JOINT NATURE CONSERVATION COMMITTEE

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

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Part 2

Reviews within MNCR Coastal Sectors

Chapter 11: Liverpool Bay to the Solway (Rhôs-on-Sea to the Mull of Galloway) (MNCR Sector 11)*

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Synopsis

The east basin of the Irish Sea (Liverpool Bay to the Solway) is predominantly of sediment including some very extensive intertidal flats. Rocky habitats occur as boulder scars, as artificial substrata (harbour walls, furnace waste) and at headlands especially in the Solway Firth where bedrock is also present in the sublittoral. However, most sublittoral areas are of sandy sediments. There are glacial lag deposits of coarse sediments including boulders at various locations especially off Lancashire and Cumbria. Water is often very turbid, of variable salinity and water temperature can fall to low levels in winter and rise very high in summer. Several significant estuaries enter the sector including the Dee, Mersey, Ribble and the Solway and much of the benthic survey work in the area has been concentrated within or just outside of these estuaries. Studies have also particularly been carried out in Liverpool Bay associated mainly with assessing the impact of sewage sludge and dredge spoil dumping but also in Morecambe Bay and the Solway especially in relation to fisheries and off the Cumbria coast near to large industrial installations. The long time-series of quantitative benthic samples taken since 1970 in the greater Liverpool Bay area provide an exceptional run of data. Degradation of estuarine communities as a result of human activities has occurred in some estuaries but more diverse faunas are now being reported compared with some years ago, notably in the Mersey. Many of the docks in the Mersey support diverse and unusual communities. Farther north, the boulder scars along the Cumbrian coast, the extensive sandflats of Morecambe Bay and the Solway and the rocky headlands in the Solway provide a variety of habitats.

11.1 Introduction

This section of the coast (Figure 11.1) occupies the east basin of the Irish Sea, which characteristically has a shallow shelving and predominantly sedimentary seabed. Wave action is restricted by the enclosed nature of the area and therefore the short wind fetch and by the gradually shelving nature of the seabed which means that much energy is dissipated before waves reach the shore. Wave action on the sediments also creates high turbidity throughout much of the area. The waters exhibit greater extremes of sea temperatures than are generally found elsewhere on the open coast of the British Isles with low sea temperatures of around 5 °C in winter and high sea temperatures of 16 °C in summer. High freshwater input combined with enclosed nature can result in the salinity of surface water falling to below 30‰ on the coasts of Merseyside and Lancashire which, together with lack of hard substrata and cold temperatures in winter are important factors that reduce the diversity of the fauna and flora in this region. (All data from Lee & Ramster 1981.)

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

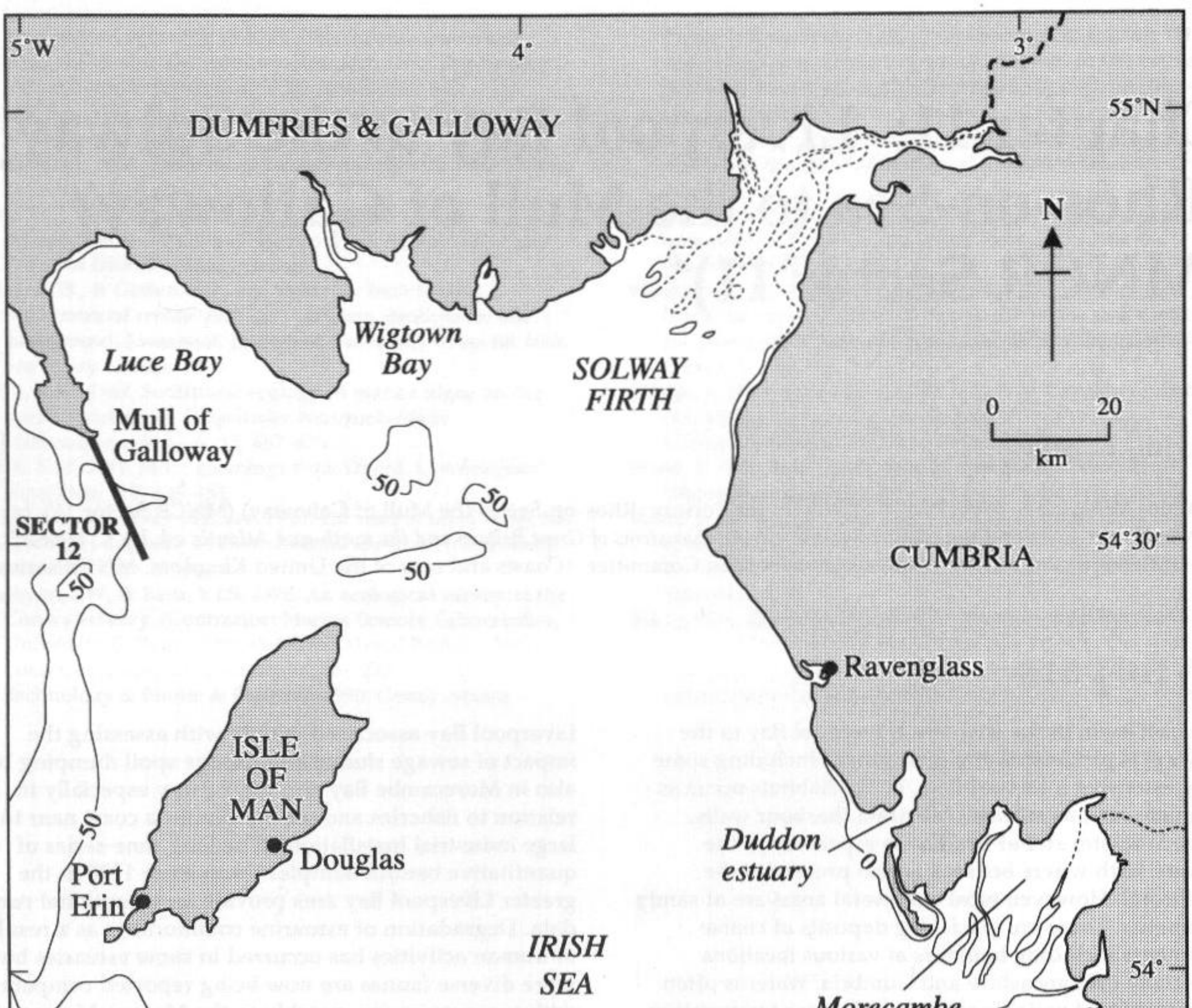

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Figure 11.1. MNCR Sector 11, showing the location of places mentioned in the text.

The shores of Sector 11 are typically of wide intertidal sandflats frequently backed by shingle on the upper shore. Extensive tracts of intertidal sand and mudflats occur in the estuaries of the Dee, Mersey, Ribble, in Morecambe Bay, the Solway Firth, and in Wigtown Bay and the smaller embayments of Dumfries and Galloway. Sedimentary substrata also predominate in the subtidal. Thus, there is considerable conservation interest related to the high productivity of intertidal areas. The large intertidal areas of Morecambe Bay, and of the other major estuaries in the area, are of international ornithological importance. The characteristics of the estuaries within this sector are described by Buck (1993).

Human pressures and impacts on this area have been considerable. Industrial and urban development has had many effects on the marine ecosystem, including pollution and loss of intertidal habitat.

Marine biological research in the area has had a long history. At the turn of the century the Liverpool Marine Biological Committee (LMBC) actively pursued marine biological research in Liverpool Bay. However, the lack of species-rich rocky shores in Liverpool Bay resulted in the committee moving the focus of their activities first to Puffin Island at the north-east end of the Menai Strait, and subsequently to Port Erin on the Isle of Man (Herdman 1920). Thereafter, marine biological research in the area proceeded at a limited pace until a comparatively recent upsurge in activity, which has been directed mainly into studies of the environmental effects of the dumping of sewage sludge and dredge spoil, and the discharges of polluting effluents. Many of these studies together with other research activities have been undertaken from the Marine Laboratory of the University College of North Wales at Menai Bridge. Work has also been undertaken from such centres as Salford, Manchester and Lancaster Universities, and has included work commissioned by industry, the water authorities and the Ministry of Agriculture, Fisheries and Food.

The first appraisal of scientific information for Liverpool Bay was prepared by the Liverpool Bay Study Group (1975). Later, in 1985, the Irish Sea Study Group (ISSG) was formed to focus attention on the environmental health of the Irish Sea. The ISSG carried out an environmental review of the Irish Sea (Shaw 1990). The results of this review were reported at a major conference held on the Isle of Man in 1990. Four specialist reports were produced covering the topics of nature conservation, waste inputs and pollution, exploitable living resources and planning, development and management (ISSG 1990a, 1990b; Norton & Geffen 1990; Smith & Geffen 1990). As part of the report on nature conservation, Mackie (1990) reviewed the state of current knowledge, and mapped the distribution of sediment types and offshore benthic communities in the Irish Sea (see Part 1 of this volume). A further Irish Sea symposium was held at Chester in 1991 (Jones & Norgain 1991). More specialised symposia have considered the effects of climate change (Irish Sea Forum 1992a), marine viruses (Irish Sea Forum 1992b) and fisheries management (Irish Sea Forum/Marine Forum 1993). Another valuable review publication is the environmental appraisal of the coast of north Wales and north-west England commissioned by Hamilton Oil (Taylor & Parker 1993).

The Marine Nature Conservation Review (MNCR) has completed survey work in this sector. Surveys were primarily littoral (Covey & Davies 1989; Covey 1990; Davies 1991; Garwood & Foster-Smith 1991; Covey & Emblow 1992; Davies 1992), but also sublittorally, employing diving and dredging techniques (Covey 1992; Emblow 1992).

11.2 Inshore areas of the north Wales coast: Rhôs-on-Sea to Point of Ayr

The sandy shores in this area are an attraction to holidaymakers, but have received little attention from marine biologists.

The Clwyd estuary was surveyed by Parsons & Pugh-Thomas (1979). As a result of past land-claim, the estuary is constrained within stone walls and has a small intertidal area. The small size of the estuary and significant freshwater input leads to extreme salinity fluctuations and Parsons & Pugh-Thomas (1979) recorded few species there of which the polychaete *Hediste diversicolor* was numerically dominant. The bivalves *Macoma balthica* and *Scrobicularia plana* and the amphipods *Corophium volutator* and *Gammarus duebeni* were also recorded at moderate abundances. However, some common estuarine species were apparently absent, including the lugworm *Arenicola marina* and the gastropod *Hydrobia ulvae*. The Clwyd estuary's conservation status was briefly summarised by the Countryside Council for Wales (1993) and by Buck (1993).

Six littoral sites on the open coast between Rhôs Point and Point of Ayr, were sampled for the MNCR by Garwood & Foster-Smith (1991). They recorded three communities from sediments, two from clean mobile sands on the open shore, and a third from a muddy area with a freshwater input behind a breakwater at Rhôs-on-Sea. On the open shore an infaunal community dominated by the polychaete *Scolelepis squamata*, the amphipod *Bathyporeia pelagica* and the isopod *Eurydice pulchra*, occurred above mid-tide level. The community recorded below mid-tide level was dominated by the polychaetes *Spio martinensis, Magelona mirabilis, Nephtys cirrosa, Lanice conchilega* and *Arenicola marina*. In places this community was modified by the settlement of vast numbers of juvenile *Lanice conchilega* which were preyed upon by the carnivorous polychaetes *Phyllodoce mucosa* and *Eumida sanguinea*. Behind the breakwater at Rhôs-on-Sea, large numbers of juvenile *Lanice* were present, but the community had an estuarine character with the polychaetes *Hediste diversicolor, Tharyx vivipara, Tharyx marioni, Capitella capitata*, the oligochaete *Tubificoides benedeni* (now *Tubificoides benedii*) and the bivalves *Macoma balthica, Scrobicularia plana* and the gastropod *Hydrobia ulvae*.

Hard substrata are very localised on this stretch of coast. Garwood & Foster-Smith (1991) provided records from two sites in Colwyn Bay, at Penmaenrhos Point and from Llandulas Point. Beds of the mussel *Mytilus edulis* were recorded on flat bedrock at Penmaenrhos Point. Boulders were present on the shore at both sites. The upper surfaces of the boulders and cobbles were dominated by the barnacles *Elminius modestus, Semibalanus balanoides* and *Balanus crenatus* overgrown by the hydroid *Laomedea flexuosa* in places. The boulders were frequently consolidated by sand, silt, mussels and by tubes of *Lanice conchilega*. The undersurfaces of loose boulders were colonised by the bryozoan *Conopeum reticulatum, Laomedea flexuosa* and the anemone *Sagartia troglodytes*, and provided shelter for the decapods *Porcellana platycheles* and *Carcinus maenas*. *Sagartia troglodytes* was also common in silty pools in mussel beds and on bedrock and boulder shores. Algae were very restricted in their distribution; *Enteromorpha* and *Fucus spiralis* colonised bedrock and concrete structures on the upper eulittoral zone.

Sublittoral records are very sparse. Rees, Nicolaidou & Laskaridou (1977) sampled from inshore muddy sand patches in Colwyn Bay. These patches were generally numerically dominated by either the bivalve *Abra alba* or the polychaete *Lagis koreni*. Winter storms caused high mortality of *Lagis koreni*, stranding many individuals on the shore. Other species were also severely affected.

11.3 The Dee estuary

The Dee estuary is one of the most important estuaries in Britain for waders and wildfowl, and is therefore of considerable conservation interest. In addition to being an SSSI, it is a Ramsar site, an SPA and large areas of the intertidal are nature reserves (Buck 1993; CCW 1993). The Dee also supports a salmon fishery. The earliest historical records of the Dee estuary date from the Roman occupation of Britain, when Chester was a major port. Since that time, the area of the estuary has been progressively reduced by sediment accretion, canalisation of the upper estuary, land-claim and saltmarsh development (Buxton, Gillham & Pugh-Thomas 1977). Detailed feasibility studies were conducted to investigate the potential for construction of road crossings and water storage reservoirs in the intertidal zone of the eastern part of the estuary (Binnie & Partners 1971, 1973). Each of the suggested schemes would have resulted in the loss of between one quarter and one third of the remaining intertidal area of the estuary.

The infauna of the Dee was surveyed intensively by Stopford (1951), Perkins (1956), and more recently by Gillham (1978). Gillham's study mapped the distribution of the dominant benthic species and used association analysis (classification) to identify five main associations of benthic invertebrates in the estuary. The bivalve *Macoma balthica* was the most frequently recorded organism in all five associations. 'Association 1' and 'Association 2' were recorded from muddy sands in the inner estuary. The dominant species in both associations included *Macoma balthica*, the gastropod *Hydrobia ulvae*, the polychaetes *Hediste diversicolor* and *Pygospio elegans*, and the amphipod *Corophium* sp.

- 'Association 1' and 'Association 2' were characterised by *Macoma balthica, Corophium* sp., *Hydrobia ulvae* and *Pygospio elegans* although only 'Association 1' additionally included the bivalve *Scrobicularia plana*.
- 'Association 3' dominant species were also dominants in Associations 1 and 2 but 'Association 3' was characterised by the polychaete *Scoloplos armiger* and also included species more typical of open coast sandy sediments such as the amphipod *Bathyporeia* sp. and the polychaetes *Nephtys* sp. and *Nerine cirratulus* (now *Scolelepis squamata*).
- 'Association 4' was found in the outer estuary and was dominated by *Macoma balthica, Nephtys* sp., *Nerine cirratulus* (now *Scolelepis squamata*) and the amphipods *Haustorius arenarius* and *Bathyporeia*. The first four associations represented a faunistic gradient, correlated with gradients in salinity, height on the shore and particle-size.
- 'Association 5' contained an impoverished fauna in which only *Macoma balthica* and *Nephtys* sp. were common. This 'Association 5' was recorded from unstable sands adjacent to low water channels, and from areas subject to desiccation high on the shore.

Garwood & Foster-Smith (1991) sampled the infauna at nine stations from four sites at the mouth of the Dee estuary near Hilbre Island. They recognised two communities at these stations:

- One community was recorded from clean sand on shores which were moderately exposed to wave action and was dominated by the polychaetes *Spio martinensis* with *Arenicola marina* and *Lanice conchilega*.
- The second community was associated with reduced salinity and relatively sheltered conditions. Lugworm *Arenicola marina* was often present at high densities, with the bivalve *Macoma balthica* and the polychaete *Pygospio elegans*, and locally the oligochaete *Tubificoides benedeni* (now *Tubificoides benedii*), the polychaetes *Hediste diversicolor* and *Scoloplos armiger*, and the bivalves *Cerastoderma edule* and *Scrobicularia plana*. This second community was variable. In the lee of Hilbre Island *Tubificoides* and *Scrobicularia* were abundant, corresponding to Gillham's (1978) 'Association 1', whereas in more exposed sites

Scoloplos and the amphipod *Bathyporeia* were present and the fauna corresponded to Gillham's 'Association 3'.

Garwood & Foster-Smith (1991) also recorded from a site adjacent to the river channel to the south-west of Hilbre, where the impoverished fauna from unstable sediments was equivalent to Gillham's (1978) 'Association 5'.

Hilbre Island is one of the few natural rocky areas in Liverpool Bay, and has thus attracted the attention of many workers. The area was intensively sampled by the Liverpool Marine Biological Committee around the turn of the century (Harvey-Gibson 1891; Harvey-Gibson, Knight & Coburn 1913, Herdman 1920). Sediment accretion has reduced diversity from that recorded historically. Only a small part of the island is not now surrounded by intertidal sediment flats. Harvey-Gibson, Knight & Coburn (1913) reported 118 species of marine algae for Hilbre, which included all the native British species of *Laminaria*. More recently, Russell (1972, 1973, 1977) described the shores of Hilbre as 'two-zone shores', on which species characteristic of a sublittoral fringe zone were absent due to sediment covering the rocks. Similar results were presented by Betteridge *et al.* (1976), who reported an algal flora of 70 species. No species of *Laminaria* were recorded. Wallace (1982) described the loss of formerly extensive reefs of *Sabellaria alveolata*. Historically, many species of nudibranchs were recorded at Hilbre, but few have been recorded recently (McMillan 1982).

Six rocky shore sites on Hilbre were surveyed for the MNCR during 1990 (Garwood & Foster-Smith 1991). The communities present on the shore were generally low-diversity examples of common rocky shore communities typically dominated by fucoids, mussels and barnacles. Some typical rocky shore species were either absent (the limpet *Patella vulgata*) or very localised (the dogwhelk *Nucella lapillus*). Some more unusual communities were also recorded. Shaded vertical rock surfaces at one site were covered by a dense turf of creeping red algae, principally *Gelidium pusillum*, bound with the silt tubes of the polychaete *Fabricia sabella*. Rockpools and underhangs in the eulittoral zone were typically colonised by the anemones *Sagartia troglodytes* and *Metridium senile*, the hydroid *Laomedea flexuosa*, the barnacle *Balanus crenatus* and the mussel *Mytilus edulis*.

11.4 Inshore areas of the open coast from the Dee to Formby

There are few littoral studies on the open coast of the Wirral and Lancashire. Bassindale (1938) sampled extensively from Hoylake to Formby including the offshore sediment flats. He recorded a rich fauna in muddy sand from Taylor's Bank in which the bivalve *Cerastoderma edule*, the burrowing sea urchin *Echinocardium cordatum* and the polychaete *Lanice conchilega* were prominent. Muddy sand off Hoylake had a different fauna, with the bivalve *Donax vittatus*, *Echinocardium cordatum*, the ophiuroid *Ophiura texturata* and the polychaete tubeworm *Lagis koreni* all attaining high levels of abundance. The Great Burbo Bank and North Bank were composed of more mobile coarse sand, with a low-diversity fauna containing the bivalve *Chione striatula* and *Lanice conchilega*. From a patch of sand, gravel and stones overlying clay on the seaward end of the Great Burbo Bank, he recorded a high abundance of the anemone *Sagartia troglodytes* with the anemone *Urticina felina* and the polychaete *Neanthes virens* present at lower abundances.

Gillham (1978) recorded the infauna of East Hoyle Bank as part of his study of the Dee estuary. He recorded a faunal association which contained an infauna characteristic of open coast sandy shores, including the polychaetes *Nephtys* sp. and *Nerine cirratulus* (now *Scolelepis squamata*), the amphipods *Bathyporeia* sp. and *Haustorius arenarius*, and the bivalve *Angulus tenuis*. The bivalve *Macoma balthica*, which was the dominant organism in all of the faunal associations from the Dee, was absent from this association.

In a study to investigate the littoral macro-infauna, Hoare (1975) sampled infauna from five sites off Hoylake in the vicinity of several short sea outfalls, and

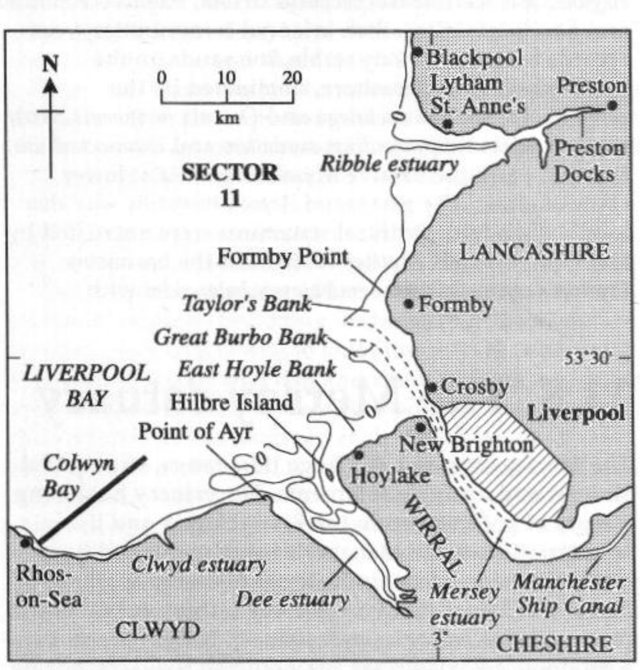

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Figure 11.2. Liverpool Bay and adjacent areas, showing places mentioned in the text.

from two 'control' sites in Red Wharf Bay on Anglesey. He recorded 18 species from Hoylake and 28 from Red Wharf Bay. The fauna recorded from the two locations were similar, except at low water where an impoverished fauna was recorded from Hoylake, due to greater exposure to tidal streams. The dominant species at the Hoylake stations were *Macoma balthica*, the gastropod *Hydrobia ulvae*, the amphipod *Corophium* spp. and the polychaetes *Capitella capitata*, *Hediste diversicolor*, *Pygospio elegans* and *Eteone longa*. There was considerable seasonal variation in the numbers of individuals recorded. During the study, the short sea outfalls were closed, and a new long sea outfall commissioned. In samples taken shortly after cessation of the discharges, Hoare (1975) found no evidence of faunal changes which might indicate 'recovery'.

Russell (1977) recorded the algae present on a shore at New Brighton. As at Hilbre Island, species characteristic of the sublittoral fringe zone were infrequent, and communities characteristic of the sublittoral fringe zone could not be distinguished. Most species recorded were present only at low abundance.

The Marine Lake, a boating pool at New Brighton, also supported a diverse assemblage of plants and animals prior to draining in 1990 and re-configuration by the Merseyside Development Corporation (Wilkinson, Allen & Hawkins 1990, in Taylor & Parker 1993).

Littoral sites on the Wirral and at New Brighton were sampled in a recent MNCR survey (Garwood & Foster-Smith 1991). Infaunal communities at New Brighton were similar to those recorded on the north Wales coast. A crustacean/polychaete community dominated by the polychaete *Scolelepis squamata*, the isopod *Eurydice pulchra* and the amphipod *Bathyporeia pelagica*, was recorded from two stations, and a second polychaete-dominated community containing *Pygospio elegans*, *Spio martinensis*, *Nephtys cirrosa*, *Phyllodoce mucosa* and *Lanice conchilega*. Rich infaunal communities were recorded from relatively stable fine sands on the north-west Wirral foreshore, dominated by the polychaetes *Lanice conchilega* and *Owenia fusiformis*, with the echinoids *Echinocardium cordatum* and *Echinocardium flavescens*, and the bivalve *Mysella bidentata* at lower shore stations. The gastropod *Acteon tornatilis* was also locally abundant. Artificial structures were encrusted by abundant mussels *Mytilus edulis*, and the barnacles *Elminius modestus* and *Semibalanus balanoides* with stunted fucoids also present. Sandstone reefs at New Brighton were colonised by the algae *Enteromorpha* sp. and *Porphyra* sp. and *Elminius modestus*, or supported dense mussel beds. The gastropod *Littorina littorea* was also abundant.

Other littoral records from the open coast adjacent to the Mersey are predominantly derived from surveys of the estuary. Curtis & Eyres (1980) sampled from Crosby to Formby on the Lancashire shore as part of a survey of the Mersey. Sites in this area were also sampled in studies by Moore (1978) and Ghose (1979, 1980), and more recently by Bamber (1988). Bamber (1988) sampled the infauna from the inner estuary, and from eight sites on the Wirral, and a further seven sites at Crosby. He was able to identify six site groups from community analysis. The sites on the north-west Wirral sandbanks formed one cluster and were dominated by the polychaetes *Nephtys cirrosa*, *Ophelia limacina*, *Phyllodoce mucosa*, *Scolelepis squamata* and *Lanice conchilega*, the amphipod *Bathyporeia pelagica* and the bivalves *Macoma balthica* and *Cerastoderma edule*. A second cluster was identified from sewage-polluted sandy shore sites at Crosby. The infauna from these sites was less diverse than from the Wirral sites, dominated by the polychaetes *Nephtys cirrosa*, *Magelona mirablis*, *Scolelepis squamata* and *Pholoe minuta*, and *Macoma balthica*. A third cluster included upper shore sites near the mouth of the river Alt, which contained a low diversity infauna dominated by *Bathyporeia pilosa* and *Nephtys cirrosa*. The remaining three clusters included only inner estuary sites.

Eagle (1973, 1975) carried out sublittoral benthic surveys both prior to, and after the commissioning of a long sea outfall on the Wirral. Three principal faunal associations were identified. These included two muddy sand associations dominated by the polychaete *Lagis koreni* and the bivalve *Abra alba* respectively, and a sand association dominated by the polychaetes *Magelona mirablis* with *Nephtys cirrosa* and *Nephtys longisetosa*. Several less frequently-recorded associations were also identified including an association dominated by the polychaetes *Lanice conchilega* and *Eumida sanguinea*, an association dominated by the opportunistic polychaete *Capitella capitata*, which appeared in areas subject to disturbance by pipe-laying operations, and an association dominated by the polychaete *Nereis succinea* which occurred in sandy sites where silt and organic matter was deposited from the sewage outfall.

