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Report for the Department of Trade and Industry

Synthesis of Information on the Benthos of SEA 6 Clyde Sea Area

Final Report
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1. INTRODUCTION AND SCOPE

In 1999, the Department of Trade and Industry (DTI) initiated the process of Strategic Environmental Assessments (SEA) for the UK prior to the issue of licenses allowing oil and gas exploration and exploitation.

The Strategic Environmental Assessment process involves extensive consultation with the public and stakeholders. This document forms part of the consultative process covering the Clyde Sea which is part of SEA area 6 (SEA6). The Clyde Sea includes the Great Plateau, the Arran Basin, the waters around Bute and Cumbrae, the major sea lochs of Fyne, Long and Striven and part of the Clyde estuary.

This review aims to provide a synthesis of current information pertaining to benthic communities and seabed habitats in the Clyde Sea. This is presented in the context of the hydrography and sedimentology of the area. The focus is on dominant species and broad descriptions of community types (biotopes). It also reviews existing major human activities in the SEA6 area that are currently affecting the benthos.

2. HISTORICAL OVERVIEW

The Clyde Sea catchment has been used by man since prehistoric times as it offers a terrain suitable for cultivation and hunting in close proximity to the firth which was exploited for food (fish and shellfish) and as a means of communication and transport by boat.

The Clyde Sea area remained relatively undeveloped until the industrial revolution when steam powered craft, utilising locally sourced coal, started to use the Clyde. The development of heavy industry and the concomitant increase in population that occurred over the period 1800 – 1950 resulted, through waste disposal in local watercourses, in a severe decline in the fauna of the Clyde environment. In particular, the Clyde estuary became so polluted and anoxic that it gave rise to acrid fogs adversely affecting the health of the local populace (Boyd, 1986).

The development of communications initiated during the industrial revolution opened up the Clyde Sea area to tourism for the first time. The area became popular with Victorian holiday makers and naturalists alike, both making use of the regular ferry services to Bute, Arran and Cumbrae – islands that became the focus of much of the early benthic sampling work (Boyd, 1986). The Firth of Clyde was also the site of a rich fishery (Tivy, 1986) and became an important sea-route for transatlantic crossings that made use of the extensive ship-building infrastructure and associated facilities.

Focused marine research in the Clyde began in 1885 following the relocation, by the 'Scottish Marine Station', of their floating laboratory vessel, 'The Ark' and steam powered research yacht 'Medusa' in Millport Bay under the leadership of John Murray (Chumley, 1918). During the period 1884 – 1892 John Murray recorded aspects of the geology and hydrography of the Clyde Sea together with faunal distributions. The results from this extensive period of research were collated into 'The Fauna of the Clyde Sea Area' (Chumley, 1918) which remains one of the most significant records of benthic fauna of this area. The report also contains a substantial bibliography of work relating to the Clyde fauna dating from 1812.

More recently, the current state of knowledge for the Clyde was reviewed by the NERC Clyde Study Group (Natural Environment Research Council and Clyde Study Group, 1974).

Today, the role of heavy industry and fisheries in the Clyde economy has declined (Tivy, 1986) and, as a consequence of this and the introduction of legislation such as the EU's Waste Water Directive, water quality is generally improving and the benthos recovering.

3. AN OVERVIEW OF THE PHYSICAL ENVIRONMENT

3.1 Hydrography

Clyde Sea hydrography has been a subject of interest for some time and has been extensively studied. An excellent synopsis of the Clyde Sea hydrography is given by Edwards (1986) and forms the basis of much of this section.

The Clyde Sea is separated from the Northern Channel by the Great Plateau, a broad sill of approximately 50 m in depth. The waters of the Northern Channel are fully saline and tidally mixed contrasting with the quieter and less saline Outer Firth. A front develops between the two bodies of water, the position of which depends on the balance between mixing and buoyant supply. Mixing of water across the front gives a residence time for water of approximately two months in the Outer Firth.

Tidal currents in the Clyde Sea are predominantly weak and are modulated by wind-driven surface currents. These set up deeper compensation flows; however, the deep water of the Arran Basin and Kilbrannan Sound still has a tendency to stagnate, particularly below seasonally induced thermoclines. The bottom waters of the fjordic sea lochs are also isolated in summer and renewed during winter when density currents flow over the sills. This flow produces a characteristic grading of sediments from coarse to fine away from the sill. In any given sea loch the depth of the sill is a major factor in determining local hydrography – above the sill there is free connection with the surrounding water mass and movement of water is dominated by pressure gradients set up by tide, wind and freshwater outflows. Below the sill dense water settles, flows are interrupted and increasingly dominated by oscillatory internal movements, weak diffusion and downward density flows (Edwards et al., 1986). The stagnation of the deep water in the sea lochs is manifest in reduced oxygen concentrations, the build-up of nutrients and changes in sediment chemistry releasing, for example, radium and causing the dissolution of manganese (Edwards et al., 1986). The reduced water exchange in the deep benthic environment of the Clyde Sea area makes it particularly vulnerable to anthropogenic impacts.

3.2 Bathymetry

The Clyde sea is a fjordic system consisting of drowned glacially over-deepened valleys separated by sills. The southern limit of the Clyde Sea area, and the ultimate sill for the Clyde Sea lochs, is formed by an unusually broad sill termed the Great Plateau (or Barrier Plateau in earlier work). The Great Plateau is predominantly <50 m deep and overlooked by the volcanic plug of Ailsa Craig. To the north of the Great Plateau lies the Arran Basin.

The Arran Basin exhibits complex bathymetry consisting of both deep channels and relatively shallow shelving areas. The deep channels pass either side of Arran (Kilbrannan Sound to the west and the Arran Channel to the east) merging to the north, at about 150 m depth to form Inchmarnock Water which continues to the sill at Otter in Loch Fyne (**Error! Reference source not found.**). Moving eastwards in the Arran Channel (Eastern branch) the water depth declines gradually towards the Ayrshire coast (**Error! Reference source not found.**).

North of the Arran Basin the Clyde Sea breaks into a series of north-south orientated sea lochs that are frequently separated into over-deepened basins by one or more sills (Edwards and Sharples, 1986). Summary statistics for the sea lochs of the Clyde area are given in **Table 1**.

Table 1 – Bathymetric summary of the sea lochs in the Clyde Sea (from Edwards & Sharples, 1986)

Name	Max depth (m)	Mean depth (m)	Volume ($x10^6$ m^3)	Number of sills
Fyne	185.0	55.5	9746.7	2
Long	97.0	23.9	805.0	2
Striven	69.0	40.6	499.5	0
Holy	31.0	17.5	59.6	0
Goil	86.0	37.3	305.8	1
Gareloch	64.0	29.8	411.0	0
Riddon	44.0	16.1	25.8	0

3.3 Sedimentology

The subtidal environment of the Clyde Sea is predominantly sedimentary in nature, Moore (1931) describing it as consisting of predominantly fine grained layered muds. The large expanses of muds in the deeper water extend around Arran into the deep basins of the upper lochs. Towards the shallower loch sides, and the Kintyre side of Kilbrannan Sound, the muddy sediments tend to gradate to muddy gravels. Relatively large expanses of sand are also found, particularly along the Aryshire coast and around Bute (Pearson et al., 1986).

The sediments in Upper Loch Fyne and Loch Striven contain relatively high proportions of organic carbon (5 – 7%) while those sediments east of Arran, including the deeper muddy sediments, contain < 1% organic carbon (Pearson et al., 1986). Areas with a high organic carbon content are associated with a high carbon/nitrogen ratio; the sediments to the west of Bute being particularly carbon- rich with a C:N ratio of >30:1 probably occurring as a consequence of the historical dumping of sewage sludge in the locality. It should be noted that the measurements made of parameters such as organic carbon and carbon/nitrogen ratios, made by Pearson et al. (1986), may have changed since the introduction of stricter controls on dumping at sea.

4. BIOGEOGRAPHIC DIVISIONS

For the purposes of this report the Clyde Sea is divided into a number of sections based on major geographical features.

The southern limit of the Clyde Sea, which separates it from the North Channel, is defined as a line drawn between Sanda Island, Kintyre and Mueller Point, Ayrshire (Chumley, 1918). The Great Plateau extends from this southern limit to a line drawn between Campbeltown Loch, Kintyre and Turnberry Point, Ayrshire which separates it from the southern limit of the Arran Basin. The northern limit of the Arran basin, a line joining Skipness on the Kintyre Peninsula, to Garroch

Head (Bute) to Farland Point (Ayrshire), adjoins Loch Fyne, the waters around Bute and the Cumbraes. For the purposes of this report the waters around the Cumbraes, extending upto Loch Long and the main sea lochs (Lochs Fyne, Long, Striven Riddon, Holy Loch and Loch Ryan) are also considered separately.

5. THE OUTER CLYDE SEA

The outer Firth consists of the Great Plateau (including the bordering Ayrshire and Kintyre coastlines), the remote island of Ailsa Craig, the Arran Basin and the Kilbrannan sound.

The bathymetry of the Barrier Plateau is quite different (Figure 2) from the more northern areas – shallower and more level with the exception of deeper channels around Ailsa Craig and Sanda Island (Deegan et al., 1973). The Arran basin contains two channels which run either side of the island of Arran, joining at a depth of approximately 150 m to form Inchmarnock Water (Edwards et al., 1986).

5.1.1 The Ayrshire Coast

The Ayrshire coast offers a quite distinct environment compared with the rest of the Clyde Sea as the relatively exposed coastline is predominantly shallow-shelved and sandy.

5.1.2 The Ayrshire coast: Littoral and Sublittoral

The coastline on the East side of the Barrier Plateau from Turnberry Point to Girvan comprises of raised beach, cliff and 'soft' shore (mud, sand or shingle) (British Geological Survey, 1997b). Significant sand dunes are present at Turnberry Bay, which is a Site of Special Scientific Interest (SSSI) (Dargie, 1997). McIntyre (1970) found populations of the bivalve *Angulus tenuis* on the sandy beach at Turnberry.

From Girvan to Ballantrae there are small areas of sand dunes (Dargie, 1997) raised beaches and cliffs (British Geological Survey, 1997a) and at Ballantrae there is a small estuarine lagoon which is about 3 ha in size and comprises less than 0.1% of the total area of British lagoons (Barnes and Bamber, 1997)

Subtidally, this area is dominated by muds and muddy-sands (Deegan et al., 1973) with increasing proportions of sand being found nearer to shore (British Geological Survey, 1997b). While there are few data relating to the benthos some research has been conducted into the historical herring stock that used to use the Ballantrae Banks as a spring spawning ground but which is now predominately autumn spawning (Bailey, 1986). This area also has a fishery for the Norway lobster (*Nephrops norvegicus*).

