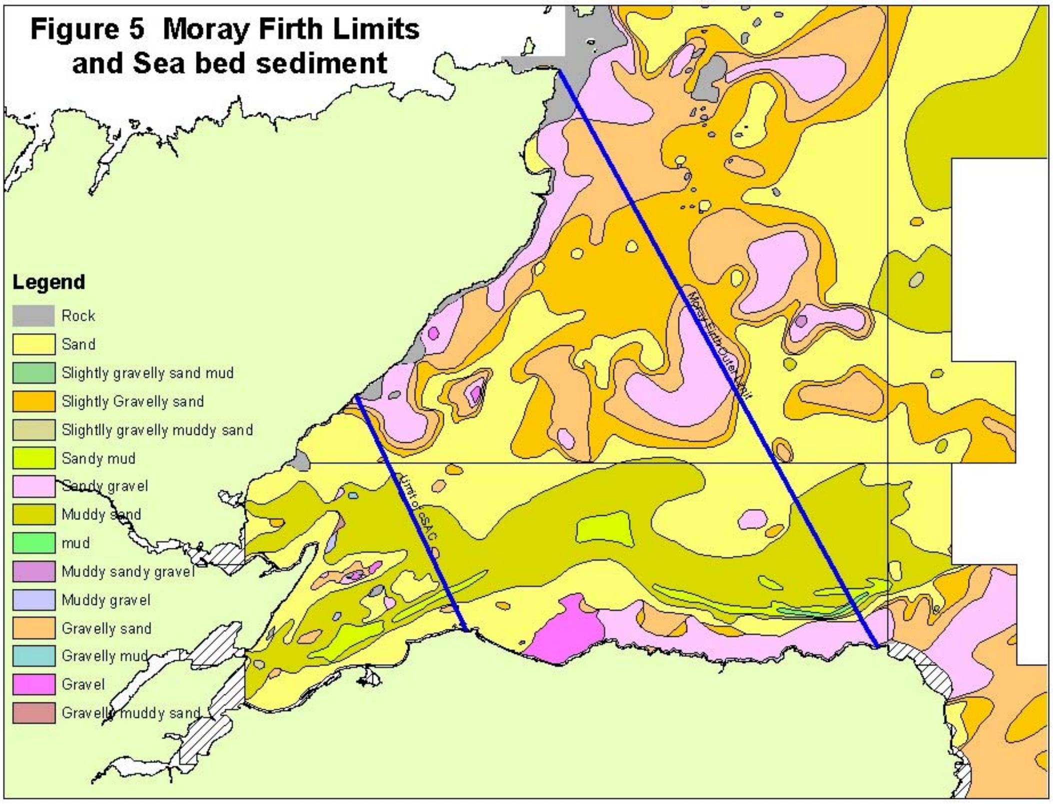


Figure 5 Moray Firth Limits and Sea bed sediment

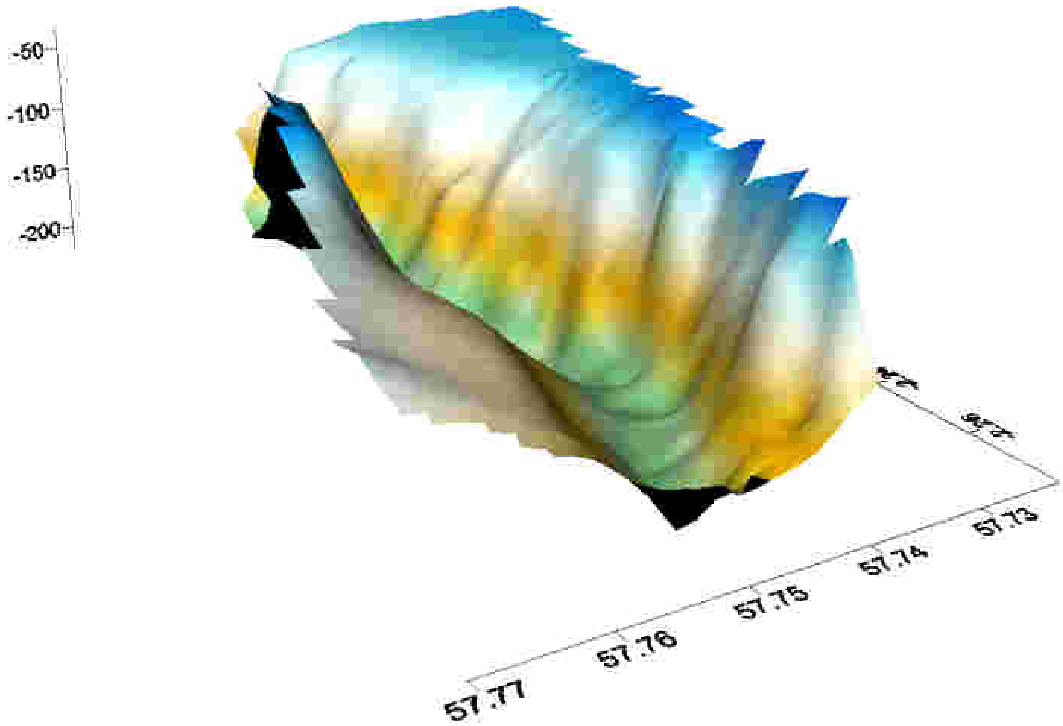


Figure 6a Bathymetry of the Southern Trench, Moray Firth, viewed from north west

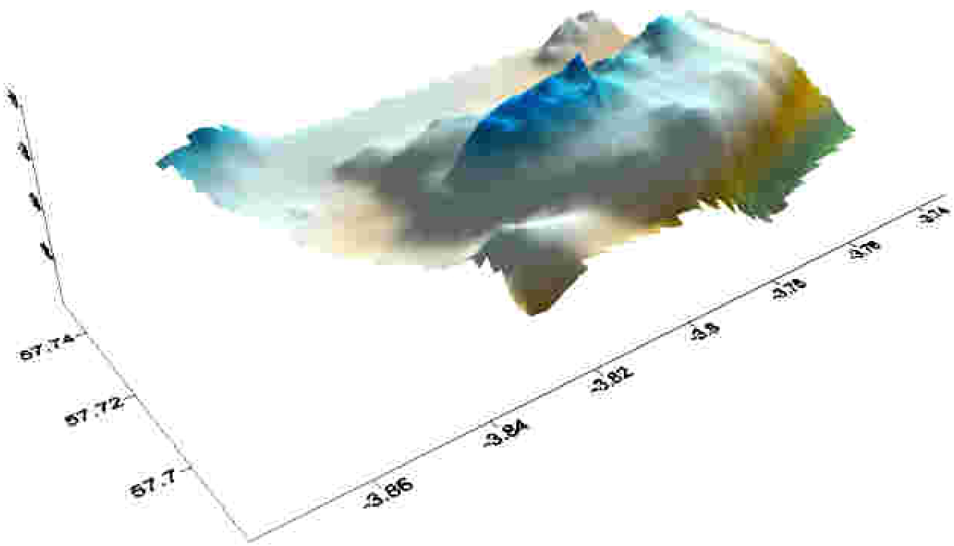


Figure 6b Bathymetry of the Guillam Bank, Moray Firth, viewed from south west

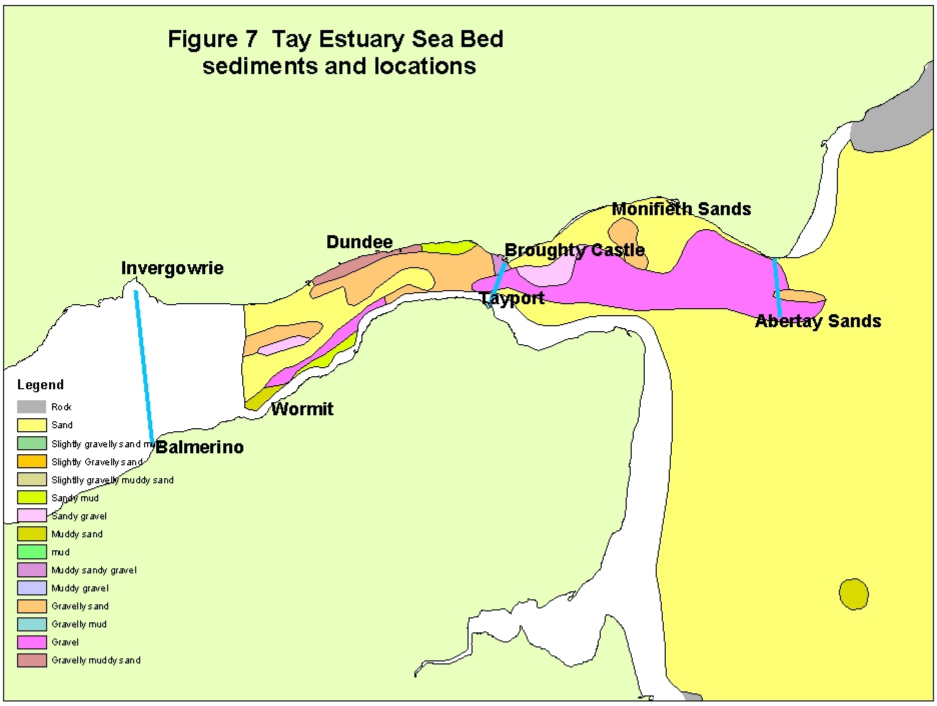