11.5 The Mersey estuary

The Mersey estuary has a large tidal range, strong tidal streams and unstable sediments. The estuary has a long history of pollution from the River Mersey and its tributaries, from the Manchester ship canal, and from direct discharges from industry and sewage works. Porter (1973) identified the Mersey estuary as one of the most polluted estuaries in Britain. In the upper estuary, a pronounced oxygen sag has occurred regularly during summer low tide periods, causing anaerobic conditions and an offensive smell. Lever (1985) considered that pollution reached its worst during 1970/1971 in the inner estuary. Pollution incidents in the Mersey have continued to be reported, including the death of wading birds from lead pollution (Williams 1980), and an oil spill from a pipeline (Hall-Spencer 1989, Davies & Wolff 1990). Like the Dee, the estuary has a history of incremental land-claim, and has been subject to plans for the construction of a tidal energy generating barrage and of an extension of Liverpool airport. Despite the pollution, the mud- and sandflats of the estuary are of international ornithological importance as feeding grounds for birds (the estuary is an SSSI, an SPA and

Ramsar site). An oil and gas exploration licence for the Dee and Mersey estuaries was awarded to Shell UK, who commissioned an environmental background summary (Rice & Putwain 1987). A draft management plan, setting broad strategic objectives for the estuary and adjacent coastal zone, was issued by the Mersey Basin Campaign Estuary Project Group in 1994 (University of Liverpool Study Team 1994). The importance of Liverpool as a port has declined in recent years with containerisation and other changes in cargo handling practice, but Liverpool remains a major port.

Marine biological study of the estuary was intense during the latter part of the 19th century (Herdman 1886–1900, 1920). The level of effort declined once the Liverpool Marine Biological Committee moved the centre of its attention elsewhere. The intertidal fauna of the Mersey estuary and adjacent parts of Liverpool Bay was described by Bassindale (1938), who recorded the fauna present from more than 100 stations. In the estuary upstream of the narrows, *Hediste diversicolor* was widespread and abundant. Other common species included the oligochaete *Clitellio arenarius*, the amphipod *Corophium volutator*, the bivalve *Macoma balthica*, and the polychaetes *Arenicola marina* and *Pygospio elegans*. Fraser (1938) described the biota of floating structures in the Mersey narrows and Liverpool Bay. Some of these sites were subsequently re-surveyed by Corlett (1948).

Thereafter there was little research activity in the Mersey until the 1970s when the estuary came under the study of postgraduate students from Salford and Manchester Universities. Theses by Ghose (1979) and Carter (1985) described the principal species and faunal associations. The fauna of the outer estuary was relatively diverse but a low diversity of species was found in the Mersey narrows, where tidal streams are strong, and from the mobile sandflats of the middle estuary. Oligochaetes dominated upper estuary sites. In a comparison with Bassindale's (1938) study, Ghose (1979) found that 18 species had apparently been lost, and two gained (the polychaetes *Manayunkia aesturina* and *Capitella* sp.). This apparent decline in species richness may be an artefact due to the lower number of stations in Ghose's (1979) study, but he attributed the impoverishment of the fauna of the upper estuary sites to pollution. However, on the evidence of data collected by Ghose (1979) and from other studies, Pugh-Thomas (1980) summarised his report on the ecology of the Mersey by concluding that the changes in the ecological state of the estuary since Bassindale's (1938) study were minor.

An intensive campaign to clean up the Mersey estuary was initiated in 1980 with the interim objectives of relieving the 'olfactory nuisance', and eliminating fouling of the shores by crude sewage and solids and fats derived from industrial effluents. In the longer term, the objectives are to bring the Mersey and the rivers of its catchment up to a standard suitable to support fisheries (Lever 1985). Carter (1985) recorded a more diverse fauna than in previous studies, and suggested that this apparent improvement had occurred since the clean-up campaign was initiated.

Bamber (1988) described the results of a survey of the Mersey estuary carried out during March 1987. Infauna was sampled from 19 sites in the inner estuary, and a further 15 sites in Liverpool Bay. He used community analysis (classification) to analyse the data collected. The analysis showed a clear separation between sites in the inner estuary and in Liverpool Bay. Within the estuary there were three site groups. Two site clusters were from upper estuary muddy stations and were dominated by oligochaetes.

- One of these clusters included sites with mud sediments, and contained a fauna dominated by the oligochaete *Tubifex costatus* with the polychaete *Manayunkia aestuarina*.
- The second of these clusters included sites which were dominated by the oligochaete *Tubificoides benedeni* (now *Tubificoides benedii*). These sites included stable muddy sand sites on Stanlow Banks in which *Tubificoides benedeni* was found in conjunction with the bivalve *Macoma balthica*, and the polychaetes *Pygospio elegans* and *Hediste diversicolor*, and impoverished sites at the edge of the saltmarsh.
- The third cluster included sites from sandier stations in the upper estuary, which contained an impoverished infauna in which the polychaete *Capitella capitata* was either dominant, or was the only species present.

Bamber (1988) noted that the common estuarine gastropod *Hydrobia ulvae* was apparently absent, and that only a single specimen of the amphipod *Corophium volutator* was found in samples from this survey, despite the presence of apparently ideal habitats. The polychaete *Hediste diversicolor* was also infrequent. Bamber's (1988) observations agree with Ghose (1979), who reported that *Corophium volutator* was absent from the inner estuary, and that *Hydrobia ulvae* in the inner estuary was "about to be eliminated". Bamber (1988) suggested that the impoverished nature of the fauna of the inner estuary could possibly have been due to a spell of severely cold winter weather, but concluded that pollution was the factor limiting the benthic fauna. The distribution of invertebrates in the Mersey estuary was also summarised by Holland (1989).

The decline in the port of Liverpool has led to many of the older docks becoming underused or disused. Sandon Dock was closed to shipping in 1977, and was run as an experimental fish and shellfish farm, and as an experimental system to assess the potential use of such disused docks (Cunningham *et al.* 1984a). An airlift pump was installed and used to break up the thermocline which developed during the summer months, and to oxygenate the water. Initially, rainbow trout *Salmo gairdneri* were reared in cages. Following a heavy spatfall of the mussel *Mytilus edulis* during 1978, mussels were harvested from the dock walls and cultured on ropes. Oyster spat was grown on to marketable size in submerged baskets. Filter-feeding by the mussels, and the breaking up of the thermocline, resulted in an improvement in water quality and a great improvement of water clarity compared with other docks and with the Mersey estuary. The dock supported a diverse biota, dominated by *Mytilus edulis*, tunicates (principally *Ciona intestinalis* and *Ascidiella aspersa*), anemones and barnacles. Cunningham *et al.* (1984a) listed over 50 species of benthic invertebrates, 30 species of benthic algae and 20 species of fish which were recorded from the dock during the study period. Aquaculture was considered uneconomical, operations ceased during 1983, and the dock was subsequently infilled.

The South Docks complex is a chain of dock basins 2 km long, adjacent to the Mersey estuary, with two river entrances, one at the south and one at the north end. In 1972 the docks were closed to commercial traffic and became derelict and heavily silted. In 1981 the Merseyside Development Corporation (MDC) was set up to develop the docks as a commercial project, and dredging work commenced in that year. Allen (1992) carried out studies on the water quality and biota of the South Docks with the aims of understanding the overall hydrography and ecology of the South Docks complex, identifying the extent of water quality problems, and developing a management for strategy for maintaining high water quality in the long term. Allen (1992) found the dock waters to be polyhaline, nutrient-rich and subject to considerable variations in temperature. The deeper docks became stratified during the summer months resulting in dissolved oxygen depletion below the thermocline which caused mortality of benthic fauna and bad smells. Because of the high nutrient levels, a succession of phytoplankton blooms developed during spring and summer, depleting the water of oxygen as the blooms decayed. The phytoplankton blooms were grazed by a typically estuarine zooplankton community, dominated by the calanoid copepods *Eurytemora affinis* and *Acartia* spp. The fauna and flora of both the dock walls and the bottom sediments were impoverished at the start of the study, but a more diverse biota developed during the study period. At the start of the study only the opportunistic polychaete *Capitella capitata* and a few oligochaetes were recorded from the sediments. Later in the study, the polychaete *Polydora* spp. reached high densities, and other species were recorded including several nereids, *Arenicola marina*, the amphipod *Corophium insidiosum*, the ascidian *Ascidia mentula* and the bivalve *Angulus tenuis*. The dock walls were dominated by Bryozoa (mainly *Conopeum seurati*) at the start of the study. A dense settlement of the mussel *Mytilus edulis* occurred in the autumn of 1988. This event was followed by a reduction in phytoplankton, an improvement in water clarity and an increase in the depth penetration of macroalgae. Towards the end of the study the dock walls were still largely covered by *Mytilus edulis*, but the cover of ascidians and by the sponge *Halichondria panicea* had increased. Several of the species recorded are of particular interest. The amphipod *Microdeutopus gryllotalpa* is predominantly a south-western species, the alga *Sorocarpus micromorus* is a rarity in Britain, and *Conopeum seurati*, *Corophium insidiosum* and *Palaemonetes varians* were considered to be characteristic of saline lagoons (Barnes 1988). The introduced ascidian *Styela clava* was also recorded.

Allen's (1992) study also examined methods of improving water quality and maintaining it at a high level. Two methods were proposed and tested experimentally. As in Sandon Dock, mixing of the dock water prevented stratification of the water column, reduced oxygen depletion and reduced phytoplankton production. Introduction of *Mytilus edulis* suspended on ropes from rafts also reduced phytoplankton and improved water clarity.

The Mersey estuary was the site of an ambitious proposal for the development of a tidal energy-generating barrage (Haws, Carr & Jones 1987; Wood 1989; Mersey Barrage Company 1990). A symposium was held at Chester in 1989 to provide a forum for discussion of the environmental impacts (Jones & Norgain 1989). A major concern was the predicted loss of intertidal habitats which are used as feeding grounds by birds (Collins 1988, Armitage 1989). Another concern was the effect of a barrage on fish and fisheries. The mortality of fish passing through turbines was discussed by Davies (1989), and the wider implications of a barrage on fisheries by Dempsey (1989). A barrage could also exacerbate the water quality problems in the estuary by reducing the tidal dispersion of sewage effluents, increasing flushing times within the estuary, reducing water exchange with the Manchester Ship Canal, and could lead to algal blooms and 'red tides' (Head 1989). The reduction in tidal range and tidal velocities would allow greater sedimentation of fine particles, resulting in muddier sediments (Burt 1989). Further studies have been commissioned to predict the effects of a barrage on plankton, fish and fisheries, saltmarshes, benthic invertebrates, birds and water quality, and to design a programme for environmental monitoring. Although a barrage was technologically feasible, there were doubts as to its economic viability, and its further development seems unlikely in the near future. A history and overview of the barrage proposals and the consultation process, with a brief review of other threats facing the Mersey estuary, was given by Farrar (1993).

11.6 Greater Liverpool Bay – offshore areas

'Liverpool Bay' is considered to include the area enclosed within a broad arc from the Great Orme to the Fylde coast and which is significantly influenced by the tidal flows of the Dee, Mersey and Ribble estuaries (Figure 11.2). The 'offshore' areas described here are more than 3 nautical miles (about 6 km) from the coast at extreme low water and deeper than 10 m. Parts of this offshore area have been used as a dumping-ground for the disposal of sewage sludge, industrial waste and dredge spoil for many years. To the north of this area, the presence of gas platforms approximately 18 miles (30 km) off Blackpool has ensured that significant benthic sampling has been undertaken, although results are not published. The seabed here is at depths of 25 to 30 m and of between muddy sand and sandy mud dominated by populations of the burrowing brittlestar *Amphiura filiformis* with the sea pen *Virgularia mirabilis*, the burrowing shrimp *Calocaris macandreae* and the crab *Goneplax rhomboides* abundant. Dense populations of the burrowing bivalve *Spisula subtruncata* occur in places (E.I.S. Rees pers. comm.). Recently, commercially exploitable quantities of oil and natural gas were discovered in Liverpool Bay, in four separate reservoirs (Hamilton, Hamilton North, Douglas and Lennox). It is intended to exploit these reserves from remotely controlled development platforms connected to the shore by pipeline, to a terminal at Point of Ayr. Some habitat disturbance is likely around the platforms during platform installation and smothering by discharged drill cuttings. However, the most marked effect on the environment is likely to be due to disturbance by pipe-laying and trenching operations.

Sewage sludge and industrial wastes have been dumped at a site approximately 30 km west of Formby Point. Dredge spoil is dumped at two sites; the majority of the spoil is dumped at site Z, 10 km west of Formby Point, while larger materials such as stones, boulders, wires and ropes are dumped at site Y, farther offshore (O'Sullivan 1975; Rees *et al.* 1992). Sand and gravel extraction also takes place from a licensed extraction area. The effects of the sludge dumping have been monitored through a long-running benthic sampling programme, which commenced in 1970 following initial studies (Rees, Walker & Ward 1972; Rees & Walker 1991; Figure 11.3). The Liverpool Bay sludge dumping studies have involved sampling at over 140 stations, many of which have been sampled over 20 times in the course of repeat surveys (E.I.S.Rees pers. comm.). The macrofaunal communities encountered during surveys undertaken in 1970 were described as corresponding to the shallow offshore sand (shallow *Venus*) community grading into a muddy sand (*Abra*) community at depths of less than about 15 m. Offshore the area had a sandy gravel (deep *Venus*) community but, where there was more mud in the sandy gravel, the community resembled the 'muddy gravel' community found in the English Channel (*sensu* Holme 1966). Rees (1975) and Norton *et al.* (1984) further reported the results of these studies. Up to 20 faunal associations were identified by classification analysis in any one year, but there was considerable variation in the infaunal communities from year-to-year. Variation in sediment composition was found to be of greater importance as a community structuring mechanism than the effects of the dumping. Rowlatt, Rees & Rees (1986) and Rees *et al.* (1992) summarised the results of further studies conducted at the dredge spoil dumping sites.

Rees & Walker (1983) carried out a long-term examination of shallow muddy sand *Abra* communities in the vicinity of the Liverpool Bay dumping stations, and at reference sites in Red Wharf bay on Anglesey. In Liverpool Bay both the rate of input of fine sedimentary particles and the frequency of disturbance was high, and the fauna was consistently dominated by opportunistic species, either the polychaete *Lagis koreni* or the bivalve *Abra alba*. In contrast, the sediments at Red Wharf Bay were more stable, and the community was more diverse. At the Red Wharf Bay reference site biotic interactions were considered to be more important than disturbance as a community structuring force. A consequence was that more conservative species were able to attain numerical dominance but the dominant species varied from year-to-year with only the amphipods *Ampelisca brevicornis*, *Ampelisca tenuicornis* and *Photis longicaudata* dominant for more than one year. A similar community dominated by *Lagis koreni* and *Abra alba* was recorded by Rees *et al.* (1992) from the dredge spoil dumping ground; this community was rapidly replaced by a sparser fauna typical of sandier sediments in the area, when spoil dumping ceased at one of the dumping sites.

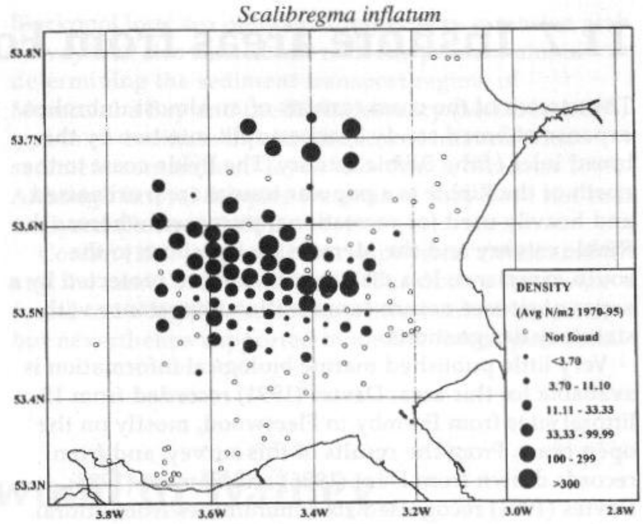

Figure 11.3. Distribution of sites sampled between 1970 and 1995 by the University College of North Wales and showing the abundance of the polychaete *Scalibregma inflatum*. (E.I.S. Rees pers. comm.)

Rees & Walker (1991) analysed the long-term temporal variations in the fauna from the monitoring studies. The overall numerical abundance of the benthos more than doubled during the 1980s, particularly at offshore stations with comparatively stable muddy and gravelly sand. Analysis of species composition showed major differences between surveys conducted during the 1970s and 1980s (consistent with the general increase in numerical density of the benthos, and large increases in the abundance of *Ampharete lindstroemi* and *Anobothrus gracilis*), but the fauna recorded in the final 1988 survey was similar to that from the original 1970 survey. The rise in abundance of the offshore benthos in Liverpool Bay was consistent in timing and extent with changes recorded in the North Sea off the Northumberland coast (Buchanan & Moore 1986), and was coincident with the replacement in Liverpool Bay, of the chaetognath *Sagitta setosa* by *Sagitta elegans* (Williamson 1983). This led Rees & Walker (1991) to suggest that the observed faunal changes in Liverpool Bay were the result of ecological amplification of wider-scale oceanographic events. The long time-series of quantitative benthic samples taken since 1970 in the greater Liverpool Bay area provide an exceptional run of data. The distribution of sample sites is illustrated in Figure 11.3.

11.7 Inshore areas from Formby to Fleetwood

This stretch of the coast consists of an almost unbroken expanse of broad sandy beaches, split into two by the broad inlet of the Ribble estuary. The Fylde coast to the north of the Ribble is a popular tourist area, urbanised and heavily used for recreational purposes, whereas the Ribble estuary and the Merseyside foreshore to the south experience less disturbance and are protected by a series of sites of nature conservation importance with statutory designations.

Very little published marine biological information is available for this area. Davies (1991) recorded from 15 littoral sites from Formby to Fleetwood, mostly on the open coast. From the results of this survey, and from records drawn from Dent (1986) and Bamber (1988), Davies (1991) recognised six communities from littoral sediments. The most widespread infaunal community was recorded from mobile fine sands on the Fylde coast, and from upper shore stations on the open Merseyside coast. This community was an impoverished crustacean/polychaete community characterised by the polychaetes *Nephtys cirrosa* and *Scolelepis squamata* with low numbers of the amphipod *Bathyporeia pelagica*. On the open coast of Merseyside, no macrofauna was found in coarse upper shore sediments, which Davies (1991) described as a 'barren' community. Lower shore sediments contained a much richer community characterised by the bivalves *Mactra stultorum, Fabulina fabula* and *Donax vittatus* and with adundant *Nephtys cirrosa*. The outer Mersey estuary around Formby contained a community dominated by the bivalve *Macoma balthica* and polychaetes. A similar community dominated by *Macoma balthica* and the cockle *Cerastoderma edule* was widespread at the mouth of the Ribble estuary. The sixth sediment community was recorded from estuarine muddy sediments in the Ribble, and at the mouth of the Wyre estuary at Fleetwood. This community was dominated by the bivalve *Scrobicularia plana* and the polychaete *Hediste diversicolor.* Davies (1991) also described three communities from hard substrata, which are very localised on this stretch of the coast. Boulder and cobble scars at Lytham and Fleetwood, and boulder training walls in the Ribble estuary, were dominated by the mussel *Mytilus edulis* with the barnacles *Semibalanus balanoides, Balanus crenatus* and the green alga *Enteromorpha* sp. Similar communities were recorded from artificial hard substrata including groynes and the pier at Blackpool, and from boulders and cobbles in consolidated clay at Cleveleys.

Popham (1966) carried out an extensive survey of the littoral infauna of the Ribble estuary. He described faunal associations from sand, muddy sand, mud, and other more restricted substrata. The polychaetes *Pygospio elegans, Arenicola marina, Lagis koreni*, and the shrimp *Crangon crangon* were recorded commonly from the sandy sediments of the outer estuary; the lugworm *Arenicola marina*, the amphipod *Corophium volutator* and the bivalves *Cerastoderma edule* and *Macoma balthica* from muddy sands; and the polychaete *Pygospio elegans* and the gastropod *Hydrobia ulvae* from muds. Since Popham's (1966) study, dredging of the shipping channel has ceased and changes in the fauna can be expected (H. Jones pers. comm.).

Four littoral sites in the Ribble estuary were surveyed by Davies (1991), and a further eight sites by Davies (1992) (as part of a survey which also included the Duddon estuary and the Ravenglass estuary system in Cumbria). From the results of these surveys, Davies (1992) described six littoral communities from the Ribble estuary:

- a 'crustacean/polychaete' community was present in the mouth of the estuary to the west of Lytham St Annes;
- a '*Cerastoderma/Macoma/Pygospio*' community characterised by the bivalves *Cerastoderma edule* and *Macoma balthica* and the polychaetes *Pygospio elegans* and *Hediste diversicolor* was recorded from extensive mid-shore sediment flats of muddy fine sand at the mouth of the estuary and from muddier sediments to the south-east of Lytham St Annes. This community included two variations:
  - in the sandier sites the polychaete *Nephtys hombergii*, the amphipods *Bathyporeia* spp. and *Corophium arenarium*, and the isopod *Eurydice pulchra* (this variation includes most records of Davies (1991) '*Macoma/Cerastoderma*' community), and
  - in muddier sediments the community was modified by the presence of large numbers of oligochaetes, the polychaete *Capitella capitata*, the amphipod *Corophium volutator*, and the bivalves *Mya arenaria* and *Scrobicularia plana* (this variation includes the '*Scrobicularia/Hediste*' community of Davies (1991)).
- an impoverished '*Arenicola/Corophium/Hediste*' community characterised by the polychaetes *Hediste diversicolor, Pygospio elegans, Capitella capitata* and *Arenicola marina* and by the amphipod *Corophium volutator* was recorded from fine sands in the middle reaches of the estuary. Davies (1992) labelled this community 'transitional' as it had features in common with both the '*Cerastoderma/Macoma/ Pygospio*' and '*Hediste/Corophium*/oligochaete' communities, and with the richer variation of this community recorded in the Duddon and Ravenglass estuaries;
- a '*Hediste/Corophium*/oligochaete' community was widespread in muddy sediments throughout the mid- and upper reaches of the estuary, characterised by *Hediste diversicolor*, oligochaetes (*Tubifex costatus* and unidentified Enchytraeidae) and *Corophium volutator;*
- communities on hard substrata were similar to those described by Davies (1991) on the open coast. Boulder and cobble scars and training walls at the mouth of the estuary were dominated by the mussel *Mytilus edulis* with the barnacles *Semibalanus balanoides,*

Balanus crenatus with the algae *Enteromorpha* sp. and *Fucus vesiculosus*;

- species richness declined up the estuary, so that an impoverished '*Enteromorpha*/barnacle' community was found on training walls adjacent to the river channel, which were subject to low salinity, exposure to tidal streams, sediment-scour and pollution.

The North West Water Authority commissioned surveys in this area, in relation to sewage discharges. A benthic infaunal survey was carried out from Lytham St Annes to Fleetwood during 1988, in the area of proposed Blackpool long sea outfalls. Another very extensive grab survey was also carried out with the primary aim of determining the sediment transport regime of Morecambe Bay and the Ribble estuary (McLaren 1989), and to co-ordinate the distribution of infauna with sediment contaminant levels (Rostron & McLaren 1989). Although littoral samples were taken they have not been analysed (Rostron 1990).

Conlan (1987) reported on the physical environment and the fauna of Preston docks. The dock waters were found to be highly eutrophic, with a marked oxycline, but nevertheless supported moderate fish populations.

11.8 Morecambe Bay (Fleetwood to Walney Island)

The area described here is encompassed within a line drawn from Fleetwood to Walney Island (Figure 11.4). The intertidal area of Morecambe Bay is 33,750 ha, which is the largest single area of intertidal sand and mudflats in Britain (Davidson *et al.* 1991). The intertidal area was once larger, but has been reduced by past land claim, particularly during the nineteenth century (Robinson 1987). The international ornithological importance of the intertidal areas of Morecambe Bay has resulted in SSSI, SPA and Ramsar designations, and the establishment of nature reserves.

The Lune Deep, at the mouth of Morecambe Bay, is an unusual geological feature. This is thought to be a relict kettle hole, formed at the end of the last ice age, when the melting of sub-surface ice caused the surrounding moraines to collapse into a large crater (McLaren 1989). The Lune Deep has a maximum charted depth of over 80 m, strong tidal streams, and steep sides from which boulders and cobbles outcrop.

There are many actual and potential impacts on Morecambe Bay. Morecambe and Grange-over-Sands are holiday resorts, but the effects of tourist pressure on the shores has been limited to a narrow strip in the vicinity of the resorts. Dredge spoil is dumped at two sites, in the Lune Deep and to the south of Walney Island. Industrial and agricultural pollution is carried into the Bay by rivers. Sewage treatment and outfall arrangements around Morecambe Bay lead to localised pollution and designated bathing beaches have failed to meet the microbiological standards of the EC Bathing Water Directive.

Several schemes have been proposed that could have a potentially damaging effect on the marine biological interest of Morecambe Bay. A proposal for the construction of water storage reservoirs in the Bay was considered as one of four alternative schemes to provide increased water storage capacity for the north-west of England (Water Resources Board 1970). This proposal led to detailed feasibility studies (Sir Alexander Gibb & Partners 1970). An initial assessment of the suitability of the estuaries of the Rivers Lune and Wyre for tidal energy generating barrages was made as part of a wider desk study examining the potential of small estuaries for tidal power (Binnie & Partners 1987). The study concluded that the Wyre was likely to be a suitable site. The Lune Deep, with its strong tidal streams and deep water, has been proposed as a site for a long sea outfall for the Fylde Coastal Waters Improvement Scheme. The Lune Deep was surveyed in 1993 by the MNCR.

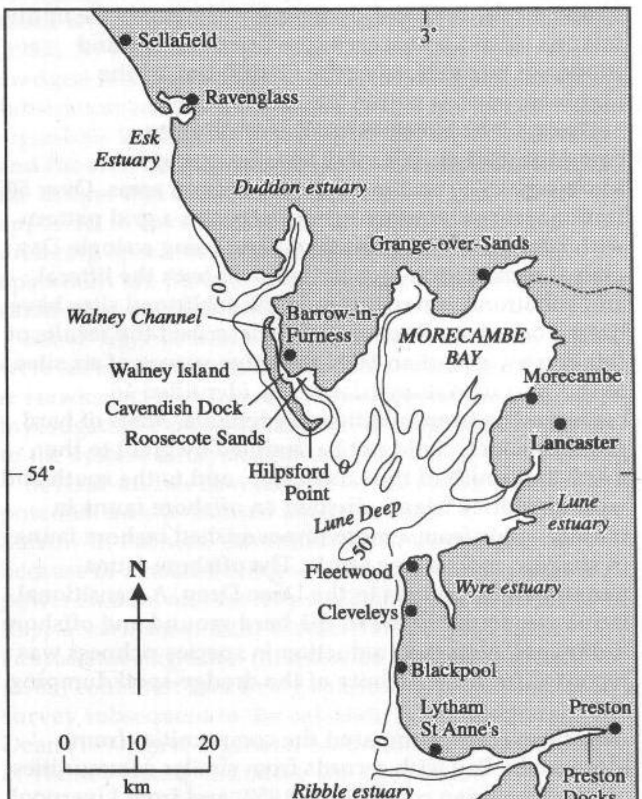

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Figure 11.4. Morecambe Bay and adjacent areas, showing places mentioned in the text.