Eleftheriou and McIntyre (1976) (cited in Connor and Little, 1998) studied the intertidal fauna of sandy beaches in the Clyde from Barassie (near Ayr) to Port Logan (Galloway peninsula). The shores fell into their 'moderately exposed' to 'sheltered' categories. Moderately exposed beaches were characterised by crustaceans and polychaetes and the bivalve *Angulus tenuis* on the lower shores whilst the sheltered beaches were dominated by bivalves in terms of biomass although polychaetes remained the most numerically abundant macrofaunal group. The beaches along the Ayrshire coast offer an important habitat to tidally migrating flatfish, such as plaice, that exploit the intertidal zone for food during high water (Poxton, 1976).

Much of the benthic research in the region has been conducted as a consequence of the polluted status of much of the Ayrshire coast. Most of this research is from the 1960s – 1980s when pollution was probably more severe than it is now following the introduction of the EU Waste Water Directive. However, it should be noted that, until at least 1998, the beaches from Ardrossan to Ayr generally failed mandatory cleanliness tests under European Directives. Of the Ayrshire beaches Irvine Bay is probably the most studied.

Irvine Bay lies between Ardrossan and Troon and, facing south-west, is relatively exposed, particularly in the northern section. Eleftheriou et al. (1986) give an account of the macro- and meiofauna from this beach, using samples collected in 1972. The shallow subtidal environment consists of fine sands with variable amounts of shell fragments, organic carbon and silt, the latter two increasing with depth (Eleftheriou et al., 1986). Of the macrofaunal species found in Irvine Bay; 34 were polychaetes, 31 crustaceans and 18 molluscs. Of these the polychaete *Chaetozone setosa* and *Spio filicornis* was particularly abundant. The heart urchin *Echinocardium cordatum* and the bivalves *Tellina spp*. and *Venus striatula* were also common while crustacea were relatively scarce (Eleftheriou et al., 1986). Of the meiofauna in Irvine Bay, which was considered organically enriched, nematodes were overwhelmingly numerically dominant (ca. 95%) followed by copepods (3.5%) (Eleftheriou et al., 1986) (see also Jayasree, 1976). The spatial and temporal variability of populations of gastrotrichs (a meiofaunal phylum) has been extensively investigated at Irvine Bay (Hummon, 1976; Hummon and Hummon, 1977) in relation to nutrient recycling.

5.2 The Kintyre peninsula

5.2.1 Campbeltown Loch to Caskey Bay including Sanda Island: Littoral and Sublittoral Zone

Historically little has been recorded from this area (Dipper and Beaver, 1999). Campbeltown Loch consists of an area of littoral sand and stones in the region to the west of Davaar Island whist the shores around the loch are mostly made up of raised beaches with cliffs on the southern and eastern coasts of Davaar Island. The loch falls within the East Kintyre area which is designated as

Regional Scenic Coast (Dipper and Beaver, 1999). In broad terms the coastline south of Darvaar Island consists of a series of cliffs separated by mudstone beaches which have been described as being very diverse and rich (Deegan et al., 1973).

Sanda Island was designated a Site of Special Scientific Interest in 1995 (SNH.org.uk, 2005) on the basis of the large number of guillemots and razorbills that nest there.

The seabed sediments in the deeper water consist of muddy sand, sandy mud and sand. Near coast seabed sediments from Campbeltown Loch to Sanda Island are sandy gravel (British Geological Survey, 1997b) while sand dunes are present at the southern tip of the Mull of Kintyre (Dargie, 1997).

The subtidal environment of Campbeltown Loch consists of mainly felsite, sandstone and quartz gravel (Deegan et al., 1973). This site was sampled in 1974 by Pearson et al. (1986) who found that the polychaete genera *Mediomastus* and *Scalibregma* and the bivalve *Abra alba* were present in large numbers. Deegan (1973) described a large bed of *Limaria hians* (gaping file shell) off the south east Kintyre coast

Off the coast of Sanda Island the seabed is a medium gravelly sand and further south of Sanda there is a higher proportion of sand. Off Sanda Island there is an isolated deep channel whose presence cannot presently be explained (Deegan et al., 1973). Again, there is very little in the literature on the fauna around the island with just a few historical records of the results of dredge sampling (Hyndman, 1842).

5.3 Ailsa Craig: Littoral and sublittoral

This island lies 15 km WNW of Girvan and is the plug of an extinct volcano formed of microgranite rich in riebeckite (British Geological Survey, 1997b). The island is surrounded by cliffs which make ideal seabird nesting sites and is a Special Protection Area (SPA), an RSPB reserve and an SSSI on this basis (RSPB.ORG.UK, 2005)

Although most of the Barrier Plateau lies in <50 m depth of water there is an interesting deep channel near Ailsa Craig that goes to over 70 m (Deegan et al., 1973). The benthos in this area has been poorly described with only few records in summaries such as the Fauna of The Clyde Sea Area series.

5.4 Arran and the Kilbrannan Sound

The sea area surrounding Arran, known as the Arran Basin, forms the southernmost basin in the Firth of Clyde (Figure 3) and lies between the east side of the Kintyre Peninsula and the Ayrshire coast. For the purposes of this report the southern limit of the Arran basin is defined as a line drawn between Campbeltown Loch, Kintyre and Turnberry Bay, Ayrshire with a northern boundary defined by a line joining Skipness on the Kintyre Peninsula, to Garroch Head, Bute to Farland Point, Ayrshire. It includes the island of Arran, which lies towards the west side of the basin and which is separated from the Kintyre Peninsula by the Kilbrannan Sound.

The Arran basin is separated from the North Channel by a broad sill named the Barrier Plateau. A deep channel runs around both sides of the island of Arran, reaching a maximum depth of approximately 160 m, and extending up Loch Fyne to the spit at Otter. The water depth decreases steadily from the channel towards the east and the Ayrshire Coast. Considering the Arran Basin and the Great Plateau combined, most of the water is relatively deep with only 14.4% of the area being less than 20 m deep and over 40% being >50 m (Table 2).

Table 2 – Bathymetry of the Arran Basin and Barrier Plateau combined.

Range (m)	Area km^2	%	Volume km^3	%
0 -10	162	5.6	28	19.3
11 -20	252	8.8	26	17.9
21 – 50	1274	44.2	62	42.6
51 -100	1049	36.4	26	17.6
101 -150	127	4.4	4	2.4
>151	18	0.6	<1	0.1
Total	2881		146	

Arran, the largest of the islands in the Firth of Clyde, is about 30 km long and 18 km wide. Much of the Arran coastline is sheltered to some degree, particularly to the west by Kintyre and to the north by the Clyde hinterland. East and particularly south facing coasts are more exposed. The coastline is varied ranging from mud through sand, cobbles, boulders and bedrock (Smith, 1984). The island is sparsely populated with the population concentrated around Lamlash and Brodick from where a ferry service connects the island to Adrossan on the Ayrshire coast. The Ayrshire coast is predominantly sandy and is relatively highly populated compared with Arran and the west Kintyre coast. The major towns along the coast include (from north to south) Ardrossan, Saltcoats, Troon, Prestwick and Ayr.

The Arran basin and coastline has been a popular site for naturalists, particularly during the Victorian era, as a consequence of its proximity to Glasgow and regular boat services. There are several accounts of the fauna and flora of coastal communities and accounts of dredging surveys dating back to the nineteenth century (e.g. Hughes, 1878; Knight, 1894). However, more recently, very little research work has been done in the vicinity of Arran with the only in-depth survey having been conducted on the molluscan fauna by Smith (1984).

5.4.1 Arran and the Kilbrannan Sound: Littoral Zone

The Arran and Kilbrannan sound area hosts a variety of shore types with the Ayrshire coast being predominantly sedimentary consisting of a series of shallow, sandy bays, while Arran is more varied (Smith, 1984).

The rocky shores of the southern coast of Arran are considered by Connor & Little (1998) to be among the richest in terms of habitat diversity in the Clyde Sea. However, this contrasts with the findings of the Paisley College of Technology (1979) who considered the southwest coast of Arran and the sandy shores of the more exposed Ayrshire coast and the Kintyre Peninsula, as being relatively species-poor. According to the Paisley College of Technology (1979) the majority of the beaches in the Clyde Sea area are dominated by the bivalves *Angulus tenuis, Cerastoderma edule,* amphipods such as *Bathyporeia spp* and polychaetes such as *Scoloplos armiger, Pygospio elegans, Arenicola marina, Phyllodoce maculata, Spio filicornis, Eteone flava, Nephtys hombergii* and *N. cirrosa*.

Perhaps the most detailed survey within the area was that conducted by Smith (1984) on the molluscan fauna of Arran. During that survey 18 beaches from around the island, but particularly Lamlash Bay and Holy Island, were surveyed. A physical description of each location, with comments on both molluscan fauna and other groups is provided by Smith (1984) and is summarised in Table 3.

Table 3 – Summary of the sites around Arran surveyed by Smith (1984)

Site	Description
Brodick	This open bay is mostly sandy and a major tourist beach. The southern end is rocky and sparsely covered with algae
Carlo Point	This small promontory with a relatively gently sloping shore consists of sandstone slabs, boulders and large shallow rock pools. Algal cover is extensive and molluscs numerous
Lochranza	Lying at the north end of Arran, this shallow, sheltered inlet is composed of steep cobble shore grading to gravel at low water. A brackish zone, containing *Cerastoderma edule* and *Ascophyllum nodosum*, is located in close proximity to the River Ranza. Away from the river's influence, the community is classified as *Dosinia-Venerupis*. Northeast of the river the beaches are rocky and host moderate covers of *Fucus serratus* and *Laminaria digitata.*
Whitefarland Point	This low, gravelly point shelters a small bay lying on its north side. The bay has a sandy floor and hosts a *Tellina* community
Imachar	Typical of rocky/bouldery shores of the west coast of Arran, this shore is moderately sheltered, short and steep and sparsely covered with algae which include *F. serratus*.
Machrie-waterfood	The shore is dominated by the egress of water from Machrie Water, one of Arran's largest rivers, that flows out over cobbles and gravels. Few molluscs were recorded other than *Littorina spp* and *Mytilus edulis*
Drumadoon Point/ Blackwater-foot	Guarding Drumadoon Bay, this point is rocky and dissected by gullies and deep pools notable for stands of the brown alga *Halidrys siliquosa* but few molluscs. *Fucus serratus* was also recorded. Blackwaterfoot lies in the middle of the bay and consists of a few rocky outcrops and platforms containing rock pools but with a paucity of molluscs
Cleiteadh More	This relatively exposed shore, typical for the south end of Arran, consists of limey sandstone reefs and sand and boulders on gravel. The shore is relatively mollusc-rich and worthy of further investigation
Kildonan	The shore here is semi-exposed and consists largely of limey sandstone ledges and large pools, some of which shelter a rich fauna and flora including polychaetes and molluscs. A bed of *Zostera marina* was also recorded.