Figure 7 Tay Estuary Sea Bed sediments and locations
Monifieth Sands
Dundee
Broughty Castle
Invergowrie
Tayport
Abertay Sands
Wormit
Balmerino
Legend
Rock
Sand
Slightly gravelly sand mud
Slightly Gravelly sand
Slightlly gravelly muddy sand
Sandy mud
Sandy gravel
Muddy sand
mud
Muddy sandy gravel
Muddy gravel
Gravelly sand
Gravelly mud
Gravel
Gravelly muddy sand

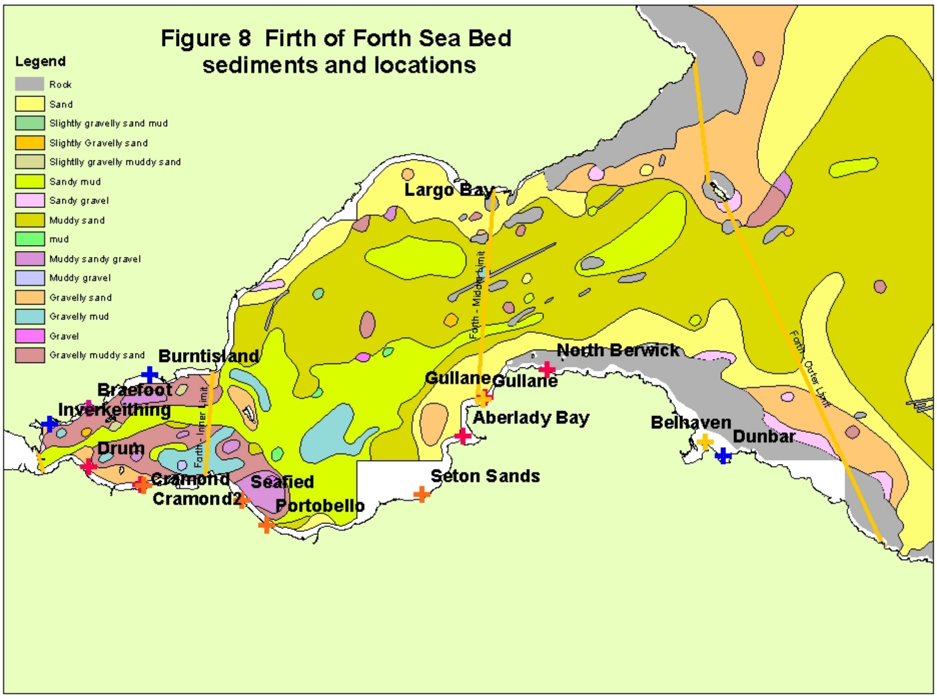


Figure 8 Firth of Forth Sea Bed sediments and locations
Legend
Rock
Sand
Slightly gravelly sand mud
Slightly Gravelly sand
Slightlly gravelly muddy sand
Sandy mud
Sandy gravel
Muddy sand
mud
Muddy sandy gravel
Muddy gravel
Gravelly sand
Gravelly mud
Gravel
Gravelly muddy sand
Largo Bay
Burntisland
Braefoot
Inverkeithing
Drum
Cramond
Cramond2
Seafied
Portobello
Gullane
Gullane
North Berwick
Aberlady Bay
Belhaven
Dunbar
Seton Sands