The review of the biology of Morecambe Bay by Robinson & Pringle (1987) highlighted the paucity of reliable marine biological studies in this area.

In order to assess the possible impact of the proposals for the construction of water storage reservoirs on invertebrate populations, Anderson (1972) conducted extensive surveys of many of the intertidal flats in the bay. She recorded a very low species richness, but abundance of the dominant species was very high at those sites with a high silt content. The bivalve *Macoma balthica* was the dominant species recorded. Three species groups were recognised, with height on the shore the principal factor determining the group present at any station:

- a group characterised by the gastropod *Hydrobia ulvae* and the amphipod *Corophium volutator* occurred on high-level flats;
- a group including the polychaetes *Arenicola marina* and *Hediste diversicolor*, the cockle *Cerastoderma edule* and the amphipod *Bathyporeia pilosa* was recorded principally at intermediate heights on the shore;
- a further group characterised by the bivalve *Angulus tenuis* and the polychaete *Nephtys hombergii* restricted to low-level flats.

A further 17 littoral sites in Morecambe Bay and its tributary estuaries were surveyed by the MNCR during 1991 (MNCR, unpublished raw data). Matchett (1969) examined the seasonal changes in the abundance of the infauna on two transects in the Lune estuary and produced maps showing the distribution of the dominant species within the estuary.

During 1988 North West Water Authority commissioned an extensive benthic survey in Morecambe Bay and in adjacent offshore areas. Over 500 stations were identified for sampling on a grid pattern with stations 800 m apart. Sampling using a single Day grab at each station was carried over both the littoral and sublittoral zones, but only the sublittoral sites have been worked up. Rostron (1992) described the results of this survey, and of an MNCR dredge survey of six sites to the west of Walney Island. She identified 16 communities from sublittoral sediments. Areas of hard ground (which could not be sampled by grab) to the north and south of the Lune Deep, and to the south and west of Walney Island, divided an offshore fauna in muddy sands from a more impoverished inshore fauna in shallow, mobile fine sands. The offshore fauna penetrated landwards in the Lune Deep. A transitional fauna was found between the hard ground and offshore sediments. A marked reduction in species richness was recorded from the vicinity of the dredge-spoil dumping site.

Rostron (1992) compared the communities from Morecambe Bay with records from similar communities off the Cumbrian coast (Jones 1952) and from Liverpool Bay (Eagle 1973; Rees & Walker 1983). The majority of subtidal samples from Morecambe Bay were similar to the *Abra* community described by Eagle (1973) and Rees & Walker (1983), which typically contains large numbers of the bivalve *Abra alba* and the polychaete *Pectinaria* (now *Lagis*) *koreni*. This community is widespread in the Irish Sea in small localised patches, mostly in embayments (Mackie 1990). In Morecambe Bay numbers of *Abra alba* were relatively low, as were numbers of the bivalve *Spisula subtruncata*, wheras the bivalve *Nucula nitidosa* was present at very high densities. Muddy areas sampled at depths greater than 15 m were characterised by the brittlestar *Amphiura filiformis*. This *Amphiura* community was similar to that recorded by Jones (1952) off Cumbria, and from elsewhere in the Irish Sea (Mackie 1990). However, densities of *Amphiura filiformis* were generally lower in the Morecambe Bay samples, and the numbers of bivalve species higher than were recorded by Jones (1952) and Rostron (1992) farther offshore. The Lune Deep fauna contained high densities of *Lagis koreni* but the community was richer than from shallower inshore sediments dominated by *Lagis koreni* in Liverpool Bay. The inshore shallow sands contained a sparse fauna dominated by the polychaete *Magelona mirabilis* and the bivalve *Tellina* (now *Fabulina*) *fabula*.

Nine sites in the Lune Deep were surveyed by diving (Emblow 1992). The sites surveyed, with two exceptions, were heavily silted boulder and cobble slopes with a dense hydroid and bryozoan turf. The sediment between the rocks supported a diverse fauna in which the anemones *Urticina felina* and *Cerianthus lloydii* and the peacock worm *Sabella pavonina* were conspicuous. At the lower extreme of the boulder slopes, there was a transition to a sediment slope with a community of dense *Sabella pavonina* and *Cerianthus lloydii*. A plain of fine, firm, rippled sand with a sparse fauna was recorded from a tide-swept site in the centre of the channel, and an impoverished flocculent mud plain at a site on the south side of the channel.

Unpublished lists of invertebrate species for the few areas of littoral hard substrata present in Morecambe Bay were included in Adams (1987). Jones, Merritt & Clare (1987) described a very restricted algal flora in the Bay, limited to the few species of opportunistic algae which were able to tolerate sand deposition and the heavy mussel spatfalls. A very detailed long-term study has been carried out by Jones (1990), who had monitored the changes in the flora and fauna of a mussel bed at Heysham since 1956. An unusual artificial habitat recorded during the 1991 MNCR survey was a tidal boating lake at Morecambe. Permanently submerged, vertical walls within the lake were dominated by lush algal cover, and by the immigrant ascidian *Styela clava*. The ramped outer slope of the lagoon was kept permanently wet by seawater spilling out from the lake, and supported dense fucoid growth (MNCR, unpublished data). Another unusual biological feature recorded from the Bay was the presence of large numbers of detached spherical colonies of the hydroids *Sarsia tubulosa* and *Tubularia larynx* (Clare, Jones & O'Sullivan 1971). The cause of the abnormal colony development was not identified, but the authors hypothesised that a possible chemical pollutant might be responsible.

Morecambe Bay is an important nursery ground for various species of flatfish, and supports a fishery for the shrimp *Crangon crangon* and cockle *Cerastoderma edule*. Massive mortalities of *Cerastoderma edule* occurred in the cold winter of 1962/1963 (Crisp 1964), resulting in the effective collapse of the fishery. The fishery did not recover until the late 1970s (Corlett *et al.* 1987). Dare (1971) described the ecology of the mussel *Mytilus edulis* in Morecambe Bay. Very large numbers of spat settled on any suitable substrata during the spring period, and suffered extremely high mortality as a result of storms and scour from equinoctial tides. Connected with heavy spatfalls of *Mytilus edulis* are periodic population explosions of the starfish *Asterias rubens* (Jones 1987).

Several recent studies deal with potential impacts in areas in the north-west part of Morecambe Bay. The fauna of Roosecote Sands was described by Piearce (1988), in a study conducted in order to assess the effects of the extraction of sand from a shore. A steep-sided borrow pit was excavated by suction dredging to a depth of 5 m below the surrounding sediment surface. The borrow pit formed a lagoon at low tide, into which extensive sediment accretion occurred once dredging ceased. The amphipod *Bathyporeia* spp. was recorded at high levels of abundance in the unstable sands filling the borrow pit. The surrounding sediments were fine sands populated by the polychaetes *Hediste diversicolor* and *Arenicola marina*, the gastropod *Hydrobia ulvae*, the amphipod *Corophium* sp., and the bivalves *Scrobicularia plana*, *Cerastoderma edule* and *Macoma balthica*.

The development of the North Morecambe Gas Field in the Irish Sea requires a new gas pipeline to connect the Gas Field with an expanded Barrow Gas Reception Terminal at Westfield, to the east of Roosecote Sands. The route crosses Walney Island, Snab Sands and the Walney Channel, and passes to the north of Head Scar. British Gas commissioned an ecological survey of the new pipeline route, including marine biological, saltmarsh and ornithological studies (George *et al.* 1992). Earlier studies provided an environmental assessment of the development of the North Morecambe Terminal (Scott & Sykes 1991).

Snowden (1982) examined the effects of a thermal effluent into the Walney Channel. He recognised four principal habitats/community types based on substratum:

- a 'mudflat' community dominated by the polychaete *Arenicola marina*, the amphipod *Corophium volutator*, and the bivalves *Scrobicularia plana*, *Macoma balthica* and *Cerastoderma edule*;
- a 'stony-area' community with the barnacle *Elminius modestus*, gastropods *Littorina* spp., and the algae *Pelvetia canaliculata* and *Enteromorpha* spp.;
- a 'man-made substratum' community similar to that from the 'stony-area' community;
- a community characterised by the sipunculan *Golfingia vulgaris* from mixed substrata of stones and pebbles with mud and sand.

Further records for this area were given in Covey & Davies (1989) and Emblow (1992). Covey & Davies (1989) sampled from the shore at Roa Island at the southern entrance to the Walney Channel. The substratum on the lower shore was composed of pebbles and cobbles, which were subject to strong tidal streams and sediment-scour. This habitat supported a rich fauna characterised by sponges including *Halichondria panicea*, *Hymeniacidon perleve*, *Scypha ciliata*, *Halisarca dujardini*, *Leucosolenia complicata* and *Myxilla incrustans*. Scattered algae were attached to the stones, which were also encrusted by the tubiculous polychaete *Pomatoceros triqueter* and the barnacle *Balanus crenatus*. Many other animals were present living between and under the boulders and cobbles. A sublittoral site at Head Scar, adjacent to the Walney Channel, was sampled by Emblow (1992). This site was tide-swept, with a substratum of cobbles and boulders which were covered in a dense epifauna of sponges and hydroids. The peacock worm *Sabella pavonina* was particularly abundant. The algal flora of South Walney was described by Rose (1990).

Trident submarines are constructed at Vickers Shipbuilding and Engineering Limited, Barrow-in-Furness. The large size of these vessels required a substantial dredging operation in the Walney Channel to allow passage from the dock to sea. The effects of the dredging were assessed by the Marine Conservation Society's Lancashire area group and the results were included in George *et al.* (1992). Prior to dredging, the substratum and fauna recorded to the south-west of Head Scar were as recorded by Emblow (1992). By November 1992 the channel had been dredged to a depth of 3.2 m bcd removing the cobble substratum and attached fauna so that only a few mobile organisms such as the nudibranch *Onchidoris bilamellata* and the crab *Carcinus maenas* were recorded. However, the deeper Piel Channel, to the south of Roa Island appeared to have been relatively unaffected by the dredging operations. Other effects of the dredging operations are thought to be increased turbidity and smothering of benthic organisms.

Saline lagoons near Hilpsford Point on Walney Island were identified as of scientific interest by Hill, Cameron & Hawkins (1987). Lumb (1988) surveyed the lagoons to investigate the possible impacts of proposed alterations to the system for oyster culture.

Several studies have described the fauna, and potential uses of disused dock basins at Barrow-in-Furness. Cavendish Dock was of interest because of a heated effluent discharged into it from a power station, and for its populations of the seagrass *Ruppia maritima* and the Mediterranean polychaete *Ficopomatus enigmatica* (Markowski 1962). Hendry *et al.* (1988) could not find living specimens of *Ficopomatus* in a survey subsequent to the cessation of the discharge. Dean [1990] gave a general acount of the natural history of Walney Island, including the littoral zone.

11.9 The Cumbrian coast: Walney Island to St Bees Head

From Walney Island to St Bees, the littoral habitats of the open coast, and at the mouth of the Duddon and Esk estuaries, are predominantly mobile fine sandflats of low species richness, containing a crustacean/polychaete community dominated by the amphipods *Bathyporeia* spp. and *Haustorius arenarius* and the polychaete *Nephtys* spp. (Perkins & Ismay 1981; Covey & Davies 1989; Davies 1992). Interspersed with the sandflats on the open shores are boulder and cobble scars, which provide hard substrata for colonisation by rocky shore species, including the reef-building polychaete *Sabellaria alveolata* (Figure 11.5). The only extensive area of rocky shore on the Cumbrian coast is at St Bees Head. A wide range of rocky shore habitats and rich rockpool and lower shore/sublittoral fringe communities have been recorded here (Covey & Davies 1989; E.J. Perkins pers. comm.). A detailed species list for the algae of St Bees Head was given by Powell (1956).

In addition to open coast sites, Covey & Davies (1989) also recorded from sites in the Esk estuary at Ravenglass, the upper Duddon estuary and from the Walney Channel. Drawing on records from Covey & Davies (1989) for the Duddon and the Ravenglass estuaries, and on records from a later survey, Davies (1992) identified ten communities in these estuaries, six from hard substrata and four from sediments. Hard substrata were very localised in occurrence. Askam pier, at the mouth of the Duddon estuary, is composed of an unusual form of artificial substratum which was formed as the result of dumping of blast furnace slag on the shore. The pier, a bedrock outcrop at Hodbarrow Point in the Duddon estuary, and railway viaduct pilings in the Ravenglass system all supported very similar communities. Other hard substrata included boulder training walls, and stones and pebbles adjacent to river channels or in the estuary mouth. The four communities recorded from sediment were:

- a 'crustacean/polychaete' community in the mouths of the estuaries;
- a '*Cerastoderma/Macoma/Pygospio*' community in muddier sands at the mouth of the Duddon estuary;
- an '*Arenicola/Corophium/Hediste*' community found throughout the central Duddon estuary and the mid- and lower reaches of the Rivers Esk, Mite and Irt in the Ravenglass system;
- a '*Hediste/Corophium*/oligochaete' community from estuarine mud in the upper reaches of the Ravenglass system.

The '*Cerastoderma/Macoma/Pygospio*' community was characterised by the bivalves *Cerastoderma edule* and *Macoma balthica* and the polychaetes *Pygospio elegans* and *Hediste diversicolor* with the polychaetes *Eteone longa*, *Arenicola marina*, and *Capitella capitata* present sporadically but at high abundance. The '*Arenicola/Corophium/Hediste*' community was characterised by the polychaetes *Hediste diversicolor*, *Pygosio elegans*, *Capitella capitata* and *Arenicola marina*; and the *Hediste/Corophium*/oligochaete community by *Hediste diversicolor*, oligochaetes (*Tubifex costatus* and

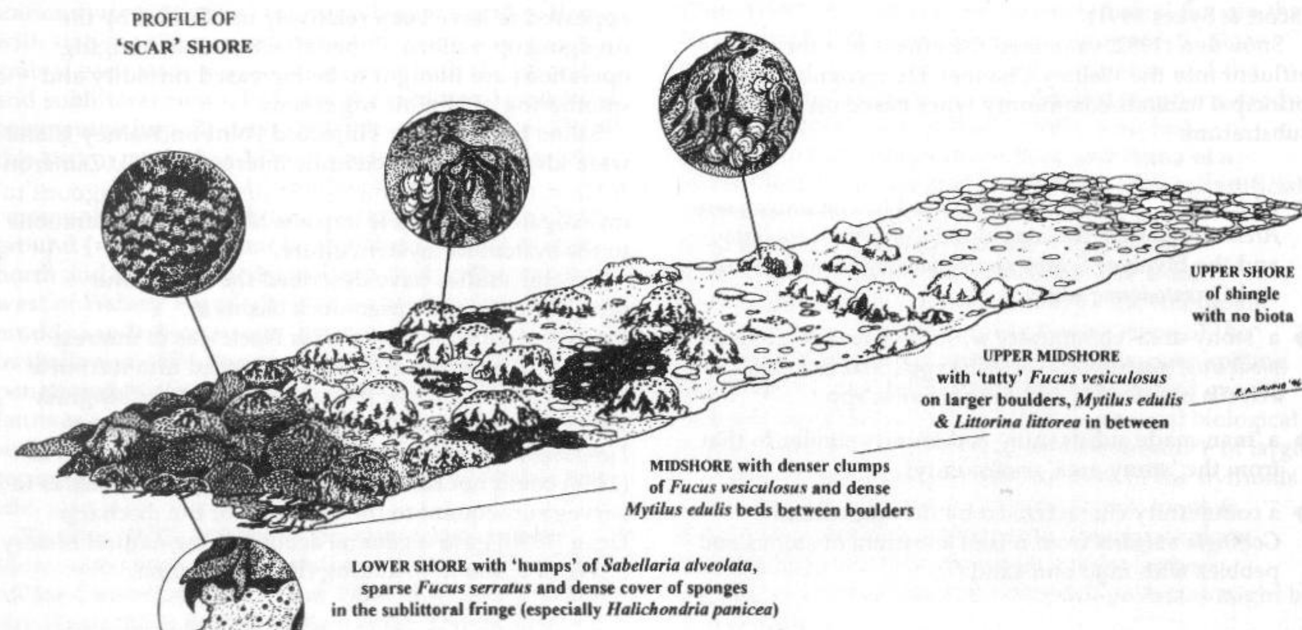

Figure 11.5. Profile of a boulder and cobble scar including colonies of the honeycomb worm *Sabellaria alveolata*. Drawing by Robert Irving.

unidentified Enchytraeidae) and *Corophium volutator*. The burrowing beetle *Bembidium laterale* was frequent in the sediments from the upper shore within the Esk estuary. At Scarth Bight, in the northern Walney Channel, a variation on the '*Hediste/Corophium/* oligochaete' community was recorded by Covey & Davies (1989), in which the bivalves *Scrobicularia plana* and *Mya arenaria* and the gastropod *Hydrobia ulvae* were common.

Sublittoral data from this coast is limited to the results of occasional dredging (Perkins & Ismay 1981, Greenwell & Perkins 1978, 1979; MNCR reported in Rostron 1992), grab surveys (Jones 1952; Jensen & Sheader 1986; Swift 1993) and a few sites from a single diving survey (Emblow 1992). Swift (1993) described an offshore benthic survey off the coast from Ravenglass to St Bees Head up to 25 km offshore. Sixty-nine stations were sampled between May 1983 and March 1989, using a Reineck box-corer to sample deep-burrowing organisms. Cluster analysis of species data from spring cruises showed three station groups associated with sand, sandy mud and muddy sand sediments. However, the results of clustering data collected from autumn cruises was less clear. Swift (1993) was particularly interested in the bioturbating fauna in the area because of their activities affecting the mobilisation of sediment bound radionuclides. He found the echiuroid worm *Maxmuellaria lankasteri* to be an important bioturbating organism, which turns over the sediments to considerable depths. The muddy sediment area covered by this survey is an area where the bottom sediments are derived from pre-glacial clays, and are muddier than those elsewhere in the eastern Irish Sea. The muddy sediments allow burrowing by the Norway lobster *Nephrops norvegicus*, and the area supports a localised fishery for this species (Taylor & Parker 1993).

Four sublittoral sites near St Bees Head were surveyed by Emblow (1992). In contrast to the rich algal communities in the littoral zone, sublittoral algal communities were poor. Bedrock on the lower shore gave way to boulders, with kelp and red algae (in poor condition) extending down to a depth of 2–3 m. The circalittoral zone was dominated by the bryozan *Flustra foliacea*, a species typical of habitats scoured by sand. At depths greater than 4–5 m below chart datum, the bouders were replaced by a mobile and impoverished sand-plain. Two sites on an exposed boulder scar off Selker, subject to moderately strong tidal streams, were also surveyed by Emblow (1992). These sites had a mixed substratum of boulders, cobbles, pebbles and gravel, which supported a rich assemblage of species, including the algae *Dilsea carnosus*, *Halidrys siliquosa* and *Laminaria hyperborea*, and a fauna consisting mainly of sponges, hydroids, colonial ascidians and the peacock worm *Sabella pavonina*.

The shore and seabed off Sellafield has been sampled by Applied Environmental Research Ltd to provide detailed baseline information of the distribution of species and of diversity within the area of potential impact of a proposed pressurised-water reactor sited at Sellafield. In addition to infaunal sampling, recording of species on hard substrata, fish sampling and zooplankton sampling was also carried out.

11.10 The Cumbrian shore of the outer Solway: St Bees Head to Dubmill Point

The area is shown in Figure 11.6. This part of the Cumbrian coast has been the scene of industrial activity for over 250 years. Mining has had a major impact, through colliery spoil dumped directly onto the shore and from the effects of acid mine drainage. Blast furnace slag has also been dumped onto the shore. There are several discharges of industrial effluents, the largest of which is from the Albright and Wilson chemical plant which discharges into Saltom Bay, to the north of St Bees Head.

Marine biological survey work in the Solway has proceeded in several discrete phases of activity. The first phase of activity was related to the monitoring of the discharges of radioactive materials from the British Nuclear Fuels Ltd reprocessing plant at Sellafield. This work involved littoral and dredge surveys and was extensive in coverage. Subsequently, and until recently, survey work concentrated on the monitoring of discharges from industry with possible fisheries implications, concentrating on the Cumbrian shore of the Solway. In the last few years there have been a number of studies of a descriptive nature, and studies concerned with monitoring the effects of new sewage treatment plants.

Within the Solway, hard substrata are limited in extent, and consist mainly of exposures of boulder clay, which are known locally as 'scars'. Once exposed, the clay is usually eroded from the boulder interstices, leaving extensive areas of boulder shores. Outcrops of bedrock are very localised. In some areas, the movement of sediments means that scar exposures may appear suddenly, only to be smothered again by sediment shortly afterwards. Perkins (1986) described the ecology of littoral scar grounds in the Solway. The richness of the biota of littoral scars was dependent on the frequency of inundation by sand. Where scars remained free from sand cover for long periods, the biota recorded was similar to that of a rocky shore. Some species typical of sedimentary shores were also recorded living as infauna within the boulder clay (e.g. the polychaete *Lanice conchilega*). The hard substratum was suitable for colonisation by the honeycomb worm *Sabellaria alveolata*, which formed large reefs on some of the Cumbrian shores. A succession of colonising species has been recorded on scars subject to periodic exposure and inundation with sediment. During the early stages of colonisation the species richness of the communities was

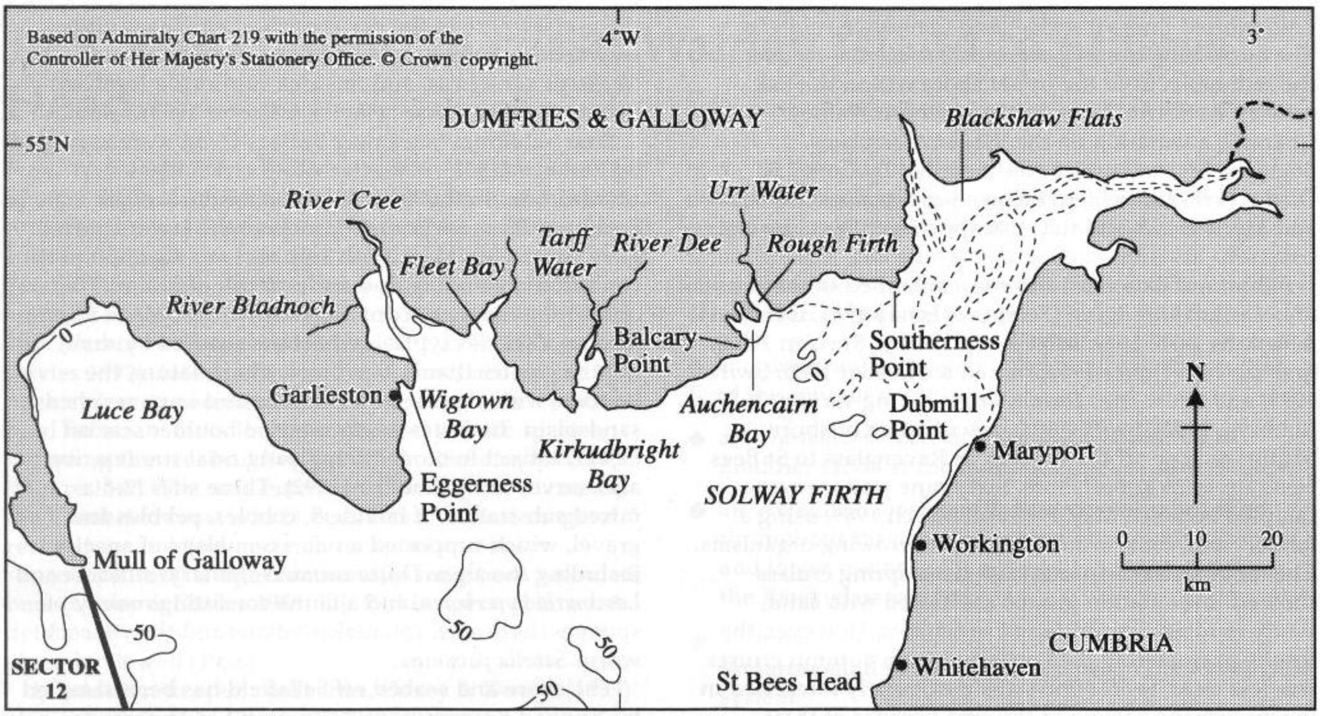

Figure 11.6. The Solway Firth, showing places mentioned in the text.

very low (Perkins 1977). In some areas, the mobile sediments very severely scoured the hard substrata, greatly reducing species diversity (Perkins 1981a).

Another form of hard substratum which is present on the Cumbrian coast is formed from the dumping of blast furnace slag on the shore. These 'slagcrete' reefs vary in hardness, but are generally soft and erode rapidly. However, they can support moderately rich algal communities when erosion rates are low (E.J. Perkins pers. comm.).

The fauna of the sandflats of the Solway Firth was recorded by Perkins & Williams (1966); descriptions of littoral sites recorded during this study were given in Perkins (1973). The fauna of the littoral sediments in the outer Solway included *Corophium volutator*, the polychaetes *Arenicola marina* and *Owenia fusiformis*, and the bivalves *Scrobicularia plana, Macoma balthica, Cerastoderma edule, Angulus tenuis, Fabulina fabula, Abra alba, Nucula sulcata* and *Donax vittatus*. Perkins & Williams (1966) also described the distribution of sublittoral communities. The sublittoral zone of the outer Solway was richer than the barren channels of the inner Solway, with fine sand sediments characterised by the bivalves *Mactra stultorum* and *Donax vittatus*, medium sands by the bivalve *Spisula solida*, and muddy sands by the polychaete *Nephtys* spp. and the bivalves *Nucula sulcata, Abra albida* and *Angulus tenuis* (Perkins & Williams 1966; Perkins 1973).