Lamlash	Located on the southeast coast of Arran, Lamlash is about 5 km across and protected to the east by Holy Island. The southern part of the bay is steep and rocky, while the central parts consist of a mix of boulders and sands hosting abundant *Tellina*. Further north are extensive boulder beaches complete with dead molluscan shells, possibly from an offshore *Ensis – Dosina – Venerupis* community.
Holy Island	Holy Island is predominantly rocky. The north- and west-facing coasts are predominantly sheltered and host mixtures of *Laminaria saccharina* on boulders, fucoids and sparse mixed *Cerastoderma – Tellina – Venerupis* communities in sand and gravel. The polychaete *Chaetopterus variopedatus,* the nudibranch *Crimora papillata* and abundant ascidians were found on the north facing site surveyed. The south- and east-facing shores are more exposed, the beaches generally short and steep, hosting algae such as *Alaria esculenta, Himanthalia elongata*, *Fucus serratus* and *Laminaria digitata*.

Smith (1984) concluded that, of the 300 mollusc species found in the Clyde area, only 170 were to be found around Arran and that Lamlash Bay and Holy Island offer the highest habitat diversity for molluscs.

5.4.2 Arran and the Kilbrannan Sound: Sublittoral Zone

The Arran Basin and Kilbrannan sound encompass habitats ranging from deep-water muds typical of the central parts of the Arran basin to mobile shallow sandy substrata typified by the shallow coastal fringe along the Ayrshire coast.

The sediment immediately around Arran is predominantly coarse, ranging from gravel to sand (Deegen et al (1973) cited in Pearson et al., 1986). The muddy sediments that make up much of the bulk of the deeper water of the Clyde Sea, extend past the northeastern tip of Arran at a distance of approximately 1 – 2 km (Pearson et al., 1986). Muddy sediments are also found towards the south of Kilbrannan sound. The communities in Kilbrannan Sound were reported to be particularly dense by Pearson et al (1986) with the biomass of benthic infauna exceeding 300 g m^{-2}. This contrasts with the east side of Arran where values were predominantly between 10 – 20 g m^{-2}. These trends in biomass (and abundance) were correlated with depth and organic matter with the highest abundances/ biomasses being found on loch-side, shallower areas.

The sediments around Arran are representative of the Clyde Sea area as a whole according to Pearson et al (1986) consisting of a mixture of *Amphiura* and *Abra* communities (*sensu* Thorson 1957) in deeper waters while the *Venus/Modiolus* communities are common in shallower water.

The deep water muds host the heart urchin *Brissopsis lyrifera*, the brittle star *Amphiura chiajei*, bivalves such as *Nucula sp* and polychaetes including *Glycera sp* (Pearson et al., 1986) and commercially important populations of the burrowing decapod *Nephrops norvegicus* which forms the basis of one of the most important fisheries in the Clyde Sea. Other burrowing crustaceans include the shrimp *Callianassa subterranea.*

In coarser sediments the brittle-stars *Amphiura filiformis* and *Ophiura albida* tend to dominate with the heart urchin *Echinocardium cordatum*. Also present in these sandier sediments are the bivalves *Thyasira spp*, *Abra spp*., *Mysella bidentata* and *Corbula gibba* and the polychaetes *Owenia fusiformis, Scoloplos armiger* and *Prionospio spp*. As the proportion of gravel in the sediments increases, species such as the brittlestars *Ophiothrix fragilis* and *Amphipholis squamata* become increasingly common, together with the bivalves *Hiatella arctica*, *Chlamys opercularis* and *Astarte sulcata* (Pearson et al., 1986).

The bivalves *Abra alba* and *Nucula tenuis* and the polychaete *Chaetozone setosa* were particularly abundant along the length of the Ayrshire coast with numbers exceeding 300 m^{-2} and, in the case of *N. tenuis*, also common to the north-east of Arran. The polychaete *Myriochele heeri* was particularly abundant in Kilbrannan sound (Pearson et al., 1986).

The Arran basin and Kilbrannan Sound have been extensively studied in the past. For example, in his account of the fauna of the Clyde Sea, Chumley (1918) records several hundred species found in the area with occasional brief notes regarding the environment (normally depth and/or bottom type) with a sometimes vague indication of location. This collation of the results of surveys, conducted over the period 1884 – 1892, is too extensive to repeat here but it includes lists of protozoa, sponges, coelenterates, echinoderms, worms, crustaceans, molluscs and fishes. It is, however, limited in that it does not give any account of densities or associations of respective organisms. Chumley’s (1918) list was updated during the period 1960 – 1971 by biologists based at Millport on the Isle of Cumbrae. From this research a series of booklets were produced entitled ‘The Fauna of the Clyde Sea’. In this series polychaetes (Clark, 1960), ascidians (Millar, 1960), molluscs (Allen, 1962), fishes (Bagenal, 1965), Euphausiacea and decapods (Allen, 1967) and Mysidacea (Mauchline, 1971a) were reviewed under separate covers. The booklets are organised by species, rather than location, making them less useful in terms of the current review. However, for any given species an indication of the location where it is normally found is usually given in addition to an indication of substratum type, depth (where appropriate) and other anecdotal observations. The locations from which species data are available, split according to group, are shown in Table 4.

Table 4 – Faunal groups reported in the 'Fauna of the Clyde Sea Area' (see text), split by region and location.

Group and reference	Region	Location
Polychaetes (1960)	Kintyre	Campletown Loch, Davaar Island, Carradale Bay.
	Arran	Loch Ranza, Brodick Bay, Lamlash Bay, Whiting Bay, Dippin, Pladda
	Kintyre	Portencross, Troon, Prestwick, Turnberry Landalfoot.
Ascidians; Millar (1960)	Kintyre	Kilbrannan Sound, Skipness, Inchmarnock Water
	Bute	Garroch Head
	Arran	Loch Ranza, Brodick Bay, Lamlash Bay, Whiting Bay
	Ayr	Ardrossan
Molluscs, Euphausiacea and decapods and Mysidacea; (Allen, 1962; Allen, 1967; Mauchline, 1971b) respectively	Kintyre	Campletown and loch, Davaar Island, Saddell, Pluck Point, Carradale Bay, Skipness, Lamont Shelf
	Arran	Bennan, Machrie Bay, Pirnmill, Catacol Bay, Loch Ranza, Cock of Arran, Sannox Bay, Corrie, Brodick Bay, Brodick, Corriegills Point, Clauchlands Point, Lamlash, Holy Island, Kingscross, Whiting Bay, Pladda
	Kintyre	Horse Isle, Ardrossan, Saltcoats, Ardeer, Irvine, Troon, Ayr, Heads of Ayr, Maidens, Turnberry. Other survey stations are mentioned, in an ad-hoc basis, in the main text.
Fishes; Bagenal (1965)		Survey stations not directly stated, but may be in the original literature reviewed.

5.4.3 The Arran basin and Kilbrannan sound: General comments

There are no records of particularly unusual species or biotopes in the Arran Basin and Kilbrannan sound.

The Community of Arran Seabed Trust (COAST), based around Lamlash Bay on Arran, has recently been established to promote the conservation of Lamlash Bay and protect it from commercial fishing, particularly scallop dredging. As part of the conservation effort numerous surveys have been conducted in the bay, by volunteers and staff from Millport Marine Station. Lamlash Bay hosts, according to the COAST website (http://www.arrancoast.co.uk/), maerl beds worthy of protection from continued dredging damage. COAST is attempting to instigate a no-take-zone in the region in an attempt to revitalise recently dwindling local sport-fishing prospects.

6. INNER FIRTH OF CLYDE, GREAT AND LITTLE CUMBRAE

Referred to in historical records as the Dunoon Basin (and also as the Loch Long Basin), the inner Firth of Clyde stretches from the mouth of Loch Long to the northern end of the island of Cumbrae (Chumley, 1918). The river Clyde enters in the northeast at Gourock, causing some stratification of salinity and temperature of the water column. The Clyde estuary itself consists of large mud flats (Connor, 1991).

A deep narrow muddy trough extends southwards to the Cumbraes and water depths range from 110 m in the deepest part of the trough to less than 10 m at the mouth of the River Clyde. The shores of the Clyde Estuary are highly industrialized and populated, providing a source of significant pollution, and this region has one of the highest measured trace metal loads of any UK estuary (Turner, 1999). An extensive historical record of benthic species occurring in the region to the north of the Cumbraes is given in The Fauna of the Clyde Sea Area (Chumley, 1918) including foraminiferans, sponges, coelenterates, echinoderms, polychaetes, crustaceans, molluscs, tunicates and fish.

The Islands of Great and Little Cumbrae lie at the south end of the inner Firth of Clyde, between Bute and the mainland. To the east of the Cumbraes lies the Largs Channel, reaching depths of 46 m while to the west lies the deeper water of the main channel between Great Cumbrae and Bute (known as the Cumbrae Basin in historical records). Depths reach 112 m in the basin to the west of Little Cumbrae.

The area around the islands of Great and Little Cumbrae has been the subject of intense scientific interest, the former being the location of the University Marine Biological Station at Millport, with studies dating back to the 1850s (Robertson, 1859). Recently, Connor (1991) reviewed information on the Clyde Sea area and included a section on the Cumbraes.

Kames Bay in the south of Great Cumbrae is predominantly sandy in the intertidal and shallow sublittoral, giving way to sandy mud in deeper water (Moore, 1931). Watkins (1942) documented the fauna of the bay with this work being updated by Clarke & Milne (1955). *Nephtys caeca* was found intertidally being replaced by *Neptys hombergii* subtidally. Other common polychaetes found in the sublittoral included *Spio filicornis* in the immediate sublittoral with *Sigalion mathildae, Owenia fusiformis* and maldanids being most dominant in the muddier sediments at around 30 m depth between the two islands. Five amphipod species were also recorded with *Bathyporeia* spp. dominating in the intertidal. *Angulus tenuis* was the dominant bivalve intertidally, being replaced by *A. fibula* in deeper water where *Abra alba* was also common. Several echinoderms including *Echinocardium cordatum* and the brittle stars *Amphiura filiformis* were recorded. The latter was replaced by *A. chiajei* in deeper water (Clark & Milne, 1955). More recently Aronson (1989) studied the dense beds of the brittlestar *Ophicomina nigra* on silty sands off Great Cumbrae and speculated this species exists in such dense aggregations because of low predation pressure.

White Bay in the north of Great Cumbrae has a rocky, fucoid-dominated intertidal with a coarser sublittoral sediment than in Kames Bay and a greater proportion of stones and shells. The fauna recorded was similar to that of Kames Bay, with the notable exception that *Philine aperta*, present in Kames Bay, was completely replaced by *Natica alderi* (Clark & Milne, 1955). The shores at Ballochmartin Bay on the eastern side of the island were described by Flatterly & Walton (1922) (referenced inConnor, 1991). Of interest was the presence of *Phoronis muelleri* and, unusually, an intertidal population of the burrowing anemone *Cerianthus lloydii*.