The communities recorded from sublittoral scar grounds were essentially similar to those normally found in sublittoral rocky areas, with rich and well developed epifaunal communities characterised by the sponge *Halichondria panicea*, the hydroid *Abietinaria abietina*, the polychaete *Sabellaria alveolata*, the gastropod *Buccinum undatum*, the horse mussel *Modiolus modiolus*, the bryozoan *Flustra foliacea* and the ascidian *Dendrodoa grossularia* in areas where the boulder clay had remained free of sand inundation for an extended period (Perkins 1981b). The biomass per unit area recorded from scars was generally one or two orders of magnitude greater than that recorded from adjacent sands. Sublittoral scar grounds were also considered to be important for the presence of commercially important species such as the edible crab *Cancer pagurus* and lobster *Homarus gammarus*, and for the fish that use them as feeding-grounds (Perkins 1981b, 1986).

The effects of coal mining and other industrial solid wastes on the marine environment of the Solway Firth was examined by Perkins (1990). Particles derived from industrial sources, such as the dumping of colliery spoil and slagcrete on the shores, and of the erosion of colliery bings, are dispersed by longshore drift and constitute a significant proportion of the sedimentary material on the Cumbrian coast. The Cumbrian shore is subject to marked sediment instability and erosion, with changes in shore levels of metres being recorded over short time-scales (Perkins 1986). Perkins (1990) considered that variations in the rate of input of industrial solids is a major factor in bringing about this sediment instability. The large quantities of coal in these sediments further contributes to this instability by reducing the cohesiveness of the sediments. The sediment instability affects the biota in several ways, the infauna of unstable sediments may be washed away by eroding sediments, both the infauna and epifauna of hard substrata may be smothered by sediment deposition, and severe scouring may restrict the biota of hard substrata. An example of the effects of sediment erosion was provided by Perkins (1990) for a site at Beckfoot. In 1962 this site was covered by sand to a depth of 2 m, which contained a fauna dominated by *Cerastoderma edule*, *Macoma balthica* and *Tellina* (now *Angulus*) *tenuis*. By 1983 the sand had been reduced to a thin layer over shingle and isolated cobbles with a fauna dominated by the opportunistic crustaceans *Eurydice pulchra* and *Haustorius arenarius*, which are typical inhabitants of mobile sands.

Another effect of coal mining on the littoral biota is caused by acid mine drainage. Acid mine drainage flows across the shore at Cunning Point, resulting in the deposition of a highly polished patina of iron oxide on the gravel, cobbles and pebbles in the flow, and on the shells of periwinkles *Littorina littorea* living in the flow (Perkins 1990). The effects of the mine drainage recorded by Perkins (1990) appeared to be localised; *Fucus serratus* was absent from the affected area, but many other species were recorded living on the shore washed by the flows.

In addition to industrial discharges, there are many coastal sewage outfalls which discharge untreated raw sewage onto the shore, or into shallow water. Work is currently underway to improve this situation by the installation of long sea outfalls and new sewage treatment works (P. Head pers. comm.). In order to assess the effects of these works, a baseline survey of the intertidal flora and fauna from St Bees Head to Maryport was carried out by Allen *et al.* (1992). They recorded from 20 sites, mainly in the vicinity of existing outfalls, but also from reference sites at some distance from the outfalls. Where hard substrata were present within 500 m of the outfall, they recorded the fauna and flora present, but infauna were sampled from four sedimentary sites. Bedrock shores were of restricted occurrence in the survey area, generally at the more exposed sites. The zonation pattern on these shores generally consisted of a band of ephemeral green algae in the littoral fringe (and in areas subject to sand-scour), a barnacle-dominated upper shore, and dense mussels *Mytilus edulis* on the lower shore. Faunal diversity was highest on the lower shore, where dogwhelks *Nucella lapillus*, anemones (*Actinia* spp., *Urticina felina*, *Sagartia troglodytes*), the starfish *Asterias rubens*, the sponge *Halichondria panicea*, bryozoans and hydroids were frequently recorded. Fucoid cover was generally sparse except at a site north of Maryport, which was less exposed than other sites, but rockpools supported lush growth of red and green algae. Cobble shores were more widespread, and usually had a band of 'slagcrete' on the upper shore. Ephemeral green algae were present on the upper shore, and on unstable boulders. Lower shore cobbles were animal-dominated, stabilised by dense mussel beds, and grazed by large numbers of the winkle *Littorina littorea* so that the algal flora was restricted to *Cladophora sericea* and the grazing-resistant species *Dumontia contorta*, *Chondrus crispus* and *Mastocarpus stellatus*. The honeycomb worm *Sabellaria alveolata* formed dense beds on some shores, although at some sites large areas of the colonies were dead, which the authors suggested may have been due to the cold winter of 1991–92. Covey & Emblow (1992) also recorded from cobble shores to the north of Maryport, which were colonised by *Sabellaria alveolata* which stabilised the cobbles and provided suitable substrata for algae and the sponge *Halichondria panicea*.

11.11 The inner Solway: Dubmill Point to Southerness Point

The area is shown in Figure 11.6. The Solway contains extensive areas of littoral sandflats (the inner Solway is a zone of sediment accretion – Marshall 1962; Rowe, Phillips & Maltby 1978). The fauna of these sandflats as recorded by Perkins & Williams (1966) and Perkins (1973), characteristically included the gastropod *Hydrobia ulvae*, the bivalves *Scrobicularia plana*, *Macoma balthica* and *Cerastoderma edule*, the amphipods *Corophium volutator* and *Bathyporeia* spp. and the polychaetes *Arenicola marina* and *Lanice conchilega*.

More recent surveys in the inner Solway include a littoral survey carried out by the MNCR during August 1991, which described sites from Balcarry Point on the Scottish coast, to Maryport on the Cumbrian coast (Covey & Emblow 1992), and monitoring surveys conducted by the Solway River Purification Board. The Solway River Purification Board carry out regular biological and trace metal monitoring of sediment shores on the Scottish shore of the inner Solway, to the east of Southerness Point, to monitor the effects of industrial discharges (Rendall 1990, 1992; Rendall & Bell 1993a). Twenty-two sediment stations are routinely sampled by coring. The dominant species recorded by both Rendall (1992) and Rendall & Bell (1993a) were the polychaete *Pygospio elegans*, the amphipod *Corophium volutator*, the mud snail *Hydrobia ulvae* and the bivalve *Macoma balthica*, a community very similar to that recorded by Covey & Emblow (1992). Rendall & Bell (1993a) examined the temporal stability of the fauna. The fauna at most sites was reasonably stable, with the exception of sites from unstable sediments adjacent to river channels, a similar conclusion to that of Perkins & Williams (1966) who found the fauna of the mobile mid-channel sandbanks to be generally less rich than the comparatively stable fringing sand banks. Rendall & Bell (1993a) also performed multi-variate analysis on their data, which suggested that the most significant factor influencing the fauna was sediment grain size (median particle size and silt/clay content).

Perkins & Williams (1966) also described the distribution of sublittoral communities in the Solway. In the inner Solway sublittoral habitats are largely restricted to the channels, which were found to be generally impoverished. Further records are available from Rendall & Bell (1993b) who sampled from five low water channel sites in the inner Solway, Eden and Esk estuaries. The very fine sand sediments in the Esk and Eden estuaries contained an extremely impoverished infauna but a single site in the main channel contained moderate numbers of the *Bathyporeia pilosa* and tellinid bivalves.

Further studies of the inner Solway have recently commenced to ensure an accurate record of the species distribution and diversity within the area of potential impacts associated with a proposed pressurised water reactor sited at Chapelcross, near Annan. In a two-year study, 20 sites near to Chapelcross in the Eden channel and on the adjacent flats have been sampled monthly since January 1992 using grabs, and a further eight sites by coring on the shore. In addition to the monthly sampling of this central 'high frequency zone', a further ten sites to seaward and ten to landward (subsequently reduced to nine) have been sampled at six-monthly intervals by grabbing, and three sites to seaward and four sites to landward by grabbing. In addition to infaunal sampling, recording of species on hard substrata, fish sampling and zooplankton sampling has also been carried out. The dominant species found in the 'high frequency zone' are *Bathyporeia pilosa, Macoma balthica, Eteone longa, Corophium volutator* and *Haustorius arenarius* (Applied Environmental Research Ltd., unpublished preliminary report).

Hard substrata are very restricted within the enclosed inner Solway. Covey & Emblow (1992) recorded from viaduct pilings and from cobbles which were interspersed with, and frequently covered by deposited mud. These mixed hard/sediment habitats were characterised by a mixture of infaunal species such as *Hediste diversicolor, Corophium volutator, Arenicola marina* and *Macoma balthica* which occurred with epifaunal species including *Littorina littorea, Littorina saxatilis* and *Balanus* (now *Semibalanus*) *balanoides*.

11.12 The Scottish shore of the outer Solway: Southerness Point to the Mull of Galloway

The area is shown in Figure 11.6. To the east of Rough Firth, the Scottish shores of the Solway Firth are predominantly sedimentary. To the west, sedimentary shores are restricted to the inlets of Auchencairn Bay, the estuaries of the River Dee, Water of Fleet, the River Cree, and at the head of Luce Bay. The shores of the open coast are generally rocky, composed predominantly of boulders, with bedrock outcrops in places. There are few large population centres on this coast, little industry, and few sources of polluting discharges. There have been a few studies of the littoral fauna and flora in this area, but information on the biology of the sublittoral is extremely scarce.

Burrows (1960) produced a preliminary list of algal records for the Scottish Solway coast. Subsequently, Wilkinson (1975) recorded estuarine algal communities in the estuaries of the Dee and Tarff, the Water of Fleet and the Urr Water. Algal species richness declined with distance upstream from the mouth of the estuaries, with red and brown algae being selectively excluded by the reduced salinity. Species characteristic of brackish water were present including *Vaucheria* spp., *Fucus ceranoides* and *Monostroma oxyspermum*. The upper reaches of the estuary were characterised by green algae and *Vaucheria* spp. Further algal records for Eggerness Point, Garlieston Harbour and the Bladnoch estuary were reported by Wilkinson (1980).

Perkins (1973) provided outline descriptions of the biota of 85 sites on the Scottish Solway coast, from the Mull of Galloway to the inner Solway. He concentrated his sampling on the inner Solway, and on the estuaries of the Rivers Cree and Dee, the Water of Fleet, and Auchencairn Bay and Rough Firth. Coverage of the open coast was limited in extent. Descriptions of all sites surveyed by Perkins (1973) and further sites surveyed by Perkins (1977, 1981a and b); Hill, Cameron & Hawkins (1987); Rendall (1990); Wilkinson (1975, 1980) and Eleftheriou & McIntyre (1976) were included in Covey & Emblow (1992).

Three littoral surveys by the MNCR provided information on the habitats and communities on this stretch of coast. Eighteen littoral sites between the Mull of Galloway and Auchencairn Bay were surveyed by Covey (1990). A further survey in June 1991 covered an additional 18 sites on the same stretch of coast, filling in gaps in the original survey coverage (Covey & Emblow 1992). Several further sites were surveyed during August 1991 (Covey & Emblow 1992) as part of a survey which concentrated on the inner Solway.

The rocky shores surveyed by Covey (1990) and by Covey & Emblow (1992) were predominantly of boulders, with bedrock outcrops on some shores. Sites on the open coast were generally exposed or moderately exposed to wave action, but sites in the embayments and in the inner Solway were more sheltered. The communities recorded from open coast shores were typical of exposed rock, but were markedly richer than equivalent communities in south Cumbria recorded by Covey & Davies (1989). Communities from hard substrata which were sheltered from wave action were comparatively impoverished; red algae were particularly sparse. The predominance of boulder shores in the survey area meant that there were few rockpools. Well developed rockpool communities were recorded by Covey (1990) from rocky shores around the entrance to Wigtown Bay. The algae *Laminaria digitata* and *Halidrys siliquosa* colonised the base of large pools, and *Fucus serratus* and *Corallina officinalis* were abundant on the sides of pools. The pools also supported rich underboulder communities. Rich cryptic communities were also recorded by Covey (1990) from the undersurfaces of stable large cobbles at a site in Luce

Bay. Towards the inner Solway, many of the rocky shores gave way to sediment flats on the lower shore, so that sublittoral fringe communities were limited to the open coast where sites were exposed to wave action. The richest sublittoral fringe communites were recorded from the area of the Mull of Galloway.

Covey & Emblow (1992) also described communities from 'mixed' habitats (defined as habitats comprised of boulders, cobbles, pebbles with sediment in the interstices, supporting both epifaunal and infaunal species). The distinction between these communities was defined primarily by the quantities of sediment in the interstices. Cobbles and pebbles on the open coast trapped little sedimentary material and were dominated by epifaunal species, with few infauna. However, where these habitats were dominated by the mussel *Mytilus edulis*, sediment retention and production of 'pseudofaeces' provided suitable habitats for colonisation by species such as the polychaetes *Arenicola marina* and *Lanice conchilega*. The polychaete *Sabellaria alveolata* was recorded in relatively small numbers from shores in Dumfries and Galloway by Covey (1990), Covey & Emblow (1992), Perkins (1973) and Cunningham *et al.* (1984b); the Galloway coast is the northern limit of this species (Cunningham *et al.* 1984b).

Covey (1990) and Covey & Emblow (1992) also provided records for sediment shores. Covey & Emblow (1992) described four communities from soft substrata:

- sediments, typically sandy muds, with a community characterised by *Corophium volutator, Hydrobia ulvae* and *Macoma balthica*. Variations (facies) of this community were recorded from estuarine muds, characterised by abundant *Pygospio elegans*, and from sandier muds characterised by *Scrobicularia plana*. These were present towards the head of the Solway Firth and in the shelter of the enclosed estuaries of the outer Solway;
- moderately exposed fine and very fine sand sediments containing a community dominated by *Nephtys* spp., *Scoloplos armiger* and *Arenicola marina* with the amphipod *Bathyporeia pelagica*;
- fine sands on the open coast generally supporting a rich infauna, with many species of polychaetes, amphipods, echinoderms and molluscs, typically including *Nephtys cirrosa, Arenicola marina, Lanice conchilega* and *Bathyporeia pelagica*. The richest example of this community was recorded from the lower shore in the centre of Luce Bay, where the burrowing urchin *Echinocardium cordatum* and the bivalves *Donax vittatus, Fabulina fabula* and *Chamelea gallina* were all numerous;
- an impoverished 'barren' sand community from upper shore sand in Luce Bay.

An additional community was recorded by Covey (1990) from muddy sand in Ardwall Sound at the mouth of Fleet Bay, where a dense bed of *Lanice conchilega* supported many other species of polychaetes and bivalves.

Dense populations of the cockle *Cerastoderma edule* occur in Auchencairn Bay and Rough Firth. Recently, suction-dredging has been introduced as a method of cockle fishing. The effects of the use of this fishing technique on the sediments and biota of Auchencairn Bay was the subject of a study by Perkins (1988). He recorded the complete disappearance of the seagrass *Zostera marina* from the dredged area. Densities of the bivalve *Macoma balthica* (and the target species *Cerastoderma edule*) were reduced in the dredged area, but densities of the polychaetes *Nephtys* spp. and *Arenicola marina* had not noticeably changed. In an NCC-commissioned study into the effects of hydraulic cockle dredging, Moore (1990) carried out experimental dredging on Blackshaw Flats in the Solway and on the Lavan Sands in the Menai Straits. At Blackshaw Flats the experimental dredging had little effect on the sediment characteristics or the infaunal species, except that densities of the gastropod *Hydrobia ulvae* were markedly reduced immediately after the dredging. The study involved dredging very small areas on the flats; large areas of adjacent sediment were undisturbed and provided a large pool of organisms which could rapidly recolonise the effected area. Extensive and intensive dredging may have a more marked and long-term effect on the biota and this has been investigated in a three-year project from 1992 to 1995 funded by Scottish Natural Heritage.

Sublittoral survey information for this area is extremely limited. The MNCR surveyed 26 sublittoral sites from the Mull of Galloway to Auchencairn Bay, by diving and dredging (Covey 1992). From these sites, 19 habitat types were identified, 14 from hard substrata and five from sediments. Hard substratum habitats and communities were strongly influenced by two factors; the strength of tidal streams and the turbidity of the water column. A distinct discontinuity occurred at the Isle of Whithorn. West of this discontinuity, communities were dominated by tunicates and sponges, with the featherstar *Antedon bifida* and *Sabellaria spinulosa*. East of the discontinuity communities were typically characterised by erect bryozoans and hydroids, overlying *Sabellaria spinulosa* in the west and the barnacle *Balanus crenatus* in the west. Turbidity increased from west to east with a consequent reduction in the depth of algal penetration. In the west of the survey area the infralittoral zone extended down to 7.5 m to 10 m below chart datum but algae extended little deeper than chart datum at Airds Point, the easternmost site surveyed. Hard substrata were more widespread in the west. Communities on hard substrata were much richer in the west, where hard substrata were more widespread in occurrence, and the water less turbid.

The sedimentary habitats split into two broad groups with a similar geographical distribution to the hard substratum habitats (Covey 1992). Luce Bay sediments were fine sand with small amounts of mud, shell-gravel and empty shells, supporting a generally rich infauna, with the echinoderms *Ophiura ophiura, Amphiura brachiata, Echinocardium cordatum* and *Lapidoplax digitata* and the polychaete *Lanice conchilega*. Off Burrow Head, an area of impoverished, duned sand occurred. Farther east, sediments in Wigtown Bay, Kirkudbright Bay and off Balcarry Point were composed of muddy sand, often with a high shell-gravel content. Dominant epifaunal species included the bryozoan *Alcyonidium diaphanum*, the hermit crab *Pagurus bernhardus*, the brittlestar *Ophiura albida* with the hydroid *Obelia longissima* on larger shells. In the enclosed areas of the larger bays, such as Wigtown Bay and Kirkudbright Bay, and in the east of the survey area, the sediment was composed of tide-swept, muddy fine sand, dominated by the bivalves *Fabulina fabula*, *Spisula subtruncata*, *Thyasira* sp. and *Abra alba*, the brittlestars *Ophiura ophiura* and *Amphiura filiformis*; and the polychaetes *Pectinaria belgica* and *Nephtys* spp.

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Chapter 12: Clyde Sea (MNCR Sector 12)*

David W. Connor and Mike Little

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Synopsis

The Clyde Sea is mostly enclosed and leads inland to several sea lochs. It receives water from a major estuary, the Clyde estuary. A wide range of studies which describe benthic species and communities in the Clyde Sea have been undertaken, mainly from the marine biological station at Millport on Great Cumbrae, by the Clyde River Purification Board (now part of the Scottish Environment Protection Agency), and as MNCR surveys. The area, in contrast to the west coast of Scotland, supports significant populations of cold-water species such as the crab *Lithodes maia* and the anemone *Bolocera tuediae*. There are typical sea loch communities present, although the lochs near the Clyde estuary are species-poor. Loch Fyne is particularly notable and includes dense beds of the fireworks anemone *Pachycerianthus multiplicatus*, extensive examples of the sealoch biotope characterised by the anemone *Protanthea simplex* and the brachiopod *Neocrania anomala*, and in deep water, dense burrowing communities and populations of the echiuran *Amalosoma eddystonense*. Extensive maerl beds occur in the Clyde. The lagoons at Ballantrae are brackish habitats and are poor in species.

12.1 Introduction

The Clyde Sea area (Figures 12.1 and 12.5) comprises the Firth and estuary of the Clyde, including the sealochs to the north and Loch Ryan in the extreme south of the area. The islands of Bute, Arran and the Cumbraes lie within the main body of the Firth. The Clyde encompasses a wide variety of habitats, ranging from the estuarine mudflats of the Clyde estuary to the deep fjordic sealochs, such as Loch Fyne, and the open coast habitats of the Mull of Galloway. Nowhere is very exposed to wave action, excepting the Mull of Kintyre and much of the Clyde can be considered to be sheltered or very sheltered from such water movement. Tidal streams throughout the area are generally weak, but reach 4 to 5 knots (2 to 2.5 m s^{-1}) in parts of the North Channel of the Irish Sea and the Kyles of Bute. The area lacks the very strong currents present on both the open coast and in the rapids or narrows systems which are common on Scotland's west coast.

Mean surface temperatures in the area range from about 7 °C in the winter to 13.5 °C in the summer (Lee & Ramster 1981), although the shallow waters of the lochs and estuaries experience much greater temperature fluctuations. Surface ice forms at the heads of some lochs in winter, and a thermocline is established during the summer. Edwards *et al.* (1986) considered the area of the Clyde to be a vast fjord with a broad sill, the Great Plateau, separating the area from the North Channel of the Irish Sea whilst a front on the Great Plateau separates tidally mixed waters in the North Channel from less saline waters in the Clyde itself.

Throughout the Clyde, the surface salinity is reduced to less than 33‰ (Edwards *et al.* 1986). The salinity barrier this creates with the open sea may be paralleled in a biogeographic separation of the Clyde from both the Irish Sea and the west coast of Scotland. Amongst the fauna of the Clyde are the spiny spider crab *Lithodes maia* and the large anemone *Bolocera tuediae* (Davies 1989): both are cold-water species which are more commonly recorded in the North Sea, but which are quite rare on Scotland's west coast. The Clyde algal flora also shows anomalies compared with that of the rest of the west coast of Scotland. There are fewer red algae but

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

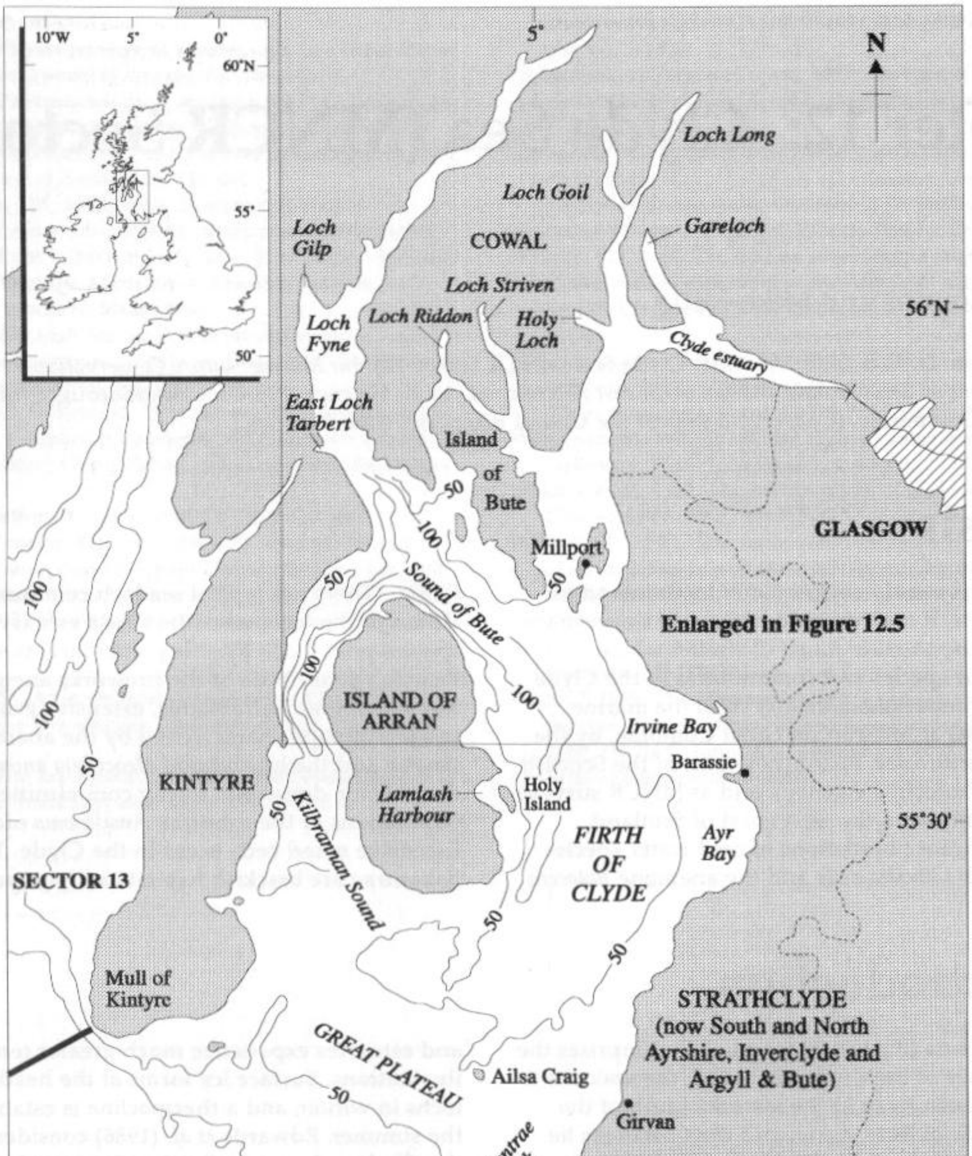

Figure 12.1. The Clyde Sea (MNCR sector 12) showing places mentioned in the text.

more brown algae than would be expected for this part of the British Isles, with a number of conspicuous and generally widespread red algae apparently absent from the Clyde (Maggs 1986). The physical characteristics of the Clyde have not been static and long-term changes in temperature were described by Barnett & Watson (1986) who noted the virtual disappearance of the bivalve *Spisula subtruncata* from the area since the 19th century, possibly as a result of temperature changes.

The area has received a much greater research effort than the rest of Scotland's west coast, due primarily to the presence for over a hundred years of a marine research laboratory at Millport on Great Cumbrae and the close proximity of the Universities of Glasgow, Strathclyde and Paisley, and other institutes. Much of the Clyde River Purification Board's (CRPB) (now part of the Scottish Environment Protection Agency – SEPA) work on hydrography, pollution and the benthos has been within the Firth of Clyde. Pollution studies in the Clyde Sea Area were reviewed by Steel, McIntyre & Johnston (1973) and were also discussed within the Clyde Study Group's assessment (Natural Environment Research Council 1974). A broad outline of pollution inputs to the marine environment of much of the western Scottish area including the Clyde was provided by the CRPB (1985, 1986).

Marine research at Millport began in 1885 when Dr John Murray brought the *Medusa* and the *Ark*, vessels converted for marine research, to Great Cumbrae to continue studies initiated earlier at the Scottish Marine Station at Granton on the Firth of Forth (Marshall 1987). The Marine Biological Association of the West of Scotland was founded at Millport in 1901, changing its name to the Scottish Marine Biological Association (SMBA) in 1911 and more recently (1992) to the Scottish Association for Marine Science (SAMS). In 1970 the SMBA transferred to Oban, at which time the Universities of London and Glasgow jointly funded the laboratories as the University Marine Biological Station, Millport (UMBSM). There was also a marine station on the Island of Bute for a brief period in the early part of the twentieth century. The station's curator was L.P. Renouf, who later moved to University College, Cork and started studies at Loch Hyne. The University of Strathclyde has laboratory facilities at Porthkil.

Much of the available information on the Clyde Sea was drawn together in a symposium volume by Allen *et al.* (1986) which described the physical, chemical and biological nature of the region and discussed resources, uses and conservation strategies. This review followed a similar assessment by the Clyde Study Group (Natural Environment Research Council 1974).

Marine faunal and floral lists for the Clyde Sea have been published over the past 80 years, starting with general accounts by King (1911) and Chumley (1918) and continuing with lists for specific groups:

Taxonomic group(s)	Reference(s)
Algae	Clokie & Boney 1979
Hydromedusae	Vannucci 1956
Polychaeta	Clark 1960
Tardigrada	Morgan & Lampard 1986
Mysidacea	Mauchline 1971
Amphipoda	Moore 1984
Arthropoda: Crustacea; Euphausiacea & Decapoda	Allen 1967
Mollusca	Allen 1962
Echinodermata	Wilkie 1989
Ascidiacea	Millar 1960
Fishes	Bagenal 1965; Gibson 1980
Mammals	Gibson 1976

The Clyde, being within easy reach of Glasgow, is a popular area for sports diving, for which Ridley (1984) gives information on dive sites and Agnew *et al.* (1986) provided guides to the more common invertebrates present in the area.

12.2 Firth of Clyde

12.2.1 General and autecological studies

Studies of algae within the Clyde date back to the 1890s when Batters (1891) first collated algal records for the area. Gibb's (1939) study, both on the shores and in the sublittoral around Cumbrae, added considerably to these earlier records. More recent algal studies were reviewed by Norton (1986) who discussed a possible reduction in the Clyde flora resulting from industrial pollution.

As with algal studies, faunistic work and autecological studies in the Clyde are numerous and date back to the early naturalists' collections of the nineteenth century. The following gives an indication of the range and subject of species and groups studied: speciation in polychaetes (Clark 1952); spread of the non-native barnacle *Elminius modestus* (Barnes & Barnes 1960); euphausiid and mysid biology (Mauchline 1958, 1967); distribution of amphipods *Gammarus* species (Elmhirst 1935); amphipod biology (Shillaker 1977); cumacean biology (Corey 1966); grazing by the chiton *Lepidopleurus* (now *Leptochiton*) *asellus* and the limpet *Acmaea* (now *Tectura*) *virginea* (Farrow & Clokie 1979); feeding of ascidians (Robbins 1981); and the fauna associated with algae (Moore 1986). Amongst the many postgraduate studies undertaken at Millport have been those relating to the ecology of species common to the area, for example barnacles (Connel 1956), amphipods (Powell 1990), hermit crabs *Pagurus* spp. (Mitchell 1975), the crab *Ebalia tuberosa* (Schembri 1980), the swimming crab *Liocarcinus puber* (Kershaw 1986), limpets (Spencer Davies 1963), tellins (Wilson 1976a), the bivalve *Venerupis pullastra* (now *Venerupis senegalensis*) (Quayle 1948), the sea urchin *Echinus esculentus* (Bishop 1985), epibenthic scavengers (Nickell 1989) and flatfish (Downie 1990).

The Clyde Sea has a productive fishery for demersal and pelagic fish and for shellfish. Bailey, Morrison &

Saville (1982) discussed the stocks of herring *Clupea harengus*, the Clyde's most important pelagic fishery, and the less important mackerel *Scomber scombrus* and sprat *Sprattus sprattus* fisheries. Cod *Gadus morhua*, whiting *Merlangius merlangus*, saithe *Pollachius virens*, hake *Merluccius merluccius* and haddock *Melanogrammus aeglefinus* account for over 80% of demersal fish landings in the Clyde (Hislop 1986). The Clyde's main spawning ground for herring on the Ballantrae Bank was investigated by Napier (1993a; 1993b). He found evidence that herring were selecting well sorted gravel as spawning grounds and that the herring spawn did not increase the organic carbon content of the gravel on a long-term basis. The biology and ecology of other fish in the area, particularly flatfish, has also been studied (e.g. Bagenall 1961; Poxton 1976; Poxton, Eleftheriou & McIntyre 1983). Populations of the mud-dwelling red band fish *Cepola rubescens* and Fries' goby *Lesueurigobius friesii* are known to be present in the area (Howard 1982; Nash 1980, 1982), the former now considered as well established within the Clyde and taken frequently by scampi (*Nephrops*) trawlers. The fishery for scampi *Nephrops norvegicus* is the largest of the shellfish catches in the Clyde, with less valuable fisheries for scallops *Pecten maximus* and queen scallops *Aequipecten opercularis*. The *Nephrops* fishery was discussed by Bailey, Howard & Chapman (1986) whilst Smith (1987) reported on the biology of larval and juvenile *Nephrops norvegicus* within the area. Creel fishing for lobsters and crabs is not as common as elsewhere on the west coast of Scotland (Mason & Fraser 1986).

12.2.2 Littoral

One of the earliest quantitative studies of sediment shore communities was undertaken in Kames Bay and at five other locations in the Firth of Clyde by Stephenson (1929). *Tellina* (now *Angulus*) *tenuis* was the most consistently present species and had the highest numerical abundance. The most widespread littoral survey was undertaken by Paisley College of Technology (1979) who examined 90 rock and sediment shores both within the sealochs and on the open coasts of the Firth. Four main rocky shore types were identified:

- Sealoch boulder shores, common throughout the lochs and dominated by a dense band of the knotted wrack *Ascophyllum nodosum*;
- Sealoch rocky shores, with a distinct zonation pattern;
- Open coast flat boulder and broken bedrock shores, with a dense kelp *Laminaria* zone and often the greatest variety of habitat types;
- Open coast steep or smooth rocky shores, with a less diverse biota than the more broken rocky shores.

The rocky shores of Lochs Riddon and Striven, the Kyles of Bute and the southern coast of Arran were considered to be the richest in the area with high habitat diversity.

In contrast, the Paisley College (1979) survey suggested that the richest sediment shores were concentrated towards the more sheltered parts of the Clyde, in Lochs Fyne, Riddon, Striven and Gareloch. Sediment shores on the more exposed coasts of Ayrshire, the Kintyre peninsula and the south-west coast of Arran tended to have both fewer individuals and a lower species-richness. The infauna of the majority of sites was dominated by bivalves (*Angulus tenuis, Cerastoderma edule*), amphipods (*Bathyporeia* spp.) and polychaetes (*Scoloplos armiger, Pygospio elegans, Arenicola marina, Phyllodoce maculata, Spio filicornis, Eteone flava, Nephtys hombergii, Nephtys cirrosa*).

The intertidal fauna of sandy beaches in the Clyde, together with shores elsewhere in Scotland, was also studied by Eleftheriou & McIntyre (1976). They examined shores between Barassie (near Ayr) and Port Logan on the Galloway peninsula, these falling into their 'moderately exposed' and 'sheltered' beach categories. The former were numerically dominated by crustaceans and polychaetes, with the bivalve *Angulus tenuis* present in significant numbers on the lower shore. On the sheltered beaches crustaceans were generally less common, and although polychaetes remained numerically abundant, bivalves often represented the greatest biomass on the shore.

More localised studies within the Firth have concentrated on shores with easy access from research establishments, notably around Cumbrae, Portencross, Hunterston and the Garnock estuary. The mainland shores have been extensively used, mainly for student projects, by the University of Glasgow, Heriot-Watt University and Paisley College of Technology (now Paisley University).

Moore (1988) reported on the lagoons at Ballantrae as part of the Nature Conservancy Council's (NCC) national survey of lagoons. The Ballantrae lagoons were found to have a rather impoverished fauna and flora, and were most interesting because of their considerable change in structure over the past century. The shingle beach at Ballantrae is a nature reserve and SSSI for its botanical and ornithological interest.

The shores around Great Cumbrae have long provided the subject matter for studies in population biology and behaviour of a range of species. Amongst early studies in Kames Bay were Watkin's (1941, 1942) observations on the night tidal migration of crustaceans, particularly *Bathyporeia* spp., and Smith's (1955) correlation of the distribution of the polychaete *Nereis* (now *Hediste*) *diversicolor* with lowered salinity in interstitial sands. Elmhirst (1931) described a diverse crustacean fauna, mainly composed of amphipods, from this sandy bay, while Stephen (1930a) and Wilson (1976a; 1976b) concentrated their attentions on populations of *Tellina* (now *Angulus*) *tenuis*, representing a long series of studies on this bivalve. The shores at Ballochmartin Bay are a classic study area originally described by Flatterly & Walton (1922). The Bay is particularly interesting for its populations of the phoronid *Phoronis muelleri* and the anemone *Cerianthus lloydii*, the latter a sublittoral species unusually occurring on the shore here. Aronson (1989) investigated the abundance of brittlestars and noted beds of *Ophiothrix fragilis* and *Ophiocomina nigra* in this part of Scotland and elsewhere in the British Isles. Aronson (1989) viewed these aggregations in relation to predator pressure from fish, starfish and crabs, which is relatively low, and concluded that such aggregations survived where fish and crab populations were low. Evans *et al.* (1994) investigated dogwhelk *Nucella lapillus* populations at seven sites around Great Cumbrae, and found evidence of recovery between 1988 and 1993, following legislation to limit the use of tributyltin antifoulants.

The slightly more remote shores of Arran were surveyed by Smith (1984) who considered the molluscan fauna to be limited due to a lack of habitat diversity around the island. She pointed to Lochranza, the southern end of Arran and the Lamlash – Holy Island areas as the richest surveyed. Of about 300 species of mollusc recently recorded in the Clyde, Smith (1984) found only 170 around Arran. Lambshead (1986) used the relatively unpolluted shores of Bute for comparison with those in the more polluted Irvine and Ayr Bays to assess the use of nematodes in "biomonitoring for sub-catastrophic sewage and industrial waste contamination". Certain statistical models, and the use of abundance data and analysis of feeding types, were found to be effective in indicating sediment contamination on the Ayrshire coast. Other Clyde meiofaunal studies have been undertaken by McIntyre & Murison (1972, 1973), Hummon (1976), Jayasree (1976), Hummon & Hummon (1977) and Hardy & Barnett (1986).

12.2.2 Sublittoral

In the sublittoral zone Kain (1962) used sites around Cumbrae for some of her extensive studies on the biology of the kelp *Laminaria hyperborea*. More recently Gordon (1983) studied populations of small fish in the bulbs of the kelp *Saccorhiza polyschides*. The sublittoral fauna of Kames Bay and White Bay were compared by Clarke & Milne (1955) who found broadly similar communities in each bay, with the exception that the niche of the opisthobranch mollusc *Philine aperta* in Kames Bay was largely taken up by the prosobranch mollusc *Natica alderi* (now *Lunatia poliana*) in White Bay. Further offshore around the Cumbraes there are large populations of brittlestars, the most widely distributed of which is *Ophiocomina nigra*. Gorzula (1976) related their distribution to substrata and discussed their abundance and habitat preferences. Nickell & Moore (1991) used baited creels to compare epibenthic scavenging invertebrates at 13 m and 113 m depth off Great Cumbrae. They found consistently higher species diversity at the deeper station.

Work on the sublittoral biology of the Firth has centred particularly on the influence of sewage disposal in the region of the Garroch Head sludge dumping-ground off the southern tip of Bute. A number of workers have examined the impact of the waste disposal on the benthic communities. Bett (1991) found a strong gradient of organic enrichment and reduced diversity in the meiofaunal and nematode population at the dump site. Bett & Moore (1992) discussed possible strategies for biological monitoring of the effects of waste disposal and use the Garroch Head benthic communities as an example. Halcrow, Mackay & Thornton (1973) found the area affected by sludge

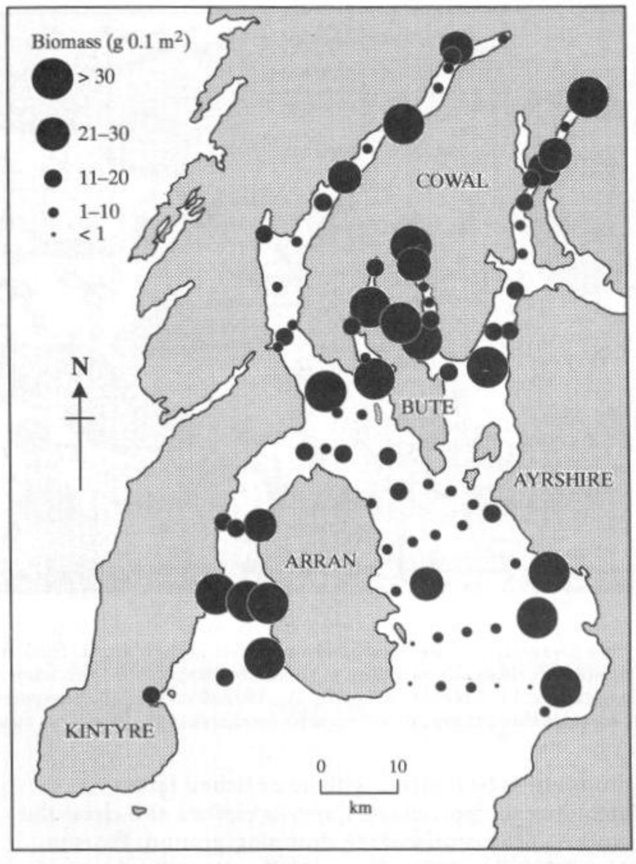

Figure 12.2. Variation in total biomass (g wet weight/m^2) of benthic infauna in the Firth of Clyde (from Pearson, Ansell & Robb 1986).

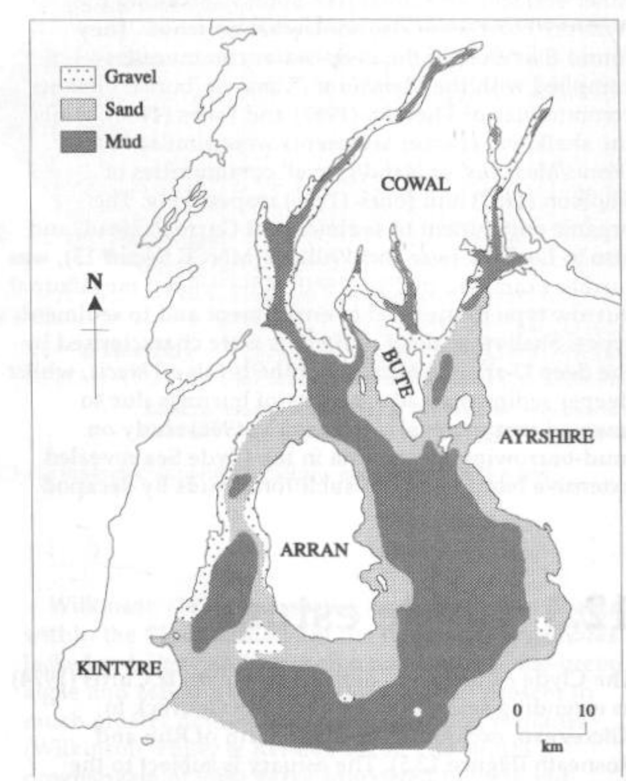

Figure 12.3. Distribution of sediment types in the Firth of Clyde (from Pearson, Ansell & Robb 1986, based on Deegan *et al.* 1973).

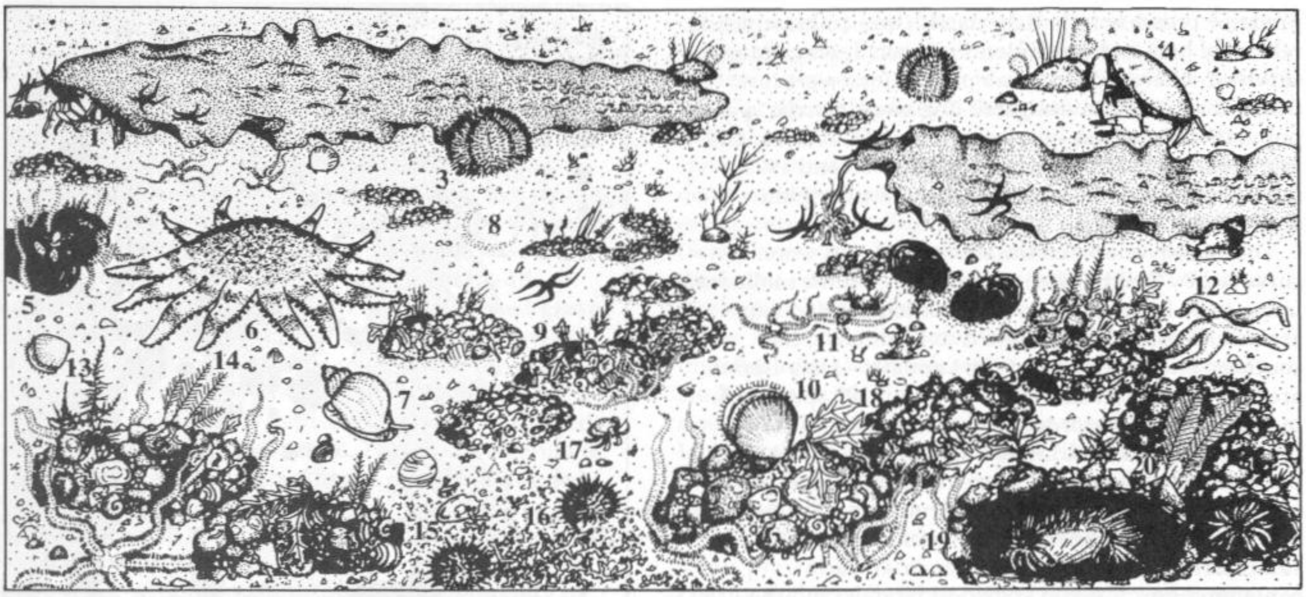

Figure 12.4. Nests of the file shell *Limaria hians* (shown in section bottom right) and associated biota. (From Howson, Connor & Holt 1994. Drawing by Sue Scott.) Major species shown are: 1. *Hyas araneus*; 2. *Laminaria saccharina*; 3. *Echinus esculentus*; 4. *Cancer pagurus*; 5. *Modiolus modiolus*; 6. *Crossaster papposus*; 7. *Buccinum undatum*; 8. *Pecten maximus*; 9. 'nests' of *Limaria hians*; 10. *Chlamys opercularis*; 11. *Ophiothrix fragilis*; 12. *Asterias rubens*; 13. *Brongniartella byssoides*; 14. *Abietinaria abietina*; 15. *Psammechinus miliaris*; 16. *Phymatolithon calcareum*; 17. *Pagurus bernhardus*; 18. *Phycodrys rubens*; 19. *Limaria hians*, and 20. *Delesseria sanguinea*.

dumping to be limited, with an enriched fauna including the polychaete *Capitella capitata* and cirratulid worms at the centre of the dumping-ground. Pearson, Ansell & Robb (1986) (Figure 12.2) related the fauna of the dumping grounds to that in the rest of the Clyde Sea area and concluded that the benthic populations in the inner sealochs, in Kilbrannan Sound and along the Ayrshire coast were also somewhat enriched. They found that most of the deep-water communities complied with the '*Amphiura*', '*Abra*' or 'boreal offshore' communities of Thorson (1957) and Jones (1950), whilst the shallower coarser sediments were similar to the '*Venus/Modiolus*' or 'sand/gravel' communities of Thorson (1957) and Jones (1950) respectively. The organic enrichment of sediments at Garroch Head, and also in Loch Eil near Fort William (MNCR Sector 13), was further examined by Pye (1980), who related megafaunal burrow type to the level of enrichment and to sediment types. Shallow sealoch sediments were characterised by the deep U-shaped burrows of the bivalve *Thracia*, whilst deeper sediments had a paucity of burrows due to lowered oxygen levels. Atkinson's (1986) study on mud-burrowing megafauna in the Clyde Sea revealed extensive bioturbation of sublittoral muds by decapod crustaceans and fish. Warwick (1988), using data from Garroch Head and Loch Eil, provided a basis for determining levels of pollution in the benthos and used the Garroch Head dataset to evaluate techniques for detecting pollution effects on benthic communities (Warwick 1987). The benthic fauna of Irvine Bay, an area receiving both industrial and urban effluents, was the subject of a study by the Department of Agriculture and Fisheries for Scotland (DAFS) carried out in 1972/73 (Eleftheriou, Robertson & Murison 1986) and from 1973 has been repeatedly surveyed by CRPB and others to monitor long-term pollution effects on the benthic communities – for example CRPB (1976a) and Lockhart (1987).

Amongst other studies of the seabed in the Clyde Sea have been those of the Institute of Geological Sciences (Deegan *et al.* 1973; Eden *et al.* 1971) (Figure 12.3). Although these were primarily aimed at investigating the geology of the area, the use of submersibles and sampling gear usefully also revealed some biological features. Amongst these are descriptions from the deepest parts of Loch Fyne with reports of bedrock cliffs to 150 m, and notes on a large bed of the file shell *Lima* (now *Limaria*) *hians* off the south-east Kintyre coast (Deegan *et al.* 1973).

12.3 Clyde estuary

The Clyde estuary was defined by Smyth & Curtis (1974) as extending seawards to a line from Gourock to Kilcreggan, excluding Gareloch north of Rhu and Rosneath (Figure 12.5). The estuary is subject to the pollution pressures from both industry and the sewage effluent from the dense population which surrounds its shores. It was considered to be highly polluted in parts (CRPB 1968) and much of the biological study undertaken has been concerned with or takes account of such environmental pressures. Long-term monitoring undertaken by CRPB suggested an improvement in water quality as indicated by its status according to the Estuary Classification System (Scottish Development Department 1987) in 1989–90. This has been illustrated

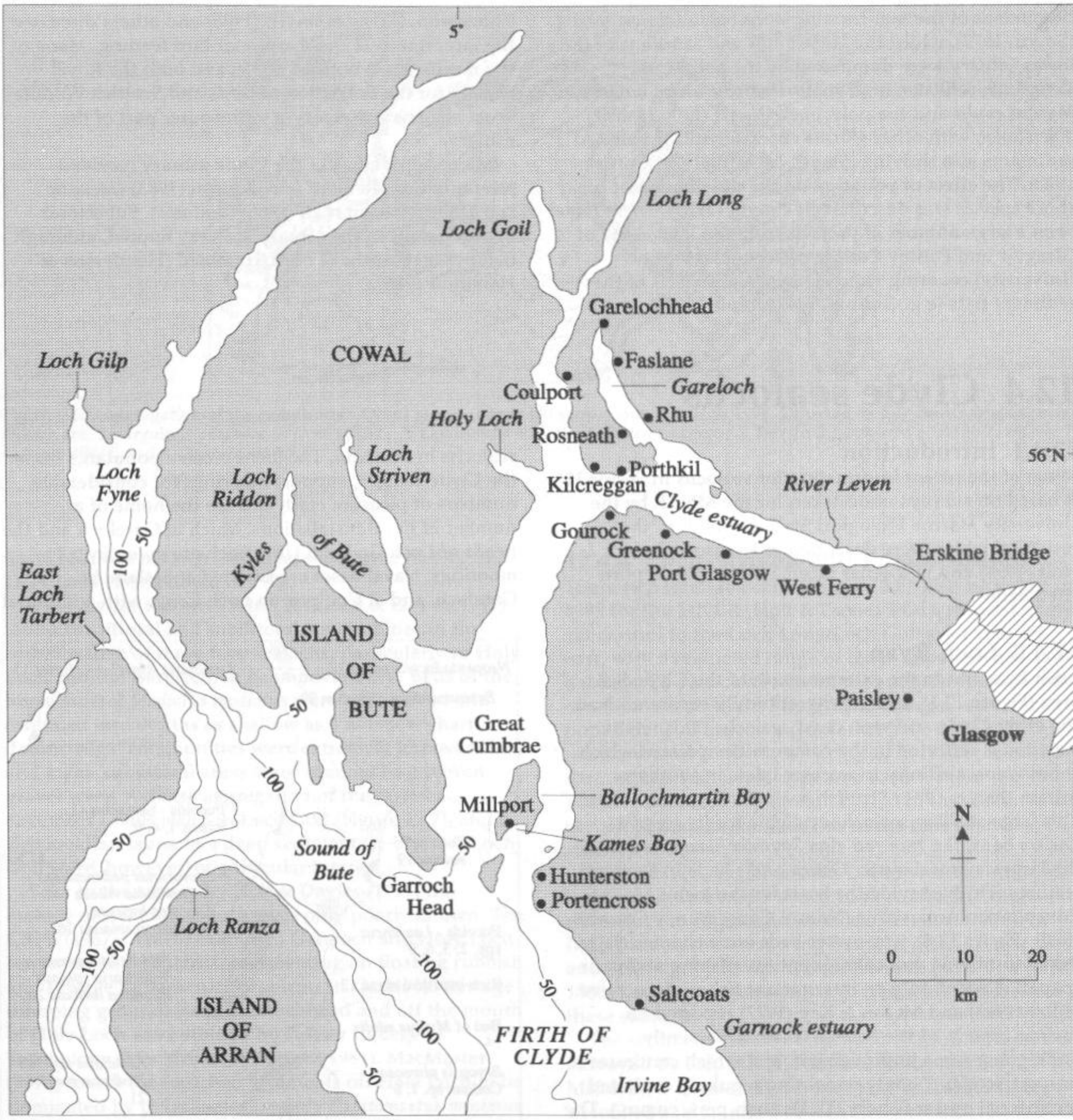

Figure 12.5. The inner Firth of Clyde, Clyde estuary and northern Clyde sealochs, showing locations mentioned in the text.

by improvements in the invertebrate populations (Mackay, Taylor & Henderson 1978; Henderson 1980); the recovery of estuarine fish communities (Henderson & Hamilton 1986) and the return of migratory salmonids (Mackay & Doughty 1986; Mackay 1990). The Natural Environment Research Council (1974) and Allen *et al*. (1986) reviewed environmental aspects of the estuary. The water quality, habitats and the conservation status of the Clyde estuary were summarised by Buck (1993).

Wilkinson (1973) recognised two main zones of algae within the Clyde estuary. In the upper estuary, shores lacked red algae and were characterised by blue-green algae and *Melosira nummuloides*, a diatom present in much greater densities than in most other estuaries (Wilkinson, Fuller & Rendall 1986). The shores downstream of West Ferry supported fucoids and associated red algae. High levels of pollution around Port Glasgow and Greenock were indicated by the dominance of the mat-forming polychaete *Fabricia sabella* (Smyth 1973), whilst the large mud- and sandflats of the lower estuary were dominated by the amphipod *Corophium volutator*, mud snails *Hydrobia ulvae*, mussels *Mytilus edulis* and the polychaete *Nereis* (now *Hediste*) *diversicolor*, with other worms characteristic of polluted sediments also thriving (Smyth & Curtis 1974; Curtis 1978). The effect of pollution on the distribution of rocky shore species was described by Smyth (1973). There have been a large number of projects from the University of Glasgow and Paisley College of Technology (now University) covering various biological aspects of these sediment flats (e.g. Girling 1984; Abdula 1985). Thompson, Curtis & Smyth (1986) and others discussed the importance of these areas for bird feeding. Many of the mudflats are notified SSSIs, and both the Royal Society for the Protection of Birds and Scottish Wildlife Trust have nature reserves in the outer part of the estuary.