Gibb (1939) documented the marine algal communities around Great Cumbrae. *Laminaria saccharina* beds occur in abundance in the shallow sublittoral around both Cumbraes, proliferating here in place of *L. hyperborea* because of the sheltered conditions (Howson et al., 1994; Kain, 1962). Of particular note is the occurrence of maerl around the islands in regions of higher current speeds (Hall-Spencer, 1994), with many of the beds being relatively pristine in nature. These maerl beds offer spatially complex habitats and support a rich and diverse associated fauna, often providing essential nursery habitats for several species including the commercially important queen scallop *Aequipecten opercularis* (Kamenos et al., 2004) which is fished locally.

Off the Fairlie sands on the mainland, stronger tidal currents have resulted in sandy and gravelly sediments here and in the Largs Channel (Holt & Davies, 1991). The extensive *Zostera* beds recorded in the 1930s (Moore, 1931) have now disappeared. Kilchattan Bay, at the southern end of Bute, is also sandy, shelving steeply into the main channel between Cumbrae and Bute (Moore, 1931). The fauna of the deep m uds around the Cumbraes was dominated by nematodes, copepods, polychaetes and ostracods, with *Scalibregma inflatum*, *Notomastus latericeus*, *Lumbrineris hibernica*, *Lipobranchius jeffreysii* and *Glycera rouxii* all numerous (Moore, 1931). Burrowing megafauna such as the mudshrimps *Calocaris macandreae*, *Upogebia deltaura* and *Callianassa subterranea* are also known to be abundant in the soft muds in these areas (Nickell, 1992).

Evan et al (1994) documented imposex caused by tributyl tin (TBT) in dogwelks from shores around Cumbrae but reported that abundance of this species increased between 1988 and 1992 whilst frequency of the imposex condition decreased.

7. INNER CLYDE SEA AND LOCH RYAN

The inner Clyde Sea area includes the Kyles of Bute and the sea lochs to the north including Loch Fyne, Loch Long, Loch Striven, Gareloch, Holy Loch and Loch Goil. For convenience this section also includes Loch Ryan.

7.1 Loch Ryan

Loch Ryan, the most southerly of the Scottish sea lochs, faces approximately north-west and is 13.4 km long. It is shallow, rarely exceeding 10 m in depth and predominantly 2 – 5 m deep (Figure 4). The loch is divided into two sections by a shingle and sand spit which extends from The Wig on the west side, south-eastwards towards Leffnoll Point. The loch has an area of 41.6 km^2 during high water and 40.3 km^2 during low water with a tidal range of up to 2.8 m during spring tides (Howson, 1989).

The enclosed, shallow nature of Loch Ryan means that it experiences higher than average seawater temperatures; 21^0 C has been recorded (Howson, 1989). No significant rivers empty into the loch and salinity remains normal throughout the year. Loch Ryan is sheltered from oceanic swell and has limited fetch so wave action is slight (Howson, 1989) while tidal currents are limited, particularly in the southern bay, with the greatest currents being found between The Spit and Cairnryan. Loch Ryan does not host any organisms of particular conservation note with the exception of the native oyster *Ostrea edulis*. Most information in this section is taken from the detailed survey and review of the loch reported in Howson (1989).

7.2 Loch Ryan: Littoral zone

The intertidal zone is predominantly rocky and steep-sided in the outer part of the loch and sedimentary (pebbles to muddy sand) in the inner loch. Howson (1989) describes several intertidal habitat types from Loch Ryan. These include steep, moderately exposed bedrock shores with boulders, located towards the loch entrance, that support a low species diversity dominated down the shore (top to bottom), by the lichen *Xanthoria sp*, periwinkles *Littorina sp*, barnacles *Verrucaria sp* and *Semibalanus balanoides*, limpets *Patella sp*., dogwhelk *Nucella lapillus* and mussels *Mytilus edulis*. Other habitats include sand-scoured bedrock ledges with varying degrees of wave exposure, supporting typical barnacle and limpet communities interspersed with the brown algae *Fucus sp*, *Gelidum pusillum* and *Laurencia pinnatifida*, the anemone *Actinia equina* and the sponge *Halichondria sp*. Other habitats present included mobile cobble, gravels and sands supporting few species but including, where sheltered, communities resilient to sand-scouring typified by the presence of the green algae *Ulva sp* and *Enteromorpha sp*. Other intertidal habitats include beds of the seagrass *Zostera noltii* and mussels *Mytilus edulis*, and sandy to muddy-sand beaches and their associated fauna. Species lists and further habitat descriptions for intertidal epifauna are detailed in Howson (1989).

Detailed benthic infaunal surveys have been conducted around the Galloway Creamery outfall, which lies at the head of the loch, since 1982 (Rendall & Bell, 1992). The sediment, which consists of fine or medium graded sand, hosts communities dominated by polychaetes such as *Nepthys hombergi, Pygospio elegans, Spio martinensis, Capitella capitata, Exogone hebes* together with the shrimp *Crangon crangon,* the molluscs *Hydrobia ulvae*, *Cerastoderma edule* and *Angulus tenuis*.

7.2.1 Loch Ryan: Sublittoral zone

Howson (1989) describes nine subtidal habitats, and associated epiflora and epifauna, extending from the head to the seaward limit of the loch and a brief summary is given here.

Broadly speaking the seabed is predominantly sedimentary, dominated by coarse sands with some exposed bedrock at the head of the loch which gradates to fine muds in the southern basin. Other sediment types include muddy sand with cobbles, such as that located at Jamieson's Point and Soleburn (see Figure 4 in Howson, 1989).

The infralittoral bedrock surveyed in the depth range of 5 – 13 m was covered with a layer of silt. The dominant macroalga was the kelp *Laminaria hyperborea* with the red alga *Phycodrys rubens* forming a bulk of the underflora together with a diverse range of epiphytic algae. Epifauna was diverse and included dead-man's fingers *Alcyonium digitatum*, the ascidian *Ascidiella aspersa*, mobile echinoderms (unspecified), a range of crustaceans including *Galathea strigosa* and *Cancer pagurus,* and fish such as the wrasse *Ctenolabrus rupestris*, *Labrus mixtus* and *Labrus bergylta* (Howson, 1989).

In areas subject to less tidal scouring the kelp *Laminaria saccharina* and a range of foliose algae, bryozoans and hydroids were found. Detached *L. saccharina* formed the substratum for numerous epiphytic algal species such as *Chylocladia verticillata* and abundant *Laurencia sp*. On stones the encrusting coralline alga *Lithothamnion glaciale* was commonly observed. Unusually, in Scotland, the anemone *Cereus pedunculatus* was also recorded (Howson, 1989).

A small patch of the seagrass *Zostera marina* was recorded at one site (McMeckan's Rocks) which lies towards the entrance. Notes were made on the associated fauna which included the crabs *Pagurus bernhardus*, *Macropodia rostrata* and *Liocarcinus depurator* (Howson, 1989).

The native oyster *Ostrea edulis* has been recorded throughout the southern basin of the loch but most frequently at the southwest end of the Spit, on ground that ranges between soft mud to muddy sand. Empty oyster shells provide an important habitat for epifaunal species including the ascidians *Ascidiella aspersa*, *A. scabra* and tufts of, among others, the red alga *Spyridia filamentosa*. One bed of the mussel *Modiolus modiolus*, associated with the ascidian *Ascidiella aspersa,* was recorded at the south-eastern tip of The Spit (Howson, 1989).

Infaunal data from Loch Ryan are sparse but details are available from the loch head near the Galloway Creamery outfall (NE of Stranraer). These data were collected on annual surveys over the period 1982 – 2000. The sediment around the outfall ranges between fine sand to silt/clay. The fine sand habitat was dominated by the polychaetes *Spio martinensis* and *Capitella capitata* and the molluscs *Hydrobia ulvae* and *Mya arenaria*. The silt/clay dominated sediments hosted the polychaetes *Eumidia bahusiensis, Nepthys hombergi, Chaetozone sp, Melinna palmata* among others and the bivalve *Abra nitida* (Rendall & Bell, 1992).

7.2.2 Loch Ryan: General Comments

Loch Ryan is a relatively large and shallow sea loch which hosts the town of Stranraer (pop.10,000) and the important ferry terminal connecting Scotland to Northern Island. Anthropogenic impacts include the dredging for shellfish (mussels and cockles) which re-suspends considerable volumes of sediment and can be deleterious to community stability (Howson, 1989). The dredging operations required to keep the shipping channel > 5m in depth are considered not to pose a threat (Howson, 1989). According to Howson (1989) the loch does not support any particularly rare species. However, the seaweed *Spyridia filamentosa*, which is abundant in Loch Ryan, is otherwise unusual in the UK. Of other conservation interest is the habitat offered by The Spit, which hosts an unusually diverse range of algal species (Wilkinson, 1980). The historic oyster fishery, which was fished till becoming uneconomic in 1954, is currently being restored (Connor & Little, 1998) through the provision of a suitable substratum for spat settlement (Hugh-Jones, 2003).

Whilst the epifauna and flora of the loch have been well described by Howson (1989) there remains little survey work of the benthic infauna from Loch Ryan with the exception of a detailed description of the benthic infauna from both the shallow-subtidal and intertidal areas around the Galloway Creamery discharge (Rendall & Bell, 1992). These surveys, which are detailed over the period 1982 – 1991 and less detailed to 2000 (D. Rendall, personal communication) are spatially limited but, unusually, represent a fairly long time-series, an important consideration when looking at temporal stability in benthic communities.

8. NORTHERN FIRTH OF CLYDE SEA LOCHS

The northern margin of the Firth of Clyde is made up of a cluster of relatively small and partly interconnecting sea lochs – Gareloch, Holy Loch, and Lochs Long, Goil, Riddon and Striven. Gareloch and Holy Loch are both shallow (maximum depths 49 m and 20 m respectively). Lochs Long, Goil, Striven and Riddon are more typically fjordic in character, with sills, steep sides and greater water depths. All the northern Firth of Cyde sea lochs are very sheltered from wave exposure by the Kintyre peninsula and the Isle of Bute. The East and West Kyles of Bute form southerly extensions of Loch Riddon. Tidal streams are generally weak, except where local topography constricts water flow. Owing to their proximity to the Clyde estuary and the major population centres of west-central Scotland, some of the Clyde sea lochs are subject to considerable human influence.