Microscopic algae of the Clyde estuary received attention from Rendall & Wilkinson (1983) (*Melosira* spp.), and McLean *et al.* (1986) (diatoms). Sublittoral investigations in the estuary are very limited, although fish populations have been examined (Henderson & Hamilton 1986).

12.4 Clyde sealochs

12.4.1 Introduction

Much of the recent information for sealochs in Sector 12 is based on surveys undertaken for the MNCR by the University Marine Biological Station, Millport, the results of which were described in Howson, Connor & Holt (1994) and in a series of separate survey reports cited below.

12.4.2 Loch Ryan

Loch Ryan lies to the extreme south of the Clyde Sea area (Figure 12.1), and is geographically separated from the other Clyde and west coast sealochs. This relative isolation is reflected in the communities present which show a closer affinity to warmer inlets in southern Britain than to other Scottish sealochs (Howson 1989). This large shallow sealoch is notable for its seagrass *Zostera* beds, the rare red alga *Spyridia filamentosa*, and the largest natural oyster *Ostrea edulis* beds in Scotland, features which provide the basis for the loch's Marine Consultation Area status (Nature Conservancy Council 1990) (Figure 12.6). The oyster beds were commercially fished until 1954, but subsequent overfishing and poor spatfall allowed only an intermittent fishery to survive. Millar (1968) and Mason & Key (1977) reported on various aspects of the fishery which is presently undergoing some improvement, and which continues to support Scotland's only remaining regularly exploited commercial oyster fishery (D. Donnan pers. comm.). The mollusc *Calyptraea chinensis*, a southern species, was probably introduced into Loch Ryan along with oysters before 1944, and a population continues to thrive in the loch (Smith 1991). Prior to the MNCR survey of the loch (Howson 1989), Wilkinson (1980) reported on the rarer algae of the area, and the sediment fauna was examined in connection with effluent discharge from a creamery at Stranraer (Craig, Lewis & Tapp 1980; CRPB 1982, 1984; Rendall 1990; Rendall & Bell 1992).

12.4.3 Gareloch, Loch Long, Loch Goil and Holy Loch

These innermost lochs of the Clyde, situated in close proximity to the Clyde estuary (Figure 12.5), with its industrial base and dense population, are probably subject to the greatest environmental pressure of any sealochs in Scotland. The lochs receive pollutants from the Clyde estuary, support moorings for considerable numbers of pleasure craft, and are the home of a number of naval installations. Much of Gareloch and the heads of Loch Goil and Holy Loch are given over to moorings. Naval bases are situated at Faslane in Gareloch, and at Coulport in Loch Long, with additional

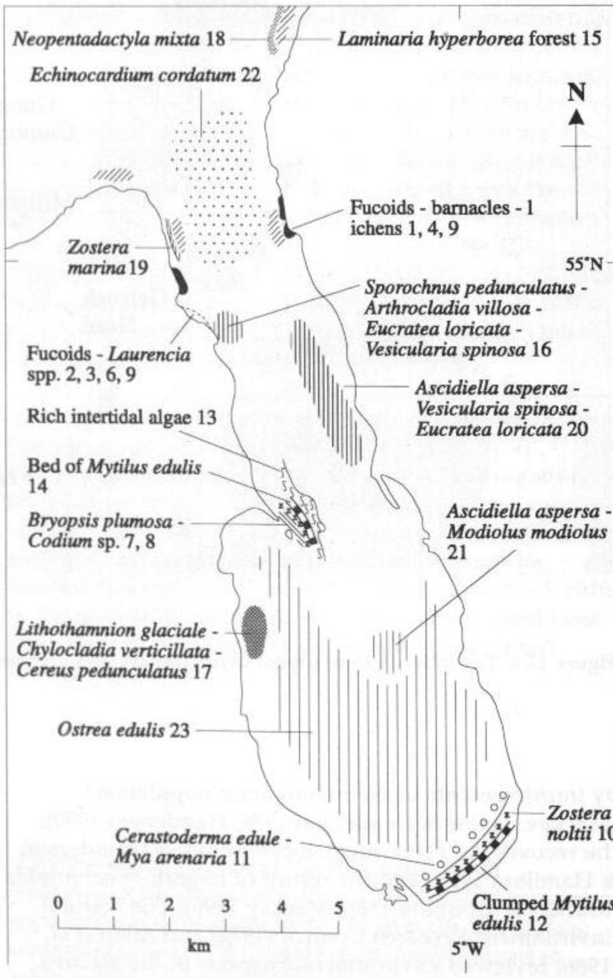

Figure 12.6. Distribution of the main communities in Loch Ryan. (Figures refer to community descriptions in Howson 1989.)

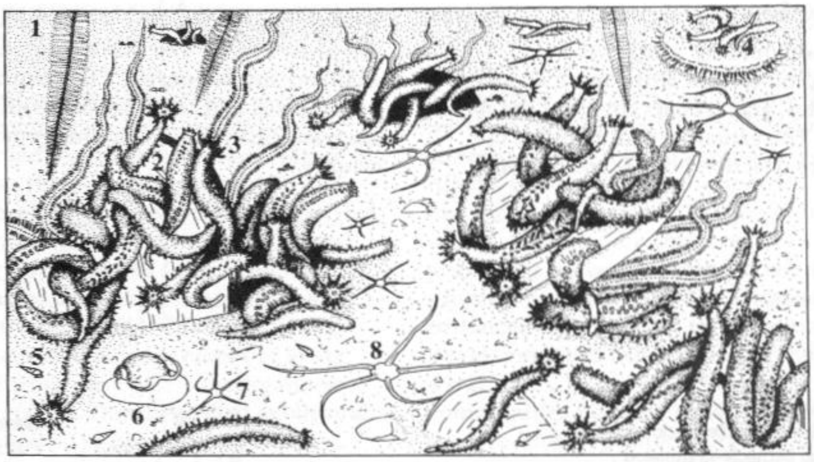

Figure 12.7. Aggregation of the holothurian *Ocnus planci*. (From: Howson, Connor & Holt 1994. Drawing by Sue Scott). Main species shown are: 1. *Virgularia mirabilis*; 2. *Ocnus planci*; 3. *Ophiopholis aculeata*; 4. *Pecten maximus*; 5. *Turritella communis*; 6. *Polinices catena*; 7. *Ophiura albida*, and 8. *Ophiura ophiura*.

naval facilities in Loch Goil. The submarine facility in Holy Loch closed down in 1992.

A survey for the MNCR in 1989 (Holt & Davies 1991) found the littoral and sublittoral communities in the turbid waters of these four sealochs, particularly in Holy Loch and the Gareloch, to be impoverished. Beds of the horse mussel *Modiolus modiolus* were widespread and extended into depths as shallow as 2 m below chart datum. Algal communities were extremely impoverished and many sublittoral areas were covered by a barren gravel scree. A dense aggregation of the rare sea cucumber *Ocnus planci* in Loch Goil (Figure 12.7), and a rich ascidian fauna in a deep sedimentary basin of Loch Goil were, however, of particular interest.

Prior to the survey by Holt & Davies (1991) the biology of the four sealochs was only poorly known. The CRPB (1967a, 1967b) examined Gareloch and Holy Loch for potential pollutants, commenting on floating rubbish and sewage as particular problems in Gareloch. Sewage dumping grounds near Garelochhead and off the mouth of Holy Loch were studied by Paisley College of Technology (MacMaster 1977; Lees 1981). MacMaster (1977) found the enriched sediments off Holy Loch to be dominated by polychaetes (mainly *Capitomastus minimus* and *Capitella capitata*) and oligochaetes. The sediments in Loch Long and Loch Goil have also attracted attention. Shand (1987) reported on the biological control of marine sediment stability by the mussels *Mytilus edulis* and *Modiolus modiolus*, whilst Pye (1980) described the burrowing fauna from these lochs and other areas in the Clyde. Dipper (1981) offered a brief description of sublittoral habitats in Loch Long from a collection of photographs by Gordon Ridley. Rocky communities characterised by the anemone *Protanthea simplex* and large solitary ascidians appeared to be widespread. Loch Long experienced a pronounced non-toxic plankton bloom in July 1990 (CRPB 1991, UMBSM 1991). More recently, SOAEFD have undertaken surveys under the EC IMPACT II project in fished and unfished sections of Gareloch in order to assess levels of seabed disturbance from fishing.

12.4.4 Loch Striven and Loch Riddon

These two small sealochs (Figure 12.5), also surveyed in 1989 for the MNCR (Holt & Davies 1991), showed many similarities to the Loch Long/Loch Goil system to the east, with a restricted range of fairly impoverished habitats. Of particular note in the sublittoral sediment communities in Lochs Striven and Riddon were dense populations of burrowing holothurians, mainly *Psolus phantapus* and *Trachythyone elongata*. In the lochs to the east, similar sediments appeared to lack these species, possibly because they remain buried in the sediment for certain periods in the year (i.e. at the time of the survey).

Loch Striven, together with Loch Fyne, has suffered toxic plankton blooms which have resulted in high mortalities in caged salmon stock (Tett *et al.* 1986). In Loch Riddon the burrowing fauna in general (Pye 1980) and Fries's goby *Lesueurigobius friesii* in particular (Nash 1980) have been examined as part of wider studies on these subjects.

The sediment shores at the head of Loch Riddon were surveyed by Stephen (1930b) and re-surveyed by McLusky & Hunter (1985). McLusky & Hunter (1985) described communities in what they considered to be an unpolluted small estuary and suggested that the area had changed little in the 53 years since Stephen's (1930b) study in 1929. The upper part of the estuary had an estuarine fauna with *Hydrobia ulvae*, *Nereis* (now *Hediste*) *diversicolor* and *Corophium volutator*, whilst the fine sands of the middle reaches had a high biomass of the bivalves *Macoma balthica*, *Cerastoderma edule* and *Angulus tenuis* and the polychaetes *Nephtys hombergii* and *Scoloplos armiger*. In the coarser and more marine sands of the lower part of the estuary mussels *Mytilus edulis* and the barnacle *Semibalanus balanoides* were prominent.

12.4.5 Loch Fyne, including Loch Gilp and East Loch Tarbert

At 70 km long and 200 m deep, Loch Fyne is the longest and deepest of the Scottish sealochs (Figure 12.5). As with other fjordic sealochs, Loch Fyne is predominantly fringed by bedrock and boulders which have barnacle-dominated communities at the more exposed and steeply sloping sites, and fucoids covering the more sheltered rocky areas. The estuarine sediments at the head of Loch Gilp were described by McLusky (1986), who compared the area with Stephen's work of 1929 (Stephen 1930b). The shore communities here were little changed and supported a fauna principally of polychaetes and oligochaetes, with extensive areas of seagrass *Zostera marina* in the upper reaches of the estuary.

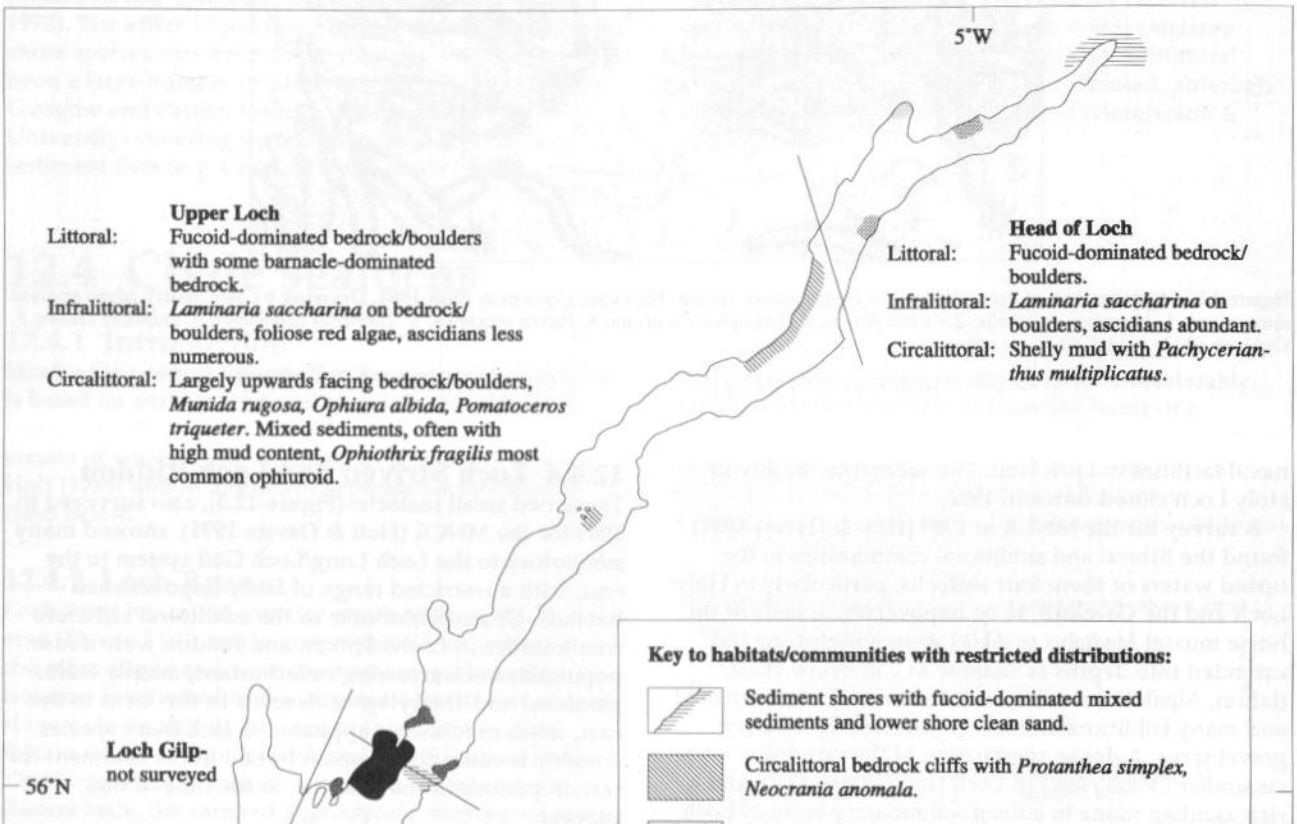

Figure 12.8. Distribution of communities in Loch Fyne (from Davies 1989).

A survey of Loch Fyne for the MNCR (Davies 1989) found both littoral and sublittoral habitat diversity to be relatively low (Figure 12.8). However, at the head of the Loch, one of the densest populations known in the British Isles of the rare anemone *Pachycerianthus multiplicatus* was recorded. Another important feature of the upper loch area was the deep bedrock which supported a good example of a community characterised by the anemone *Protanthea simplex* and the brachiopod *Neocrania anomala*. The upper part of Loch Fyne was consequently promoted as a Marine Consultation Area (Nature Conservancy Council 1990). Eden *et al*. (1971) provided valuable details of the deeper areas of lower Loch Fyne, gathered during geological investigations using a manned submersible. They described sublittoral cliffs which extend from 85–151 m depth, on which ascidians, fan worms, anemones and sponges grew. Elsewhere, dense beds of brittlestars and featherstars were recorded, while the sediment plains below 150 m were occupied by a range of burrowing species including the Norway lobster *Nephrops norvegicus*. More recent examination of the seabed by remote video camera for the MNCR (Howson & Davies 1991) showed the upper loch to support dense megafaunal burrowing communities, in contrast to the outer loch where trawling activities had disturbed the deep mud faunas. An extensive population of the nationally scarce echiuran worm *Amalosoma eddystonense* was found at the mouth of Loch Fyne, and large numbers of the cold-water anemone *Bolocera tuediae* were present on hard ground within the loch.

Other studies in Loch Fyne include work on the brachiopod and clam populations. Populations of the pectinid clam *Chlamys* (now *Pseudamussium*) *septemradiatum* in the upper loch were described in Allen's (1953) work on the species. *Terebratulina retusa*, a brachiopod common in the deep rocky areas in the loch, was investigated by University of Glasgow staff (Cohen *et al*. 1993) concerned with population genetics and physical requirements. The Dunstaffnage Laboratory produced a geographic information system for future development of fish farming in the loch (NERC/SMBA 1992). The CRPB (1976b) examined the benthic communities near the construction site of a gas-production platform off East Loch Tarbert. The samples revealed a modified *'Amphiura filiformis/chiajei'* community in which polychaetes were prominent, but the urchins *Brissopsis lyrifera* and *Echinocardium cordatum* were present in lower numbers than in similar communities elsewhere.

The phytoplankton ecology of Loch Fyne has been studied from the SMBA laboratory at Dunstaffnage, particularly in connection with toxic blooms which have caused fish mortality in salmonid farms (Gowen, Lewis & Bullock 1982; Jones *et al*. 1982; Tett *et al*. 1986). Zooplankton studies have been undertaken within the loch since the 1920s, with the emphasis on euphausiid biology (e.g. Mauchline 1966).

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Chapter 13: West Scotland (MNCR Sector 13)*

David W. Connor and Mike Little

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Synopsis

The coast from the Mull of Kintyre to the Point of Ardnamurchan including the islands of the Inner Hebrides is highly indented and includes several large sealoch systems. Differences in exposure to wave action are reflected by communities characteristic of extremely exposed conditions, including ones with the known southern limit of distribution of *Fucus distichus* on Islay, to extremely sheltered situations. In many of these sheltered locations on the open coast, deep water extends close inshore and many deep-water species occur in rocky habitats near to the coast. Some areas such as Loch Sween are very well studied and include special features such as very sharp zonation patterns on rocky shores, tidal rapids, maerl beds and seagrass beds. The strongest tidal streams occurring on the open coast in Britain are found in the Gulf of Corryvreckan where distinctive communities of a restricted range of species occur. Other sounds particularly the Sound of Mull and the Sound of Jura, have strong tidal streams with associated rich biota. Loch Etive has a large freshwater input and restricted entrance so that many of the communities present are characteristic of brackish conditions. A glacial relict species, the bivalve *Thyasira gouldii*, occurs in Loch Etive. In Loch Creran, the only extensive and well developed reefs of the calcareous tubeworm *Serpula vermicularis* in Great Britain occur. The Firth of Lorn has particularly rich sublittoral communities. Loch Linnhe, at the head of the Firth of Lorn has been subject to the effects of pulp mill effluents and the organic enrichment gradient has been studied in some detail.

13.1 Introduction

Sector 13 (Figures 13.1 and 13.2) includes the Scottish mainland coast from the Mull of Kintyre to the Point of Ardnamurchan, together with the Inner Hebridean islands of Islay, Jura, Colonsay, Mull, Coll and Tiree. The mainland coast is dissected by a series of sealochs which are oriented on a south-west/north-east axis. Within Sector 13, this combination of a highly dissected coast and a series of offshore islands means the area is subject to a wide range of physical conditions which leads to a very high habitat diversity. The west-facing coasts of the offshore islands are almost fully exposed to the force of the Atlantic, receiving only slight protection from the Outer Hebrides and from Ireland. In contrast, the mainland sealochs are protected from the prevailing south-westerly winds by the Inner Hebrides, and are for the most part sheltered or very sheltered from wave action. Weak tidal streams in many of the sealochs contrast with the strong tides generated in the Sounds of Mull and Jura. The tides in the Gulf of Corryvreckan between Jura and Scarba are the strongest on the open coast of Britain, reaching over 8 knots (4 m s^{-1}), and forming standing waves, overfalls and whirlpools.

Mean surface sea temperature in the area varies from about 7–7.5 °C in February to 13.5 °C in August, with surface salinity in the region of 34-34.75‰. An amphidromal point occurs between Islay and the Kintyre peninsula, giving a spring tidal range of less than 1 m in this area. The spring tidal range increases

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

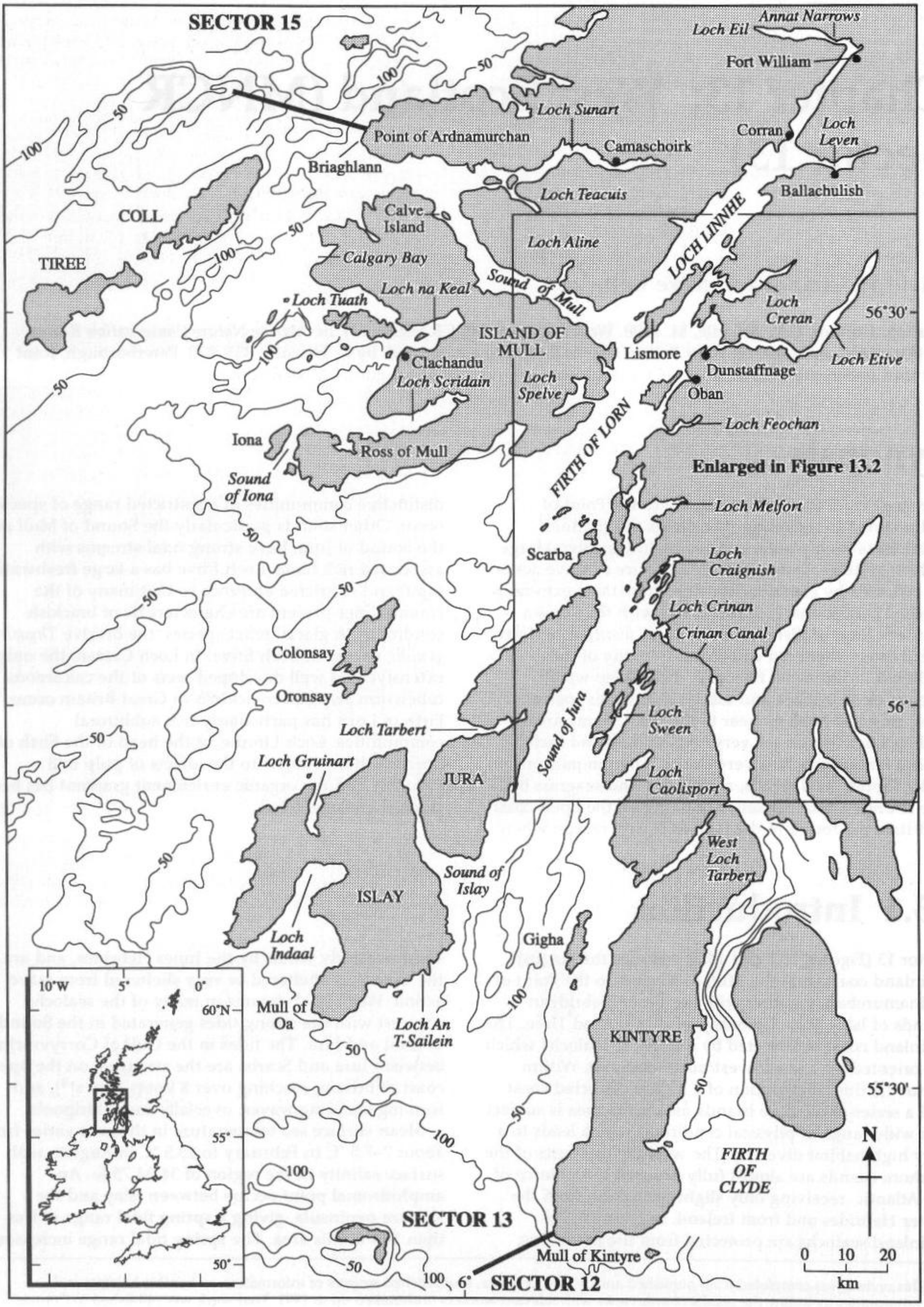

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Figure 13.1. West Scotland (MNCR Sector 13), showing places mentioned in the text.

farther north in the Firth of Lorn and around Mull, and reaches nearly 4 m at Ardnamurchan (all data from Lee & Ramster 1981).

A distinct frontal system, known as the Islay front, lies between Islay and Malin Head in County Donegal, Ireland, in the summer months (Simpson *et al.* 1979), and may be important as a biogeographical boundary for the distribution of species in this region. For instance, some species, such as the hydroid *Gymnangium montagui* (Erwin *et al.* 1986) and the ascidian *Stolonica socialis* (D.W. Connor pers. obs.), appear to reach their northern limit of distribution on the north coast of Ireland. Others, such as the alga *Carpomitra costata*, are present in Northern Ireland (Erwin *et al.* 1990), but seem to be restricted in Scotland to offshore locations such as St Kilda and the Uists. A further range of species appears to reach their northern limits within the west Scotland area, including 18 species of alga (Maggs 1986). Maggs (1986) considered the flora of west Scotland to be notably richer for red algae than either the Clyde Sea or the coast north of Ardnamurchan. Algal species common in the area, such as *Acrosorium uncinatum*, *Lomentaria orcadensis* and *Kallymenia reniformis* are not recorded from the Clyde, while 40 more species are recorded from west Scotland compared with north-west Scotland (Maggs 1986). The benthic sampling programme of the Scottish Marine Biological Association (SMBA) and the Department of Agriculture and Fisheries for Scotland (DAFS) in the mainland sealochs in the 1960s also revealed broad-scale differences in community structure between the Clyde Sea, west Scotland, and the coast north of Ardnamurchan Point (T. Pearson pers. comm. to C. Lumb).

The Scottish Marine Biological Association (now the Scottish Association for Marine Science (SAMS)), based at Dunstaffnage near Oban since 1970, has been the main centre for marine research within Sector 13. In 1989 the laboratory came under the management of the Natural Environment Research Council as the Dunstaffnage Marine Laboratory (DML). Ecological studies by SMBA staff have included surveys of benthic sedimentary communities in sealochs near to the laboratory. Lochs Linnhe, Eil, Creran and Etive have been particularly intensively studied, providing details of many of the fundamental aspects of sealoch ecology. The Loch Linnhe and Eil work gave some of the earliest insights into the pollution gradients arising from organic enrichment, in this case from paper pulp mill effluent. The SMBA, in conjunction with the Marine Biological Association (MBA) at Plymouth, undertook a major survey of the shores of Great Britain for the Nature Conservancy Council (NCC) in the late 1970s (Bishop & Holme 1980; Harvey *et al.* 1980). Loch Sween has been studied extensively since the 1930s, with much recent work contributing to NCC's proposal for Marine Nature Reserve status for the loch (NCC 1990a). Other surveys in western Scotland, both of the shores and the nearshore sublittoral zone, have also been initiated by the NCC (e.g. Smith 1981; Hiscock 1983). Since the early 1980s, Loch Creran and Clachan Sound have been frequently used for ecological studies by staff and students from Heriot-Watt University, Edinburgh, and the Gatty Marine Laboratory, St Andrews, respectively. Results of the above studies are further discussed below under appropriate area sections.

13.2 Mainland open coast

Of the rocky shores investigated in this part of Scotland by the SMBA/MBA team, four areas were considered to be of national or international importance (Harvey *et al.* 1980). Loch Sween received the highest rating because of its unusually clear zonation patterns, small tidal range and very rich sponge-dominated rapids communities. Loch Etive, Clachandu on the Island of Mull, and the Point of Ardnamurchan were also nationally rated sites. Loch Etive was noted for its wide range of salinity conditions with associated changes in fauna and flora, and Clachandu was considered particularly important for its rich shallow pools on the lower shore. At Ardnamurchan the shores were found to be rich examples of wave-exposed bedrock, while the boulders at nearby Briaghlann sheltered large numbers of the uncommon crab *Xantho incisus*. A number of other sites from this region were selected as of particular marine biological importance (Powell *et al.* 1977) and are noted below under their appropriate sub-headings.

The SMBA/MBA rocky shore surveys (Harvey *et al.* 1980), undertaken for the NCC, followed earlier extensive studies on the ecology of shores in Argyll by Kitching (1935), Lewis (1957) and Lewis & Powell (1960). Kitching's (1935) work provided valuable early descriptions of shore zonation patterns of the larger brown algae and barnacles, particularly in relation to wave exposure and to rock inclination. Lewis's surveys (Lewis 1957; Lewis & Powell 1960) extended from the Clyde to the north coast of Scotland. Their examination of over 100 sites from a wide range of physical conditions provided considerable further detail of the variation in rocky shore communities. They discussed zonation patterns in relation to substrata, tidal streams and freshwater influence, as well as Kitching's (1935) main concerns of wave exposure and inclination. Much of the early interest in the shores of Loch Sween was generated by these surveys (Lewis & Powell 1960).

Other studies covering a variety of sites on this coast concerned more specific topics; Millar (1952) gave habitat and distributional data for 25 species of ascidians from five shore sites in the Firth of Lorn area. The MNCR in conjunction with the University Marine Biological Station Millport (UMBSM) carried out a short survey in the Firth in 1989 and considered the quality of the area to be very high in terms of nature conservation value (UMBSM/MNCR, unpublished data). Moore (1985) studied the amphipod fauna of kelp holdfasts at sites between the Mull of Galloway and Loch Aline in the Sound of Mull. He found that each area supported a distinctive amphipod community, and that species

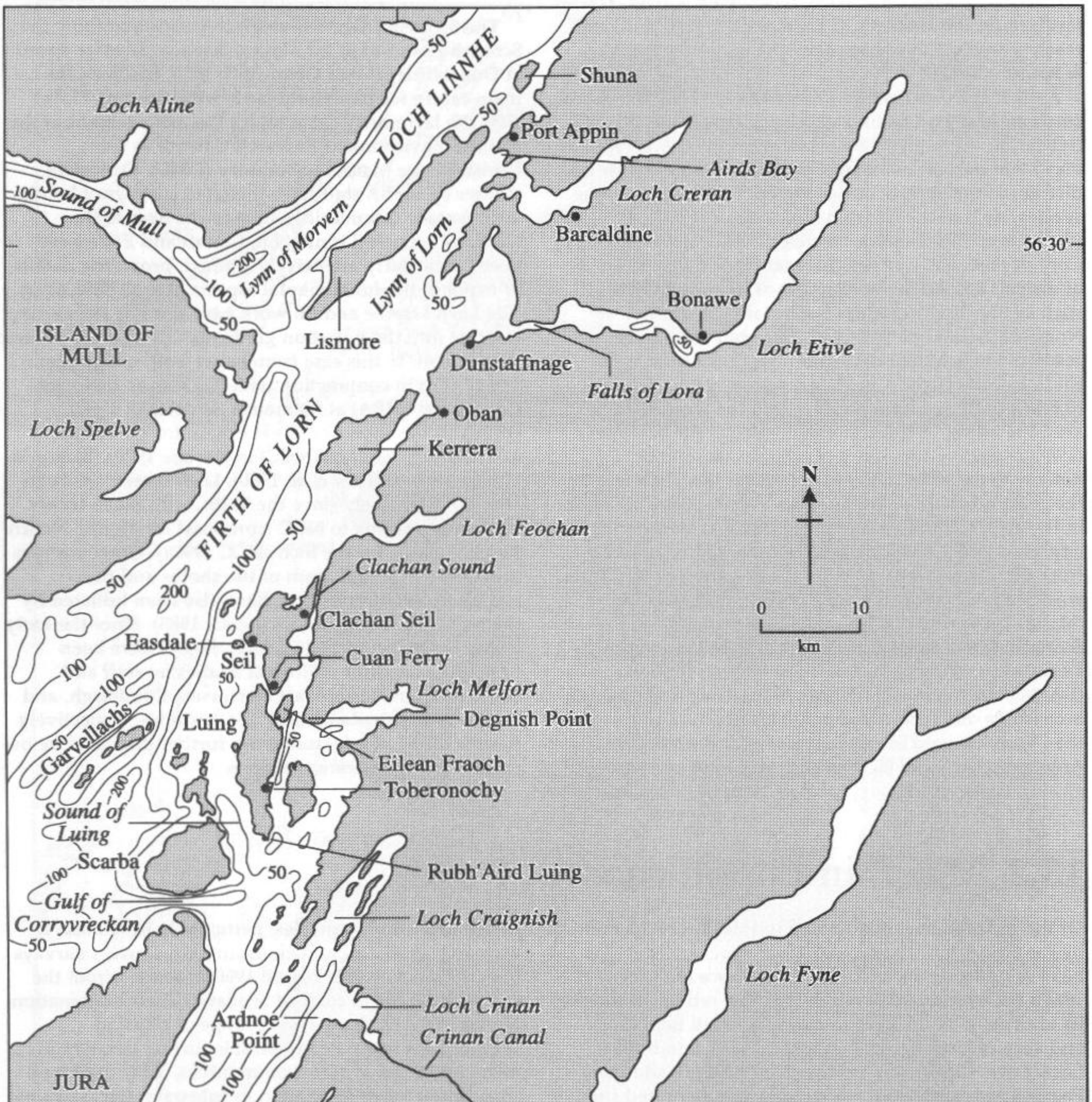


Figure 13.2. The Sound of Jura and Firth of Lorn area, showing places mentioned in the text.

composition remained relatively constant with time over a two-year period. Gibson (1987) provided a species list for fish recorded from Dunstaffnage Bay, and Gibson, Ansell & Robb (1993) gave a good account of the fish and crustacean community of a sandy beach in Ardmucknish Bay. They found annual cycles in richness and abundance related to patterns of recruitment and mortality. Comely & Ansell (1989a, 1989b) recorded the occurrence of the nemertine *Carcinonemertes carcinophila*, and the eunicid polychaetes *Iphitime cuenoti* and *Iphitime paguri*, in sublittoral crabs taken near Oban.

Biological investigations of the nearshore sublittoral zone have been particularly directed towards the lochs and the larger Hebridean islands and are further discussed below. However, Kitching (1941) provided some of the earliest direct observations of the sublittoral zone in the British Isles with studies on kelp forest ecology at Carsaig Island in the Sound of Jura. Information on the offshore benthos is sparse, with much of the biological information arising from non-biological investigations, namely the geological work of Eden *et al.* (1971) and the sedimentary studies of Farrow, Cucci & Scoffin (1978). The Institute of Geological Sciences conducted a series of surveys with a manned submersible in certain offshore and deep-water trenches in western Scotland (Eden *et al.* 1971). Although primarily aimed at geological investigations of the seabed, photographs taken during the surveys revealed biological details for many hard bottom areas for which access is generally not possible by SCUBA diving. Within Sector 13, they surveyed sites in the Firth of Lorn and on the offshore Stanton and Blackstones Banks, respectively 180 km and 110 km west of Colonsay. Sparse brittlestar populations (*Ophiothrix fragilis* and *Ophiocomina nigra*) were present on the Stanton grounds, and the bryozoan *Pentapora foliacea*, known from only a few outlying sites in western Scotland, occurred on the Blackstones Bank. Collins (1991) investigated the growth rate of the brachiopod *Terebratulina retusa* associated with a horse mussel *Modiolus modiolus* bed in the Firth of Lorn and found that the *Modiolus* shells were a vital substratum for settlement and development of juvenile *Terebratulina*.

The bottom deposits between Gigha and Ardnamurchan, including those around the Inner Hebridean islands, were found to have a particularly high calcareous content (Farrow, Cucci & Scoffin 1978). The proportion of barnacles, mussel spat, mollusc fragments, calcareous algae (maerl), echinoids and Foraminifera in these deposits was determined. The data showed an increase in calcareous content with increased wave exposure, such that sediments around Tiree and Iona were composed of over 80% carbonate deposits. In the Sound of Iona some sediments were composed entirely of calcareous algae, but generally barnacle plates of recent origin formed the main component of such sediments. Despite observations of abundant echinoderms on the seabed, and in particular dense aggregations of brittlestars, echinoderm deposits failed to achieve greater than 10% of the sediment content throughout the area investigated. Chapman (1984) provided information on the catches of Norway lobster *Nephrops* in the area, finding a positive correlation between catches and annual sea surface temperature.

13.3 Mainland sealochs

13.3.1 Introduction

Much of the recent information for sealochs in Sector 13 is based on surveys undertaken for the MNCR by the University Marine Biological Station, Millport, the results of which were described in Howson, Connor & Holt (1994) and in a series of separate survey reports cited below.

13.3.2 Sealochs between Kintyre and Oban

Of the seven sealochs that lie between Oban and the Kintyre peninsula, Loch Sween is by far the most thoroughly studied, with descriptions of the shores dating back over 60 years (Kitching 1935) and surveys of the sublittoral undertaken intensively since the 1970s. Although the other sealochs had received some previous attention, they were only recently surveyed systematically, as part of the UMBSM survey of sealochs for the MNCR (Howson 1990).

The shores of Loch Sween were included in studies on rocky shore ecology by Kitching (1935) and Lewis (1964), in which the basic concepts of barnacle and algal zonation patterns were described (Figure 13.3). Because of a very small tidal range, the loch exhibits a compressed but distinct zonation, particularly well shown on the uniform steep rocky slopes of Loch na Cille. The shores are notable for their abundance of the barnacle *Chthamalus montagui* (recorded as *Chthamalus stellatus* but now known to be a separate species) which is considered more typical of exposed coasts, and for the development of a turf of the filamentous algae '*Trailliella*' and '*Falkenbergia*' (phases of *Bonnemaisonia hamifera* and *Asparagopsis armata* respectively) on the lower shore. The tidal rapids system at Linnhe Mhuirich is richly colonised, especially by sponges, and is particularly important for its shore populations of maerl and a loose-lying growth of the calcareous alga *Corallina officinalis*. Figure 13.4 illustrates some of the communities found in Linnhe Mhuirich rapids. The littoral biology of Loch Sween was summarised by Hiscock & Smith (1986). Smith (1982a) described the littoral Mollusca of the loch. Smith (1985) examined both polychaetes and molluscs and concluded that Loch Sween was "an average polychaete locality" and "not the most attractive region for Mollusca".

In the sublittoral, Loch Sween has a range of communities typical of a sheltered sealoch, ranging from habitats in the more exposed loch entrance to those of the extremely sheltered arms of the Loch Sween system (Earll 1982, 1984; Lumb 1986; Lumb & Hiscock 1990). There are several beds of the seagrass *Zostera marina* in the upper parts of the loch, whilst coarser sediments at the mouth of the loch support populations of the heart

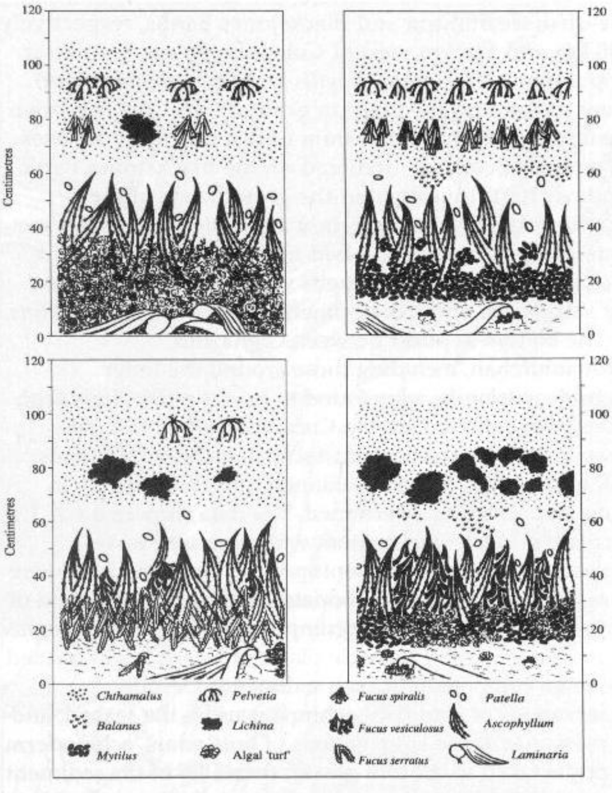


Figure 13.3. Diagrammatic representation of the zonation of communities on the shores of Linnhe Mhuirich, Loch Sween. The upper left figure shows lower shore communities on rock, whilst the other three figures indicate communities on lower shore stones and shingle (from Lewis & Powell 1960).

urchin *Echinocardium cordatum*. Brackish areas have stands of the seagrass *Ruppia* sp. and the lagoon cockle *Cerastoderma glaucum*. The burrowing megafaunal mud communities have been particularly well studied (Atkinson 1987, 1989), revealing populations of the thalassinid shrimps *Jaxea nocturna*, *Calocaris macandreae*, *Callianassa subterranea* and *Upogebia stellata*, together with the Norway lobster *Nephrops norvegicus* and the echiuran worm *Maxmuelleria lankesteri*. Loch Sween, together with the open coast to Ardnoe Point by Loch Crinan, is an MCA (NCC 1990b) and Loch Sween itself was proposed as a Marine Nature Reserve (NCC 1990a), although formal proposals were subsequently withdrawn following local opposition. Connor (1990a) reviewed the conservation importance of the Loch's communities.

Howson (1990) gave results for a survey of Lochs Feochan, Melfort, Craignish, Crinan, Caolisport and West Loch Tarbert. The area is one of the more accessible parts of western Scotland, and is particularly popular for yachting. Yachts are moored in several of the lochs, and easy access to the west coast from the Clyde is provided by the Crinan Canal. The sheltered sediments of these lochs supported typical sealoch communities, with the Norway lobster *Nephrops norvegicus* common in the deeper sediments, and the anemone *Sagartiogeton undatus* present in shallower water. In Loch Melfort sheltered bedrock was often colonised by the anemone *Protanthea simplex* and the brachiopod *Neocrania anomala*, and beds of brittlestars were widespread. Notable features in Loch Feochan included large numbers of the tiny anemone *Edwardsiella carnea* living in rock crevices. Towards the entrances of the lochs, the strong tidal influences of the Sound of Jura provided increased diversity of communities, with the entrance to Loch Craignish being particularly rich. Here, large numbers of the sea fan *Swiftia pallida*, the ascidian *Diazona violacea* and the sponges *Axinella infundibuliformis* and *Mycale lingua* characterised rocky areas. Tide-swept gravels and cobbles were covered by rich algal meadows, with the rare brown alga *Desmarestia dresnayi* notably common. Gubbay & Loretto (1991) recorded dense concentrations of sea cucumbers in the inner basin of Loch Craignish. At Ardnoe Point at the entrance to Loch Crinan, the Mediterranean cup coral *Caryophyllia inornata*, rare in British waters, reaches its most northerly known limit. Loch Melfort and Loch Feochan lie within the Firth of Lorn MCA (NCC 1990b).

The estuarine shores in West Loch Tarbert and Loch Crinan (the River Add), together with those at the head of Loch Gilp, were compared by McLusky (1986). These sediment shores typically had deposit feeders, such as *Corophium volutator*, in the upper estuarine areas and filter-feeders, such as *Cerastoderma edule*, in the lower estuarine areas. The algae of the River Add have also been found to reflect distributions typical of such estuarine areas (Wilkinson & Roberts 1974), with green and blue-green algae penetrating farther up the estuary than red algae. A review of the conservation status of Loch Crinan was provided by Buck (1993). An extensive bed of *Ascophyllum nodosum* ecad *mackaii* at the head of Loch Feochan and a distinct band of the rare green alga *Codium adhaerens* at Degnish Point in Loch Melfort were highlighted as important features of the shores in Powell *et al.*'s (1977) survey of the Argyll shores.

13.3.3 Lochs Linnhe, Etive, Creran, Leven and Eil

The Loch Linnhe complex is situated at the upper end of the Firth of Lorn, north of Oban, at the southern end of the Sound of Mull. The lower part of Loch Linnhe is confluent with both the Firth of Lorn and the Sound of Mull, and is divided by the island of Lismore into the Lynn of Lorn and the Lynn of Morvern. Lochs Etive and Creran open into the Lynn of Lorn via constricted tidal narrows. Loch Leven branches off farther north-east along Loch Linnhe near the Corran Narrows which separates the upper and lower sections of Loch Linnhe, and there is a further restriction, Annat Narrows, near Fort William, which leads to Loch Eil. The loch complex is the largest, and at nearly 70 km from the head of Loch Eil to the tip of Lismore, the second longest sealoch in western Scotland. Depths of over 220 m are present in the Lynn of Morvern.

Loch Etive receives the greatest input of fresh water of any of the large sealochs in Scotland, giving a marked brackish character to its communities, and providing the main justification for its MCA status (NCC 1990b). Gage made extensive comparative studies between the sediment communities of Loch Etive and Loch Creran (Gage 1972a, 1972b, 1974; Gage & Geekie 1973a, 1973b;

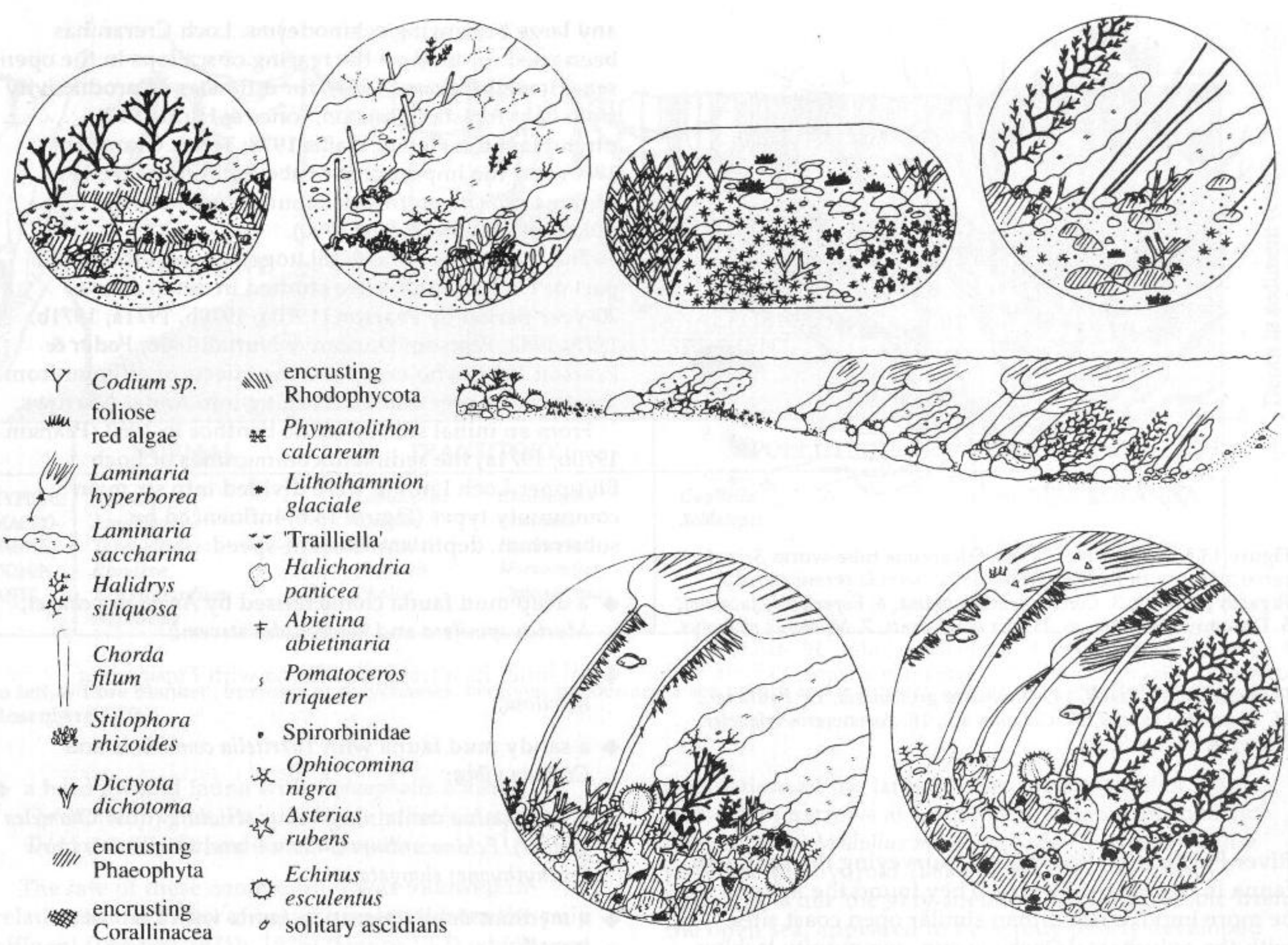


Figure 13.4. Communities in Linnhe Mhuirich rapids, Loch Sween. Enlarged portions of the cross section are shown. Based on Lumb & Hiscock (1990).

Warwick & Gage 1975; Gage & Coghill 1977). While the deeper sediments are typically characterised by sea pens *Funiculina quadrangularis* and brittlestars *Amphiura* spp. the shallow sediments contain a number of brackish-water species. The bivalve *Macoma balthica*, the mud snail *Hydrobia ulvae* and the amphipod *Corophium volutator* are present down to a depth of 5 m, and the polychaete *Scoloplos armiger* and oligochaete *Tubificoides benedii* extend below this depth. The freshwater influence is notable also on the rocky areas, with the brown alga *Fucus ceranoides* forming extensive beds near Bonawe. The Falls of Lora are perhaps the most spectacular narrows entrance of any Scottish loch, and are characterised by communities composed of only a few species, each present in high abundance. The small bivalve *Thyasira gouldi*, believed to be an ice-age relict population, lives near the head of Loch Etive. Millar (1988) noted the presence of the ascidian *Didemnum albidum* within the Loch, the first records for Scotland of this boreal species. Loch Etive was surveyed for the MNCR by Holt (1991). Killeen & Smith (1992) reported several new records of bivalves from the Dunstaffnage Channel and Loch Etive. These included *Aclis gulsonae*, previously recorded only from northern France.

Loch Creran also has MCA status (NCC 1990b), as it is particularly important for its well developed reefs of the calcareous tubeworm *Serpula vermicularis*, a species which usually occurs only as isolated individuals. The *Serpula* clumps have a rich associated fauna of ascidians and hydroids (Figure 13.5). The distribution of the *Serpula* reefs was surveyed for SNH (Moore 1996) and found to occur in a belt around most of the loch at depths of between 1 to 13 m with maximum cover of the seabed exceeding 10% in places. Elsewhere in the loch are beds of the horse mussel *Modiolus modiolus* and seagrass *Zostera marina* (Connor 1990b). The population of the crinoid *Antedon bifida* in the loch was used by Woodham (1990) in his study of infestation by the annelid parasite *Myzostomum cirriferum*. Loch Creran has rich sediment shores, whilst coarse sublittoral sediments in the entrance channel have high numbers of the rare anemone *Edwardsia timida*. The loch was surveyed in 1989 by an MNCR/UMBSM team (Connor 1990b), and had received much attention previously from Gage (see above) and a large number of student projects from Heriot-Watt University. The effluent from an alginate factory at Barcaldine prompted investigations by the Clyde River Purification Board (1976). Fibrous waste covered the seabed and the sediment was found to be devoid of macrobenthic fauna in the immediate vicinity of the outfall. Proposals to divert the effluent discharge from Loch Creran to the Lynn of Lorn led to the Clyde

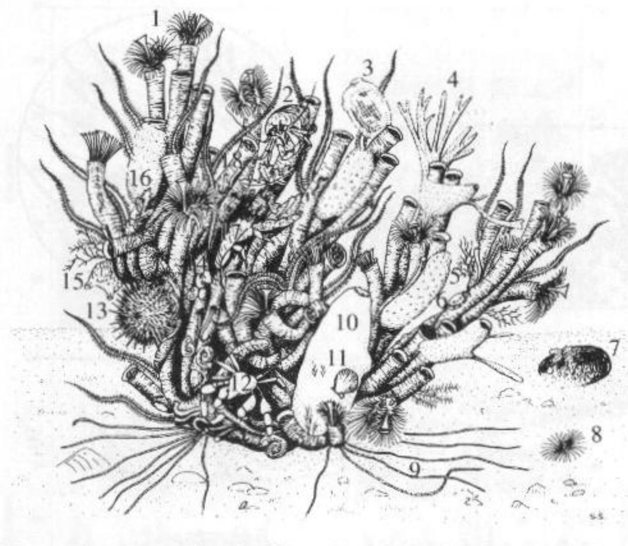


Figure 13.5. A small reef of the calcareous tube-worm *Serpula vermicularis* with associated fauna. 1. *Serpula vermicularis*, 2. *Pagurus prideaux*, 3. *Corella parallelograma*, 4. *Esperiopsis fucorum*, 5. Didemnidae indet., 6. *Pisidia longicornis*, 7. *Modiolus modiolus*, 8. *Chone infundibuliformis*, 9. Terebellidae indet., 10. *Ascidiella aspersa*, 11. *Chlamys distorta*, 12. *Inachus dorsettensis*, 13. *Psammechinus miliaris*, 14. *Dendrodoa grossularia*, 15. *Pyura* sp., 16. *Phycodrys rubens*, 17. *Galathea* sp., 18. *Pomatoceros triqueter*. Drawing by Sue Scott.

River Purification Board (1978) surveying the sediment fauna in the Airds Bay area. They found the infauna to be more impoverished than similar open coast sites, with the polychaete/*Amphiura* spp. community lacking any large burrowing echinoderms. Loch Creran has been used for tests on the rearing of scallops in the open sea (Howell & Fraser 1984), for estimates of productivity from kelp forests (Johnston, Jones & Hunt 1977), phytoplankton (Tett & Wallis 1978; Tett & Grantham 1980) and the impact of the tube-building polychaete *Melinna palmata* on the meiofaunal community (Olafsson, Moore & Bett 1990).