The main source of recent information on the benthic biological communities of this group of sea lochs is the survey conducted in 1989 by the Marine Nature Conservation Review (MNCR) (Holt & Davies, 1991). A review of the MNCR findings is given by Dipper & Beaver (1999), who present detailed maps of the distribution of benthic biotopes in all of the lochs. The following sections provide a brief synopsis of the environments and communities described from this group of lochs. Dipper & Beaver (1999) should be consulted for more detailed descriptions.

8.1 Littoral zone

Owing to the extremely sheltered conditions prevailing there is typically no clear gradient in shore environments and communities from the entrances to the heads of these sea lochs. Shores in Gareloch and Holy Loch consist mainly of cobbles, pebbles and scattered boulders. The steeply-sloping shores of Lochs Long, Goil and Striven create a very narrow intertidal zone mainly formed of bedrock with areas of mixed boulders and smaller stones. Shore communities are usually dominated by fucoid algae (*Ascophyllum nodosum* and *Fucus* spp), mussels (*Mytilus edulis*) and *Littorina* spp. Barnacles (*Semibalanus balanoides* and *Cthamalus montagui*) and mussels predominate on steeper bedrock shores.

Sediment shores are absent or very limited in extent in the northern Firth of Clyde sea lochs. The exception is Loch Riddon, where the outflow of the River Ruel creates one of the few extensive estuaries in western Scotland. Sediments grading from sand to fine mud support a typical estuarine fauna, with species such as *Hediste diversicolor, Corophium volutator* and *Hydrobia ulvae* in regions heavily influenced by freshwater input, and *Arenicola marina, Cerastoderma edule* and *Macoma balthica* in the more marine conditions of the lower estuary.

8.2 Sublittoral zone

The infralittoral in these sea lochs is characterized by a low-diversity community typical of such sheltered conditions, namely a forest of the kelp *Laminaria saccharina* growing on boulders or mixed stony substrata heavily grazed by the urchin *Psammechinus miliaris.* Intense urchin grazing results in an impoverished understorey community often limited to encrusting pink coralline algae and grazing-resistant animals such as the serpulid polychaete *Pomatoceros triqueter*. Extensive beds of horse mussels (*Modiolus modiolus*) occur down to 12 m depth in parts of Holy Loch, Loch Long and Loch Goil, usually with a rich epifaunal assemblage growing on the shells.

Mixed sediments of mud or sandy mud with shell debris and cobbles cover extensive areas of the sublittoral in the northern Firth of Clyde sea lochs. The holothurian *Ocnus planci* has been reported from muddy gravel at one site in Loch Goil. This species is known from only a few sites in the UK. Fine, organic-rich muds occur in the deeper parts (> 20 m) of the loch basins, typically supporting communities of sea pens (*Virgularia mirabilis*) and burrowing megafauna such as *Nephrops norvegicus.* The sea pens and burrowing megafauna biotope occurs widely in sea lochs across the west of Scotland, and the examples described from the northern Firth of Clyde appear to be rather impoverished. A unique record from 65 m depth in Loch Goil is the ascidian *Styela gelatinosa.* This arctic species is not known elsewhere in the UK and the population in Loch Goil is probably a glacial relict.

Sublittoral rock is uncommon in Gareloch and Holy Loch but more extensive in Lochs Long, Goil, Riddon and Striven. On bedrock cliffs and steep slopes the characteristic sheltered sea loch community characterized by the anemone *Protanthea simplex* is found. Typical associates of this species are the ascidian *Ciona intestinalis,* the polychaete *Sabella pavonina* and the brachiopod *Neocrania anomala.* Loch Long also has some relatively uncommon species such as the anemones *Bolocera tuediae* and *Edwardsiella carnea* and the stoloniferan *Sarcodictyon roseum.*

Significant areas of tidal rapids are confined to the vicinity of the Burnt Islands at the north end of the East Kyle of Bute, where flow speeds of up to 3 knots have been recorded. This area supports a forest of the kelp *Laminaria hyperborea,* contrasting with the *L. saccharina* which dominates in the more quiescent conditions of the inner sea lochs. Increased tidal flow allows the growth of a rich community of sessile suspension-feeding animals including the anthozoans *Alcyonium digitatum* and *Metridium senile* and the hydroid *Tubularia larynx.*

8.3 General comments

Almost all of the biotopes and species described from the northern Firth of Clyde sea lochs are known to be widely distributed in other loch systems along the west coast of Scotland (Howson et al., 1994). The sole known exception is the ascidian *Styela gelatinosa*, which appears to be unique to Loch Goil. Because of its rarity in the UK this species is the subject of a Biodiversity Action Plan (BAP).

There is a limited amount of trawling and creeling for *Nephrops norvegicus* in Lochs Long, Goil, Riddon and Striven. Salmon farming takes place in the Kyles of Bute. The main human impacts in Gareloch and Holy Loch are related to military activities. Gareloch is the site of the major Royal Naval submarine base at Faslane, and the town of Helensburgh is a major local population centre. The United States Navy submarine base at Holy Loch closed in 1990 and a major effort has since been made to clear debris and litter from the loch bed.

9. LOCH FYNE

Loch Fyne is the longest (length approximately 70 km) and deepest (maximum charted depth 200 m) of the Scottish sea lochs. It is a typical steep-sided fjord, with sills at Minard and Otter Ferry. South of Otter Ferry, the lower loch is continuous with the deep water of the Arran Basin. Three small subsidiary sea lochs (Lochs Shira, Gair and Gilp) open into the western side of Loch Fyne.

At the harbours of East Loch Tarbert and Inverary, tidal ranges at neaps are 1.8 and 2.5 m respectively, with a range of 3.1 m at springs in both localities. There are few published temperature records, but surface temperatures of 7.8^0 (January) and 12.5^0C (August) have been recorded at the mouth of the loch. The freshwater catchment area is 698.8 km^2, with annual freshwater runoff estimated at 1340.4 $Mm^3\ y^{-1}$ (Edwards & Sharples, 1986). Stratification by salinity is most marked in the upper reaches of the loch (Davies, 1989). Tidal streams are generally very weak except in the narrows at Otter Ferry, where outgoing tides may attain rates of 2 knots. Loch Fyne has a relatively long ‘flushing time’of 13 days, a value exceeded only by Loch Etive among the Scottish sea lochs (Davies, 1989). Loch Fyne is generally sheltered from prevailing southwesterly winds by the land mass of Kintyre but the long ‘fetch’ arising from its extended shape and orientation can generate sea swells in the upper reaches of the loch.

From the distribution of littoral and sublittoral communities, (Davies, 1989) recognized three subdivisions of Loch Fyne, a lower loch region extending from the entrance to Otter Ferry, an upper loch from Otter Ferry to Strachur, and the head region from Strachur to the furthest inland extension of the loch. This terminology is used below and in sections 5.2.1 and 5.2.2.

Muddy or sandy gravel is the dominant sediment type in the the littoral and shallow sublittoral zones of Loch Fyne (Deegan et al., 1973). This sediment contains much skeletal carbonate and lithic fragments of glacial origin. In the deeper regions of Loch Fyne sediments are largely silty clay, with deposits up to 130 m thick in the lower loch. Manganese nodules and manganese deposits on mollusc shells occur in Loch Fyne at depths of 20-200 m (Davies, 1989). Hard substratum is widespread in the littoral and shallow sublittoral of the upper loch where the steepness of the glacial valley walls prevents accumulation of sediment. Hard substratum is less abundant in the lower loch where sides are less steep, but much of the littoral is still rocky. Observations from manned submersible in the lower loch (Eden et al., 1971) have revealed a submerged glacial U-shaped valley with smaller subsidiary valleys, all with extensive exposures of steep and vertical bedrock in the 25-150 m depth range.

Loch Fyne has a long history of marine sampling and recording extending back to the early 19th century (Dipper and Beaver, 1999). Davies (1989) summarized much of the information from the older literature and discussed this in relation to the the results obtained from surveys in the littoral and shallow sublittoral zones by the Marine Nature Conservation Review (MNCR) in the late 1980s. The MNCR survey also used towed video to survey habitats and biological communities throughout much of the length of Loch Fyne at depths below the reach of SCUBA diving (Howson & Davies, 1991). The results of both surveys were summarized and reviewed by Dipper and Beaver (1999). Little new information has been added since then, and the following accounts therefore rely largely on the results presented in the MNCR publications.

9.1 Littoral zone

The steeply-sloping sides of Loch Fyne create a very narrow intertidal zone occupying only about 4% of the total HW area. The loch shows only a weak gradient of wave exposure from mouth to head, and consequently the pattern of distribution of communities is less clear than in most sea lochs opening on the west coast of Scotland. In consequence, local topographic variation assumes a relatively greater importance (Davies, 1989). Most of the intertidal zone in Loch Fyne is rocky, consisting of either bedrock or boulders. On rocky shores the supralittoral zone is lichen-dominated, with bands of the brown algae *Pelvetia canaliculata* and *Fucus spiralis* below this. The upper shore barnacle *Chthamalus montagui* occurs in areas of sparse algal cover, with the littorinids *Littorina littorea* and *L. saxatilis* occupying crevices and fissures. Community composition in the midshore differs according to degree of wave exposure, with thick fucoid growth (*Fucus vesiculosus, F. serratus* and *Ascophyllum nodosum*) on more sheltered shores and barnacle-dominated communities in more exposed areas. Sheltered, fucoid-dominated rocky shores are found throughout the upper loch and in small, sheltered areas of the lower loch. Barnacle-dominated shores show the inverse of this pattern, with greater representation in the lower loch (Davies, 1989). *Semibalanus balanoides* is the dominant barnacle species, co-occurring with large numbers of limpets (*Patella vulgata*) and dogwhelks (*Nucella lapillus*).

Davies (1989) recorded the sublittoral fringe communities on bedrock shores at three sites, in all cases characterised by foliose brown algae (*Laminaria digitata* or *Halidrys siliquosa*). Rockpools occur in the upper and midshore at several localities in Loch Fyne. These are typically lined with encrusting coralline algae (*Corallina officinalis*) and may contain species more typical of the sublittoral zone such as the anemones *Metridium senile* and *Sagartia elegans,* the brittlestar *Ophiocomina nigra* and the ascidians *Botryllus schlosseri* and *Ascidia conchilega.*

Sediment shores in Loch Fyne are confined to the head of the loch and to local embayments, where substrata ranging from cobbles to fine sand can be found. Most embayments have sparse to thick fucoid cover with the brackish water-tolerant *Fucus ceranoides* growing where freshwater streams enter the loch. Mussels (*Mytilus edulis*) grow under the fucoid cover on the lower midshore. The lower shore typically consists of sand lying over gravel, with little or no algal growth. The lugworm *Arenicola marina* is usually present at high densities. Where the lower shore consists of coarser sediments *Fucus serratus* and *Mytilus edulis* are the dominant organisms. Extensive beds of young mussels are also found at Otter Spit, growing on clean sand and probably acting to consolidate the substratum (Davies, 1989).

9.2 Sublittoral zone

As noted for the littoral zone, shallow sublittoral (ie. within SCUBA diving range), communities in Loch Fyne are not strongly influenced by degree of wave exposure. The major factors determining community composition appear instead to be substratum type, inclination and strength of tidal streams (Davies, 1989). In conditions of extreme shelter towards the head of the loch (north of Strachur) silty boulders or cobbles extend to 5-10 m depth and support a community of foliose algae (*Laminaria saccharina* and *Phycodrys rubens*) and solitary ascidians (*Ascidia mentula*). Below this zone is a steep slope of shelly mud in which the large cerianthid anemone *Pachycerianthus multiplicatus* is the most conspicuous species. Highest densities of *P. multiplicatus* occur near the head of Loch Fyne and in Loch Shira. In the latter site the anemone occurs in water depths of as little as 5 m, an unusually shallow record for the species. Loch Shira also supports a sparse bed of eelgrass (*Zostera marina*).

Infralittoral habitats and communities show more diversity away from the head of the loch (Davies, 1989), although boulder or bedrock substrata with *Laminaria saccharina* are widespread. Within the kelp zone and below it there is a greater diversity of foliose red algae than found near the head of the loch. Common species include *Phycodrys rubens, Delesseria sanguinea* and *Polysiphonia elongata.* Solitary ascidians are much less abundant than at comparable depths in the upper loch.

Community structure on circalittoral rock varies according to depth and inclination of the substratum. Davies (1989) reports that vertical bedrock extending to 30 – 40 m depth supports a community type widespread in Scottish sea lochs, characterized by the anemone *Protanthea simplex,* the brachiopod *Neocrania anomala,* the polychaete *Sabella pavonina,* the ascidian *Ciona intestinalis* and a variety of encrusting sponge species. On shallower or less steeply-sloping substrata *Protanthea simplex* is absent and encrusting coralline algae are major space-occupiers. Common animals in this habitat include the squat lobster *Munida rugosa,* the brittlestar *Ophiura albida,* the serpulid polychaete *Pomatoceros triqueter* and the barnacle *Balanus crenatus.*

Tidal flows are accelerated at Otter Ferry where water passes over a major sill and through a constriction in the loch width. Sediments here are coarse, with pebbles and cobbles overlying gravel, sand and mud. Accelerated tidal flow creates favourable conditions for suspension-feeding organisms, including dense beds of the brittlestars *Ophiocomina nigra* and *Ophiothrix fragilis.* A diverse assemblage of sessile cindarians occurs among the brittlestars. Common species include the hydroids *Sertularia argentea, Rhizocaulus verticillatus* and *Halecium* spp., and the anthozoans *Alcyonium digitatum* and *Metridium senile.* Davies (1989) noted that large numbers of the gaping file shell *Limaria hians* at two sites south and west of the narrows at Otter Ferry might indicate the existence of a single extensive bed of this species, possibly covering > 1 km^2. Drifts of dead maerl gravel occur off Ardlamont Point, Skipness Point and several other sites but no living maerl has been recorded. Associated epifauna include brittlestars (*Ophiothrix fragilis*) and the predatory sea star *Luidia ciliaris*, with the bivalve *Clausinella fasciata* and the tubicolous polychaete *Chaetopterus variopedatus* dominating the infauna.

Shallow circalittoral sediments in Loch Fyne are typically a mixture of mud, sand, gravel, pebbles and cobbles in varying proportions. Local composition of infauna mainly reflects the mud and sand content of the sediment. Conspicuous species such as *Arenicola marina* and *Chaetopterus variopedatus* are most common in the sandier sediments of the lower loch.

In the MNCR survey reported by Davies (1989) the author noted that soft mud communities characterised by sea pens and burrowing megafauna were not recorded in Loch Fyne within the depth range accessible to divers. These communities are very characteristic of the Clyde Sea area, including its sea lochs (Atkinson, 1986) and Davies suggested that they might occur in the deeper areas of Loch Fyne. Their occurrence was confirmed by a towed video survey conducted in early 1990, in which 13 separate tows allowed observation of 59 km of seabed covering much of the linear extent of the loch (Howson & Davies, 1991). Soft mud was found occur throughout the deeper, central bed of the loch from the head to the entrance at depths of 23 – 186 m. Shell debris was more apparent south of the Minard Islands, with coarser sediments occurring in shallower water and around the sills at Otter Ferry and Minard. Soft muds throughout the loch were extensively burrowed by the thalassinidean mudshrimp *Calocaris macandreae. Pachycerianthus multiplicatus* was common near the head of the loch but was not seen south of Furnace. Sediment mounds made by the echiuran worm *Maxmuelleria lankesteri* were conspicuous in the upper loch and at the entrance to Loch Shira. *Nephrops norvegicus* was scarce in the upper loch but more abundant in the central and outer sections. The sea pen *Virgularia mirabilis* was frequently seen between 23 – 62 m depth in Loch Gilp, the central basin and at the head of Loch Fyne but was scarce or absent in the deepest areas surveyed.

The Lamont Shelf was the most wave-exposed part of the loch surveyed by towed video and supported a substratum of coarse muddy sand intermixed with areas of gravel with cobbles and boulders. The most abundant burrowers here were the thalassinidean *Callianassa subterranea* and the echiuran worm *Amalosoma eddystonense* (Howson & Davies, 1991). Areas of hard substratum consiting of boulders and bedrock outcrops occurred sporadically throughout the deeper areas of Loch Fyne. Rock surfaces were typically dominated by the large anemone *Bolocera tuediae* with the squat lobster *Munida rugosa* frequent between the boulders.

9.3 General comments

The distribution of benthic biotopes in Loch Fyne has been mapped in detail by Dipper & Beaver (1999). There appear to be no biotopes or species unique to Loch Fyne and all those reported occur widely in other Scottish sea lochs. However, Loch Fyne does support several nationally-scarce or uncommon species including the anemones *Pachycerianthus multiplicatus, Bolocera tuediae* and *Gonactinia prolifera*, the echiuran *Amalosoma eddystonense* and the brachiopod *Terebratulina retusa.* The population of *P. multiplicatus* at the head of Loch Fyne is one of the densest known, with comparable abundance reported only from Loch Duich (Davies, 1989).

Salmon farming and trawling for *Nephrops norvegicus* are the major human impacts on Loch Fyne's benthic ecosystems. There are several active salmon farms in the loch and further sites with approved leases. From towed video observations Howson & Davies (1991) noted that most of the upper loch showed little evidence of trawl disturbance, probably reflecting the low abundance of *Nephrops norvegicus* in this area. The lower loch, in contrast, was extensively ploughed by trawls. Burrows of *N. norvegicus* were more common in the vicinity of boulders or bedrock outcrops, presumably because these provide some shelter from trawling.

10. ANTHROPOGENIC ACTIVITIES AND IMPACTS

Pollution in the Clyde estuary arises from both the dense populations and industry in the area. Although heavily polluted, surveys by the Clyde River Purification Board in 1968 suggested improvement in water quality and benthic faunal populations (McKay et al., 1978). There has also been a study of the intertidal organisms of the Clyde estuary to assess the effects of changing levels of pollution and how it affects the winter flocks of wading birds (Smyth et al., 1974)

Mariculture is an important industry in the Clyde Sea area especially in Loch Fyne and around the Kyles of Bute (Robson, 1997). Salmon farming is predominant but there is also a small halibut, mussel and oyster industry in the area. All discharges from aquaculture sites are regulated by the Scottish Environmental Protection Agency (SEPA) and samples from shellfish for human consumption have to be submitted to FRS Marine Laboratory for bacteriological examination (Robson, 1997). The seabed in the immediate vicinity of a fish farm will be polluted, depending on a number of factors including stocking density, tidal currents and depth.

Coastal quarrying, as defined by Crumpton (1997a) is carried out in the Clyde Sea Area. In 1994 there were three sand and gravel quarries, two silica sand quarries and one igneous quarry - all on the east side of the Clyde and since 1996 SEPA have regulated their discharges. There has also been one site at the North of Arran designated as suitable for a ‘superquarry’. The main environmental objections to the superquarries are 1) the potential release of contaminated ballast water from transport ships which could have an impact on the local fish farms and the aquatic environment in general, and 2) the impact on the landscape (Crumpton, 1997a)}. There are many landfill sites in the Clyde Sea Area along the coast again mostly on the east coast of the Clyde where the human population is highest. Discharge from these sites is also monitored by SEPA (Crumpton, 1997a)

At present there is no marine aggregate extraction in the Clyde Sea Area and there are no licenses granted for the disposal of solid industrial waste (scottishexecutive.gov.uk, 2005). Navigational dredging is carried out in the Clyde Sea Area and in 1994 250,525 tonnes were deposited at offshore sites. This was approximately 10% of the 1993 figures. (Crumpton & Goodwin, 1997)

There has been a history of dumping sewage sludge and in 1998 1,631,600 tonnes were deposited at Garroch Head (Seas Ltd., 1999). This site was monitored from 1978 until the cessation of dumping at sea in the Clyde in 1998 by SMBA (now SAMS) then Seas Ltd. As well as fauna, heavy metals, organo-chlorines, carbon/nitrogen ratio and redox potential were measured and samples of the epifauna were analysed for microbiology. In August 2005 there will be a re-survey of the Garroch Head ground to study the recovery of the seabed (led by FRS Marine Laboratory).

There is no oil or gas development in the Clyde Sea Area but there is an oil terminal at Finnart, Loch Long (Crumpton, 1997b). There are also fuel holding tanks at Bowling in the Clyde estuary.

At Faslane in the Gareloch the Royal Navy has its Scottish headquarters and it is also home to the United Kingdom’s strategic nuclear deterrent (www.royal-navy.mod.uk, 2005). The new Astute class of submarine will be maintained at Faslane from 2008 (www.royal-navy.mod.uk, 2005). Coulport, Loch Long is an ammunition store and processes and maintains the Trident Weapon System (www.royal-navy.mod.uk, 2005).

The Firth of Clyde is used intensively for recreational pursuits such as yachting and scuba diving. All the main activities tend to be based near centres of higher population on the southeast coast of the Clyde. The main impact from the tourist industry is the increase in sewage but SEPA, in its five year survey 1990 – 1995, has shown that 88% of coastal and 55% of estuarine waters in the region were of ‘good’ or ‘excellent’ quality (Crumpton, 1997c).

Fishing in the Clyde sea area is dominated by small boats (<15 m) (Tarbert Fishery Association, pers. comm.) trawling for queen scallops (*Aequipecten opercularis*), Norway lobsters (*Nephrops norvegicus*) and scallops (*Pecten maximus*). Fisheries statistics for Ayr (statistics. defra. gov. uk., 2001) show that fish, crustacea and shellfish landings greater than 100 tonnes were restricted to 6 species/ families (Table 1).

Table 4 Landings, greater than 100 tonnes, from Ayr (statistics. defra. gov. uk., 2001)

Species		Tonnes landed
Queen scallop	*Aequipecten opercularis*	4912
Norway lobster	*Nephrops norvegicus*	952
King scallop	*Pecten maximus*	860
Dogfish	unspecified	342
Haddock	*Melanogrammus aeglifinus*	319
Skates and Rays	unspecified	155

Historically there has been a herring fishery in the Clyde but in recent years landings have declined from a long-term average of 14,200 tonnes between 1893-1960 to 2400 tonnes between 1979 and 1984 and under 10 tonnes in 2001 (statistics. defra. gov. uk., 2001) This fishery was based on a stock of spring-spawned fish from Ballantrae Banks and from Iron Rock Ledges, south of Arran (Bailey et al., 1986).

In this area there is a small fishery for sprats (*Sprattus sprattus*) mostly from the lower end of Loch Fyne and in the northern part of Kilbrannan Sound. The sprats are known to spawn south of Arran (Bailey et al., 1986).

Mackerel (*Scomber scombrus*) are also caught in the Clyde Sea area but not in significant numbers. It is thought that the closest spawning grounds are in the northwest approaches (Bailey et al., 1986)

Although there is no major demersal fishery in the Clyde, many of the commercially important fish seem to spawn in the area and eggs and larvae have been found over the whole region, although the precise locations for most species are not known (Hislop, 1986).

Since 1950 samples have been examined for plaice (*Pleuronectes platessa*) eggs and larvae. It has been found that plaice spawn in the Clyde in early Spring from February to April and eggs and larvae are found all over the area. Highest concentrations were found off the Heads of Ayr, Ayr Bay, close to Ailsa Craig and in Irvine Bay (Poxton, 1986)

Shellfish encompasses both Crustacea and Mollusca and the major species caught in the Clyde Sea area are lobster (*Homarus gammarus*), mussel (*Mytilus edulis*), oyster (*Ostrea edulis*), edible crab (*Cancer pagurus*), queen scallop (*Aequipecten opercularis*), king scallop (*Pecten maximus*), Norway lobster (*Nephrops norvegicus*) (Mason, 1986). The Clyde Sea area shellfish fishery is significant and in 1983 the value of the fishery was £4.5 million. The diversity of the shellfish industry is due to the many different sediments found in the area ranging from the fine muds for *Nephrops* to sandy gravel suitable for queen and king scallops (Mason, 1986).

The *Nephrops* fishery has become the dominant fishery of the Clyde and has steadily increased from 1950 to over 4500 tonnes landed in 1985 (Bailey et al., 1986). By 2001 the annual tonnage landed in the Clyde had dropped to 952 tonnes which is approximately 1/20 of the total catch in Scotland (statistics. defra. gov. uk., 2001). *Nephrops* are caught all over the Clyde Sea Area where there are areas of soft muddy sediments (Bailey et al., 1986) in depths of 14-230 m (Allen, 1967) usually by light trawl or creels. There has been much scientific research done on stock assessment in the Clyde area (Tuck et al., 2000; Tuck et al., 1997a; Tuck et al., 1997b) as well as on discards from the fishery (Wieczorek et al., 1999).

Due to lack of suitable ground there is only a small fishery for lobsters (*Homarus gammarus*) in the Clyde Sea area and only 5 tonnes were landed in 2001 (statistics. defra. gov. uk., 2001). There were no official figures for landings of the edible crab (*Cancer pagurus*) until 1975 when there was a steady increase up to 1984 and subsequent decline to 2001 when only 10 tonnes were landed at Ayr (statistics. defra. gov. uk., 2001). Figures for the landings of the velvet swimming crab (*Necora puber*) were first recorded in 1979 when a market in Spain was established. In 2001 <10 tonnes were landed at Ayr (statistics. defra. gov. uk., 2001). The principal fishing grounds are in Kilbrannan Sound (Mason, 1986).

Mussels (*Mytilus edulis*) occur in quite large numbers in submerged beds or on the shore. They were originally used as bait for line fishing but due to the decline in this method of fishing, mussel gathering is no longer a fishery in the area and in 2001 no mussels were recorded as being landed at Ayr (statistics. defra. gov. uk., 2001).

Loch Ryan had the largest fishery for the native oyster (*Ostrea edulis*) but the fishery had severely declined by 1957. Recently the fishery has been redeveloped and, in 2002, 17 tonnes were marketed which comprises approximately 98% of the official Scottish production. It has also been noted that the future of the oyster fishery depends on the size of the spatfall and how it is captured (Hugh-Jones, 2003).

Both king scallops (*Pecten maximus*) and queen scallops (*Aequipecten maximus*) are caught in the Clyde Sea area in a narrow strip on either side of the Clyde and round Arran – generally between 10 and 40 m. In 1973, the peak of scallop fishing in the Clyde, 7493 tonnes of queen scallops were landed at Ayr (statistics. defra. gov. uk., 2001) and most were known to come from the Clyde (Mason, 1986).

The cockle (*Cerastoderma edule*) is found in several areas of the Clyde, including the Isle of Bute, Fairlie and Stranraer. It is only used for bait and not for human consumption. There used to be a fishery for the periwinkle (*Littorina littorea*) which is found between tide marks all over the Clyde and between 1974 and 1983 381 tonnes were gathered from the Clyde (Mason, 1986). In 2001 there were no landing figures for the Clyde (statistics. defra. gov. uk., 2001). A by-catch of squid (*Loligo forbesi*) has provided an opportunist fishery in the Clyde and landings have steadily increased over the last five years – 7 tonnes in 1999 up to 11 tonnes in 2001 (statistics. defra. gov. uk., 2001).

Experiments have been carried out to assess the damage caused to maerl beds by hydraulic blade dredging. It was ascertained that dredging by this method could cause dispersion and settlement in other areas and therefore a case was made for ceasing all hydraulic dredging on maerl grounds (Hauton et al., 2003). Reference has been made earlier to the scheme at Lamlash Bay, Arran to have a No Take Zone at the northern end of the bay to protect the maerl beds (http://www.arrancoast.co.uk/).

11. FIGURES

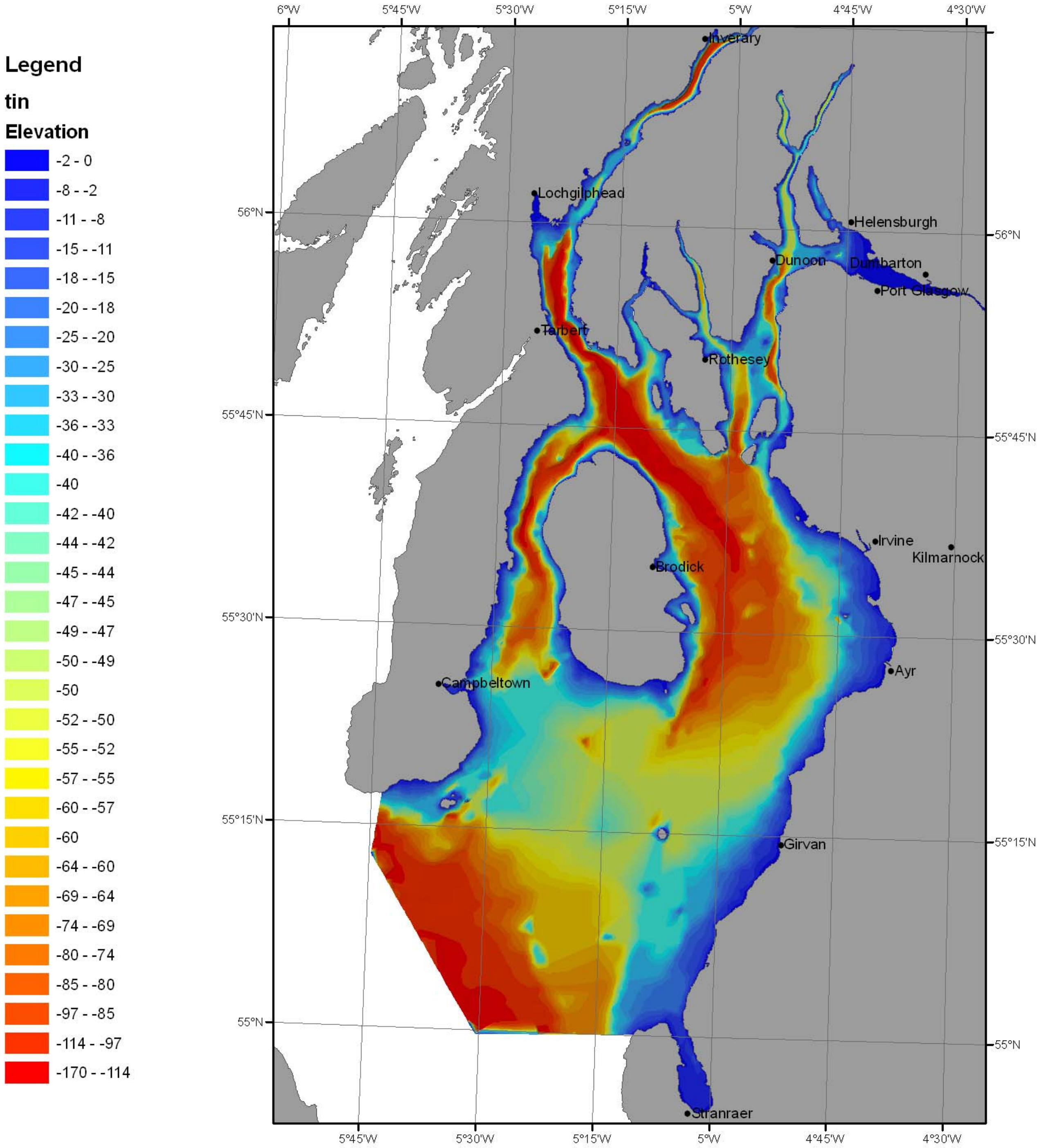

Figure 1 Bathymetry of the Firth of Clyde

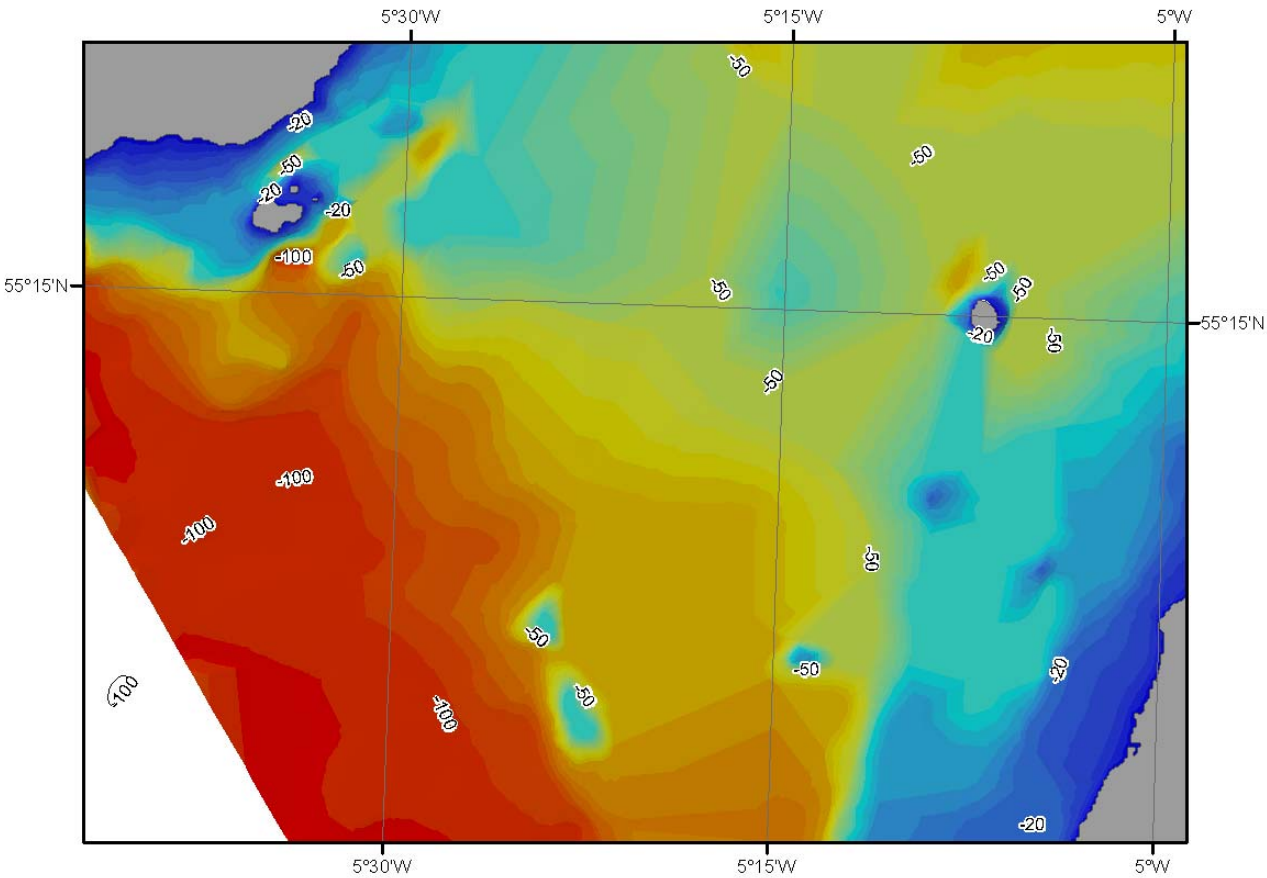

Figure 2 Bathymetry of the Clyde Sea entrance sill.

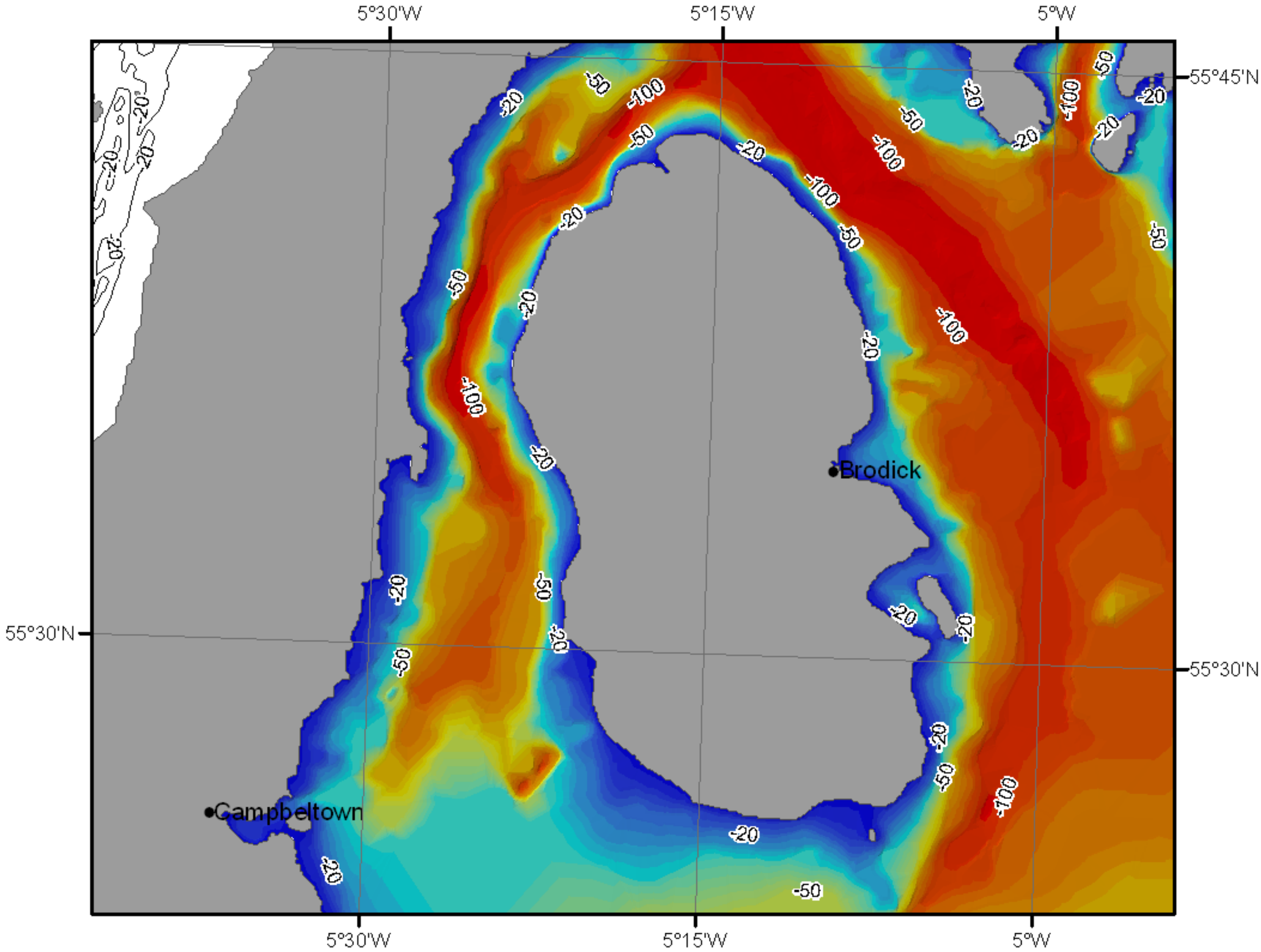

Figure 3 Firth of Clyde: bathymetry around Arran.

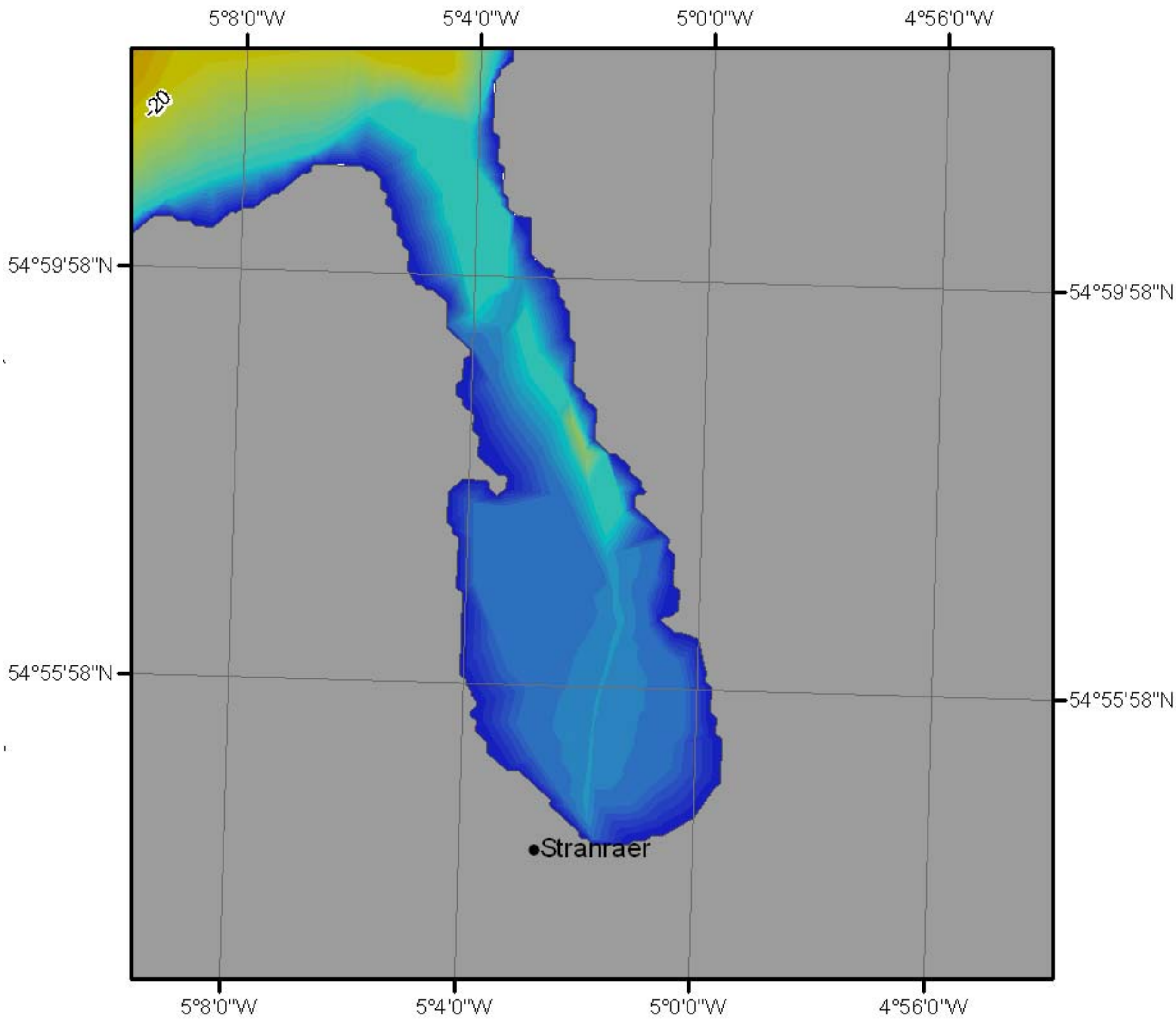

Figure 4 Bathymetry of Loch Ryan

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