The sediments of Loch Eil, together with the upper part of Loch Linnhe, were studied in detail over a 20-year period by Pearson (1970a, 1970b, 1971a, 1971b, 1975, 1982; Pearson, Duncan & Nuttall 1986; Feder & Pearson 1988) who examined the effects of effluent from a pulp and paper mill discharging into Annat Narrows.

From an initial survey of the benthos in 1963 (Pearson 1970b, 1971a) the sediment communities of Loch Eil/upper Loch Linnhe were divided into six main community types (Figure 13.6) influenced by substratum, depth and current-speed:

- a deep mud fauna characterised by *Amphiura chiajei*, *Myrtea spinifera* and *Terebellides stroemi*;
- an inner loch transition fauna with *Eupolymnia nebulosa*;
- a sandy mud fauna with *Turritella communis* and *Corbula gibba*;
- a sand fauna containing *Venus striatula* (now *Chamelea gallina*), *Echinocardium cordatum* and *Cucumaria* (now *Trachythyone*) *elongata*;
- a medium depth transition fauna with *Lucinoma borealis*;

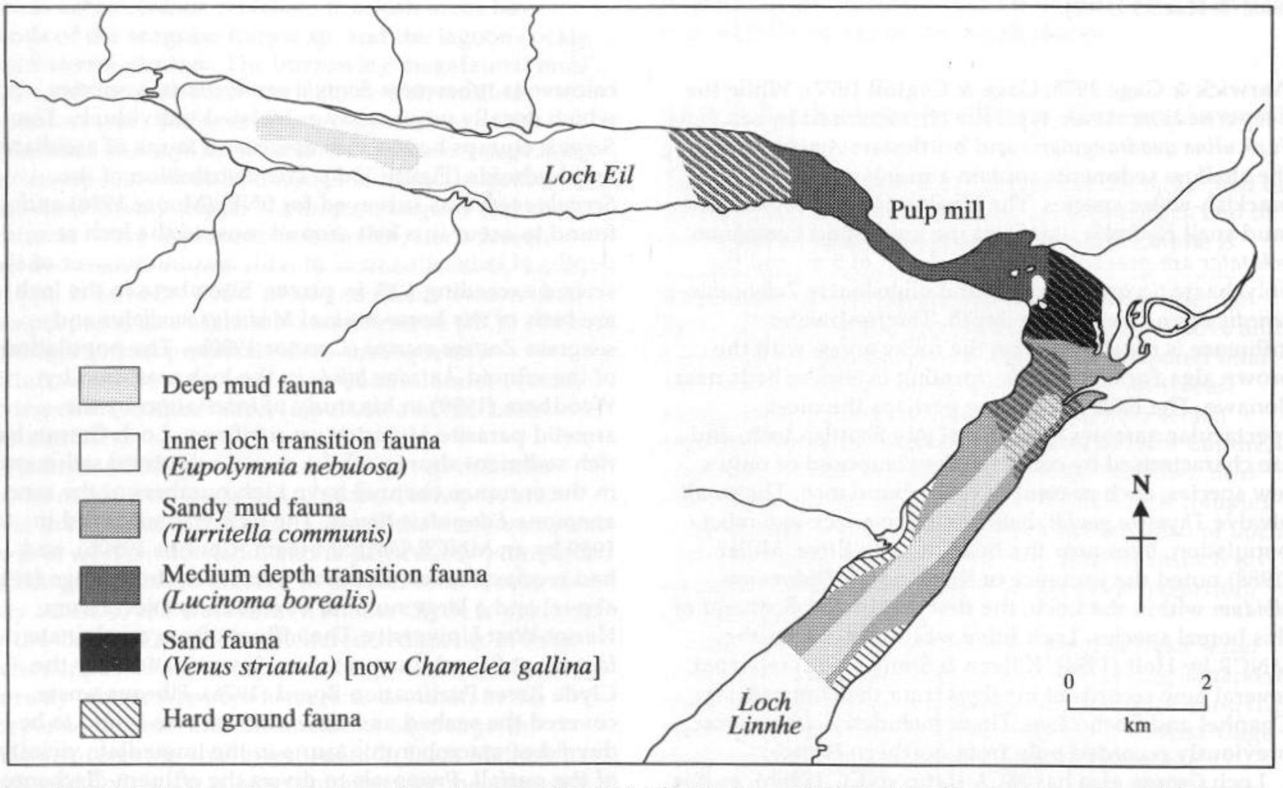
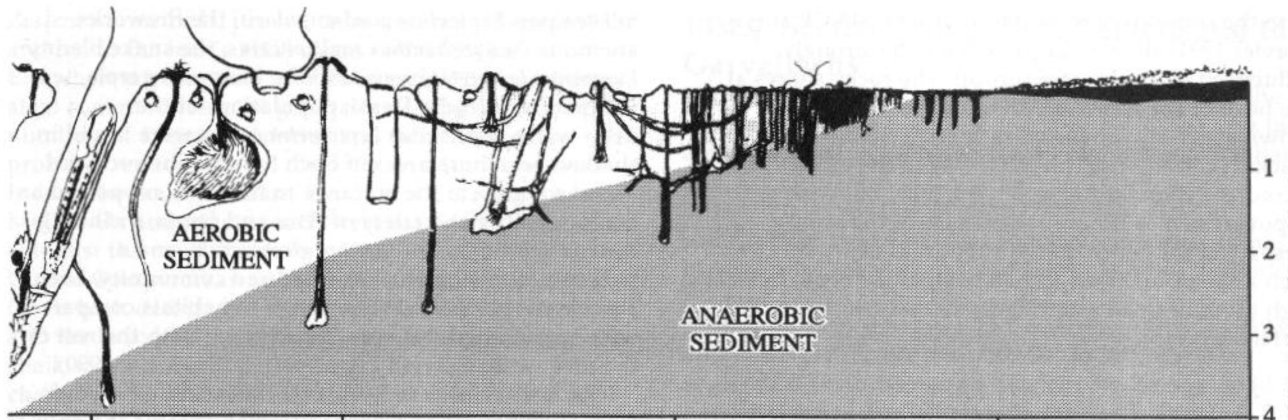


Figure 13.6. Distribution of the dominant faunal communities in Lochs Linnhe and Eil prior to influence from pulp mill effluent (re-drawn from Pearson 1971a).



	NORMAL	TRANSITORY		POLLUTED	GROSSLY POLLUTED
TYPICAL MACRO-FAUNA DOMIN-ANTS	*Nucula* *Amphiura* *Terebellides* *Rhodine* *Echinocardium* *Nephrops*	*Labidoplax* *Corbula* *Goniada* *Thyasira* *Pholoe*	*Chaetozone* *Anaitides* *Pectinaria* *Myriochele* *Ophiodromus*	*Capitella* *Scolelepis*	No MACROFAUNA Surface covered by Fibre 'blanket'

Figure 13.7. Diagrammatic representation of faunal and sedimentary changes under increasing organic loading showing, from right to left, a 'fibre blanket', burrows of polychaetes, bivalves, brittlestars, a sea urchin and a Norway lobster *Nephrops* (from Pearson & Rosenberg 1976).

- a hard ground fauna with *Ophiopholis aculeata, Ophiothrix fragilis, Psammechinus miliaris, Astarte* (now *Tridonta*) *elliptica* and *Eunice pennata.*

The fate of these communities was followed in relation to the influx of organic material from the pulp effluent (Pearson 1971b, 1975) (Figure 13.7) which was found to have the greatest effect at stations closest to the discharge point in Annat Narrows, and an increased effect following a greater input of effluent in 1969. Initially species already present in the area (predominantly bivalves and echinoderms) underwent a large increase in numbers as a result of increased food supply from the organic effluent. Gradually these species were replaced by others, which had initially been present only in low numbers, before themselves being replaced by entirely new species (mainly annelids). Finally, the few annelids which accounted for the main component of the fauna also declined as organic enrichment reached its peak. Following the closure of the pulp mill in 1980, there was some evidence of faunal recovery by 1982 (Feder & Pearson 1988).

Loch Linnhe and Loch Eil were surveyed in 1989 for the MNCR (Connor 1990b) and were found to have a wide range of communities commensurate with the large size of the lochs. Around the limestone island of Lismore, rocky circalittoral habitats supported a greater variety of hydroids and bryozoans than is typical for sealochs, reflecting the area's proximity to the rich hydroid and bryozoan turf communities of the Firth of Lorn (see below). In the tide-swept channels near Port Appin and off Shuna Island a mosaic of communities included dense beds of the file shell *Limaria hians*. The sediments of the outer loch typically supported large numbers of burrowing sea cucumbers, including *Psolus phantapus* and *Thyonidium commune,* and extensive populations of the large bivalve *Arctica islandica*. The tide-swept narrows at Annat were notable for their rich horse mussel *Modiolus modiolus* beds covered by dense stands of the hydroid *Tubularia indivisa* and other hydroids, while the very sheltered Loch Eil, remote from the open sea, appeared to have only poorly developed communities, such as the *Protanthea simplex* and *Neocrania anomala* association of sheltered bedrock.

The fish populations of the Loch Linnhe and Loch Eil system have attracted a number of studies: Cooper (1980) examined the movement of gadoid populations between sealochs and the open coast; Gordon & de Silva (1980) described the inshore fish populations of lochs in the upper Firth of Lorn area; and Nash (1982) compared the population of Fries's goby *Lesueurigobius friesii* in the Firth of Lorn with that in the Clyde.

The shores of Loch Linnhe and Loch Eil have been relatively little studied, with Smith (1978, 1981) providing the main contribution. She described fucoid-dominated rocky shores, freshwater-influenced gravels with *Fucus ceranoides*, and sediments with the bivalves *Cerastoderma edule, Dosinia exoleta* and *Venerupis senegalensis.* Smith (1981) considered Loch Eil and upper Loch Linnhe to be unusual in that the most brackish part of the system is not at the head of the loch because saline water flows beneath the freshwater to enter Loch Eil, making it more saline than upper Loch Linnhe.

Little information was available for Loch Leven prior to an MNCR survey in 1990 (Davies 1991). Before this Smith (1981) surveyed the current-swept shores at Ballachulish narrows and considered them to be of high importance. Patches of shell-sand had the bivalves *Tridonta montagui* and *Gari tellinella,* species rarely seen littorally, while a profuse growth of sponges, hydroids and ascidians thrived under the shelter of *Fucus serratus.* The rare gastropod *Margarites groenlandicus* was common and beds of horse mussel *Modiolus modiolus* extended up onto the shore from the sublittoral. The MNCR survey (Davies 1991) showed Loch Leven to be strongly influenced by freshwater run-off. The rocky shores at the head of the loch supported dense stands of the brown alga *Fucus ceranoides*, a species characteristic of brackish conditions. This gave way to the more usual fucoid zonation farther down the loch, but with impoverished communities because of the strong freshwater influence. In the sublittoral many species such as *Modiolus modiolus* had been killed because recent high input of fresh water had reduced salinity in the surface layers.

13.3.4 Loch Sunart, Loch Teacuis and the Ardnamurchan Peninsula

Loch Sunart is an MCA of the most outstanding quality, with a very wide range of habitats and an exceptionally rich fauna and flora (NCC 1990b). Of the shores surveyed by Smith (1978) the Camaschoirk area had the widest range of habitats, with rich infaunal bivalve communities, saltmarsh, patches of the seagrass *Zostera nana*, beds of the lugworm *Arenicola marina* and areas of fucoid algae. A more extensive survey of the shores was undertaken in 1990 for the MNCR (Davies & Connor 1993).

The sublittoral zone of Loch Sunart was surveyed by Mackinnon & Lumb (1988) and subsequently by an MNCR/UMBSM team (Davies, J. 1990). The Loch included a wide range of communities typical and representative of sealochs, many of which are very good examples of their type. Also within the Loch there were communities more typically found on the open coast, supporting species which are rare in Scotland, or are present in densities much greater than is known elsewhere. Within the Loch there were extensive beds of the file shell *Limaria hians*, and rich mud faunas with the tall sea pen *Funiculina quadrangularis*, the fireworks anemone *Pachycerianthus multiplicatus*, the snake blenny *Lumpenus lampretaeformis*, and the burrowing crab *Goneplax rhomboides*. Dense populations of the deep-water featherstar *Leptometra celtica* were found in shallow nearshore areas of Loch Sunart. The rock and island complex at the entrance to the Loch supported an exceptionally rich variety of flora and fauna, including the red sea-fingers *Alcyonium glomeratum*, and a particularly rich sponge and hydroid community. Loch Teacuis supported a smaller range of habitats compared with Loch Sunart, but these, in keeping with the rest of the area, were generally species-rich (Davies, J. 1990).

The Ardnamurchan Peninsula extending westwards from Loch Sunart and Ardnamurchan Point is the only very exposed mainland location between Kintyre and the Minch. The coastline comprises a series of exposed steep rocky headlands characterised by barnacle- and limpet-dominated biotopes with *Alaria esculenta* in the sublittoral fringe. There are also a few locally sheltered bays in which the rock is covered by dense fucoid algae and white sandy beaches supporting burrowing crustacean and polychaete communities. Many of the open coast sublittoral communities were characteristic of surge gullies with hydroid, bryozoan and anthozoan turfs in the gullies between stacks. Offshore rock pinnacles were colonised by large *Laminaria hyperborea*, dense foliose red algae and sponges and colonial ascidians. Deeper, the faces were dominated by dense dead-man's fingers *Alcyonium digitatum*, large colonies of the sulphur yellow sponge *Cliona celata*, other sponges including large *Pachymatisma johnstonia* and *Haliclona viscosa* and the cup sponge *Axinella infundibuliformis*. Anemones, cup corals and hydroids formed a turf over much of the rock surface while overhangs and the roofs of caves supported colonies of the rarely encountered zoanthid anemone *Parazoanthus anguicomus*.

13.4 Inner Hebrides (southern islands)

13.4.1 Introduction

A compilation of studies relating to the environment of the Inner Hebrides was brought together by Boyd & Bowes (1983). This symposium volume included papers on inshore hydrography and oceanography, seals, shellfish resources and nature conservation, together with papers on marine ecological studies which are discussed below.

13.4.2 Islay and Jura

Smith (1982b) undertook an extensive survey of the shores on these, the most southerly of the Inner Hebrides, concentrating her efforts on the molluscan fauna. She recorded 93 molluscan species and considered this low total to reflect the lack of variety of microhabitats in the more sheltered areas of the islands. Loch Tarbert was considered potentially the most interesting area on Jura, with the extensive rocky platforms on Islay's north coast, and the mixed sheltered shore at Loch an t-Sailein, with its population of the cockle *Cerastoderma glaucum*, also of interest. Perhaps Islay's best shores however were those on the exposed west coast where the alga *Fucus distichus anceps* probably reaches its southerly limit and where there was a very diverse fauna and flora for such an exposed area. Powell *et al.* (1977) pointed to Islay's southern coast as having the smallest spring tidal range (0.6 m) in Britain, with consequent compression of shore zonation patterns. There are extensive sediment shores in Loch Gruinart and Loch Indaal that are important bird feeding grounds, which are notified as SSSIs (Buck 1993). The fauna of the latter shore was investigated by Stroud, McKay & Robertson (1984) in relation to the bird populations. The snail *Hydrobia ulvae* was common on the upper shore and was replaced by the bivalves *Angulus tenuis* and *Cerastoderma edule* and the polychaete *Nephtys* sp. on the lower shore, showing the shore to be similar to other west coast estuaries.

The sublittoral communities in Loch Indaal, including rich algal communities associated with the seagrass

Zostera marina beds, proved to be unusual (Hiscock 1983) and led to the loch's MCA status (NCC 1990b). Elsewhere on Islay and Jura, Hiscock (1983) found the algal communities to be generally rich, but felt the high numbers of *Echinus esculentus* and *Balanus crenatus* probably reduced faunal diversity. In addition to Loch Indaal, the Sound of Islay, the Gulf of Corryvreckan, the Mull of Oa and Islay's south-west coast were selected as amongst the most interesting in the area. Bedrock in the Gulf of Corryvreckan to the north of Jura was notable for its high density of the hydroid *Sertularella cupressina* and the bryozoan *Securiflustra securifrons*. Elsewhere shallow-water surge gullies had communities characterised by the ascidian *Dendrodoa grossularia* and the sponge *Clathrina coriacea*, and circalittoral rocks supported large numbers of the ascidian *Polycarpa rustica* (now *Polycarpa scuba*). Tide-swept pebbles in the Sound of Islay were richly colonised by hydroids and bryozoans. Sediments around the islands ranged from coarse gravels, with maerl and the sea cucumber *Neopentadactyla mixta*, to soft muds and populations of the sea pen *Virgularia mirabilis*.

The south-east coast of Islay was surveyed by Easton & Pagett (1984) to assess the possible impact of fish-farm development. They concluded that the area's low flushing time and high numbers of predators would not be advantageous to such developments. Discharges from distilleries on Islay and Jura attracted hydrographic and chemical surveys by the Clyde River Purification Board (1984), with results indicating local pollution of shore communities and some increase in heavy metal contaminants.

In the Sound of Jura, Brown (1983) described the range of communities associated with gravels, muddy sands, sands and muds in the area. He paid particular attention to the shelled invertebrates, and noted that maerl deposits yielded similar fauna to other gravel deposits. Loch Tarbert was re-surveyed in 1990 for the MNCR (Connor 1991b). The loch is almost entirely unspoilt and is notable for its tortuous inner channel.

13.4.3 Colonsay and Oronsay

Little information is available for either the shores or the sublittoral zones of these two islands. An expedition by the British Sub-Aqua Club Pendle Branch (1981) outlined the main features of the coast with recording at five sublittoral sites. The shores comprised cliffs, raised beaches, gently sloping rocky shores, and a wide expanse of sand and mud between the two islands. In the sublittoral, the soft coral *Alcyonium digitatum* and the sea urchin *Echinus esculentus* were noted as absent from the west coast sites, and maerl was recorded on the east coast. Powell *et al.* (1977) included the islands in their survey of Argyll shores, but gave no specific detail on their findings. They did not rate any of the sites to be of high marine biological interest. Norton *et al.* (1969) provided a checklist of algae for the islands from a sublittoral survey. They found bedrock extended to only about 9 m depth before giving way to coarse sands. A very dense forest of kelp *Laminaria hyperborea* was found to have a rather sparse understorey of foliose red algae and the richest collecting grounds for algae were the shallow sheltered sediments.

13.4.4 Scarba, Luing, Seil, Kerrera and the Garvellachs

This island group lies in the Firth of Lorn between the mainland and the islands of Jura and Mull. The area has a complex hydrography with a diverse range of habitats and supports some of the richest and most varied marine life in western Scotland. This has attracted considerable attention from biologists and there now exists a substantial quantity of information to support the area's MCA status (NCC 1990b).

Shore studies date back to the work of Kitching (1935) and Lewis (1957), continuing with Todd's ongoing research at Cuan Ferry and Clachan Sound (e.g. Todd & Lewis 1984; Todd & Turner 1986, 1988). The tidal narrows at Clachan Sound between the mainland and Seil Island are of particular importance (Powell *et al.* 1977) and were described in some detail in the classic work of Lewis (1964). Smith & Nunn (1985) considered Clachan Sound to be a very rich area with an unusually diverse intertidal mollusc fauna, but in 1990–91 dramatic changes in species composition were apparent, probably resultant from natural causes (Smith & Nunn 1992). In addition to a rich and diverse range of communities here some algae exhibit unusual growth forms in the strong tidal streams. Smith (1984) surveyed the shores of Luing and the Garvellachs, finding the area to be exceptionally interesting, with the richest shores at Toberonochy, Rubh' Aird Luing and Eilean Fraoch on Luing. She considered the rock formations, which provide a large number of crevices, and the high exchange of water movement in the area, to be significant factors in increasing species diversity. Amongst the rich molluscan fauna was the clam *Palliolum striatum* and the file shell *Limaria hians*, species uncommon in the sublittoral and rarely recorded on shores. The brachiopod *Neocrania anomala* was common on shore, well above its normal sublittoral habitat. Millar (1952) listed 25 species of ascidians from shores in the area.

In the sublittoral around Scarba, Luing and the Garvellachs, Picton *et al.* (1982) and Buehr (1984) described a wide range of communities rich in species and including a number of rare algae and animals. Rocky areas were particularly rich in red algae, hydroids and bryozoans and were often characterised by the presence of the cup sponge *Axinella infundibuliformis* and the sea fan *Swiftia pallida*. The rare anemone *Amphianthus dohrnii* was found on some of the sea fans. The islands north of Scarba are one of the few known locations for the large cerianthid anemone *Arachnanthus sarsi*. The rare brown alga *Desmarestia dresnayi* was found to be common in the tide-swept Sound of Luing, while the coarse sediments around the Garvellachs supported the very rare brittlestar *Ophiopsila annulosa*. Elsewhere the range of communities reflected the variation in habitat from wave-exposed to very sheltered conditions and a wide variety of tidal stream strengths. Of particular interest are the extreme tides of the Gulf of Corryvreckan, which reach 8 knots (4 m s^{-1}) or more. Species such as the dead-man's fingers *Alcyonium digitatum*, the anemone *Urticina felina* and the hydroid *Sertularia argentea* which normally thrive in tide-swept areas were confined to sheltered surfaces on a pinnacle in the sound and replaced by the hydroid *Tubularia indivisa* and the barnacles *Balanus crenatus* and *Balanus balanus* (not *Balanus hameri*, as stated in Picton *et al.* 1982; R. Holt, pers. comm).

Norton & Milburn (1972) described the sublittoral algal communities in the area from diving observations. In the flooded slate quarry at Easdale they recorded 75 species of algae and noted the absence of a *Fucus serratus* zone and the replacement of kelps by *Codium fragile* var. *tomentosoides*. Kelp *Laminaria hyperborea* was recorded as deep as 24 m, and foliose algae to 36 m depth. They considered the presence of the brittlestar *Ophiocomina nigra* to be a limiting factor to colonisation of rock at certain sites.

The nudibranch fauna of Kerrera was studied by Brooke, Brown & Smith (1979), who recorded 52 species from the island, including the first British record of *Adalaria loveni*.

13.4.5 Mull and the Sound of Mull

Powell *et al.* (1977) and Smith & Gault (1983) described a range of shores on Mull. The former study, part of the extensive SMBA/MBA surveys, selected Clachandu and Calgary Bay as sites of greatest interest. Clachandu is an area of shallow pools, shingle flats and boulder areas, where the brown alga *Cystoseira nodicaulis* occurs and the crab *Xantho incisus* approaches its northern limit. The lagoons are rich in species with the annual brown algae *Leathesia difformis* and *Mesogloia lanosa* particularly common. The alga *Cystoseira tamariscifolia*, another species near its northern limit, grew in quantity at Calgary Bay, together with other uncommon algae. Smith & Gault (1983) found the north-west coast of Mull to have the greatest variety of habitats and corresponding richness in species, and the east coast to be less diverse. In the Ross of Mull the head of Loch Scridain has a complex array of habitats, while the shores of Loch na Keal and Loch Tuath, and around Calve Island, were also highly rated.

In the sublittoral, Bishop (1984) described sites in the Sound of Mull and Loch na Keal, and Davies (1990) described surveys of Mull's western sealochs. Ryland's (1963) survey of bryozoans included five sites in the Sound of Mull. Spectacular underwater vertical cliffs were found by Bishop (1984) in both Loch na Keal and the Sound of Mull, the former site having a band of red sea fingers *Alcyonium glomeratum* below 30 m, and all sites having high densities of sponges, hydroids, anthozoans and erect bryozoans. Davies (1990) found the circalittoral cliffs in Loch na Keal to be unusual, with the sea fan *Swiftia pallida* and the anemone *Protanthea simplex* occurring together. The former is normally associated with moderate exposure to wave action whereas the latter is normally confined to very sheltered sites. Exposed coarse sediments on the north-west coast were found to contain populations of the ascidian *Molgula oculata*, a species of northern origin which is uncommon around the British Isles. The Sound of Iona was selected as an MCA (NCC 1990b) because of the presence of extensive beds of maerl throughout the channel, as described above (Farrow, Cucci & Scoffin 1978).

Price & Tittley (1978a, 1978b) provided considerable detail on the distribution of algae both onshore and in the sublittoral for a large number of sites around Mull. The shores range from those with extreme shelter supporting large beds of the detached form of knotted wrack *Ascophyllum nodosum* ecad *mackaii*, through the fucoid-dominated sheltered shores to exposed shores where *Fucus vesiculosus* f. *linearis* was almost absent and replaced by barnacles, limpets and, in the sublittoral fringe, the kelp *Alaria esculenta*. In the sublittoral, the more exposed sites were characterised by forests of kelp, *Laminaria hyperborea*, often accompanied by *Saccorhiza polyschides*, while increasing shelter gave growths of *Laminaria saccharina*, *Chorda filum* and *Halidrys siliquosa*. A characteristic underflora of the *Laminaria hyperborea* forests included *Delesseria sanguinea*, *Dictyota dichotoma*, *Desmarestia aculeata*, *Nitophyllum punctatum* and *Pterosiphonia parasitica*. *Lomentaria articulata*, *Membranoptera alata*, *Polysiphonia urceolata*, *Ptilota plumosa* and *Palmaria palmata* were typically restricted to the kelp stipes, whilst *Callophyllis laciniata*, *Cryptopleura ramosa*, *Phycodrys rubens* and *Plocamium cartilagineum* were generally distributed on both the stipes and in the underflora.

Of the sealochs on Mull, Loch Spelve was intensively sampled in relation to the effect of fish-farming on the environment. Brown, Gowen & McLusky (1987) reported a limited effect on the macrobenthos, with unaffected communities occurring at 25 m from the cages. A later paper considered other environmental pressures (Gowen *et al.* 1988).

13.4.6 Coll and Tiree

Coll's shores remain to be surveyed, and Smith (1983) considered only the molluscan fauna of Tiree's coast. The shores there consisted mainly either of exposed clean sandy beaches or irregular rocky shores, often subject to some sand-scour. The molluscan fauna was generally rather poor, with only 70 species recorded during her survey. At the time of Smith's (1983) survey, a population of the purple sea urchin *Paracentrotus lividus*, a species usually restricted to south-western coasts of England and Ireland, was noted at one site (R. Mitchell pers. comm.). The population appeared to be of one age class and might have resulted from a single settlement of larvae. Stephen (1930) recorded a poor but typical fauna from Tiree's sandy beaches, including populations of the bivalves *Macoma balthica* and *Tellina* (now *Angulus*) *tenuis*, and the polychaetes *Nephtys caeca* and *Aricia* (now *Lumbrineris*) *latreilli*.

Dipper (1981) surveyed the sublittoral zone of Tiree and the south coast of Coll. The relatively exposed nature of the area restricted sediment habitats to coarser sands and gravels, from which the anemone *Arachnanthus sarsi* was recorded for the first time in Britain. A lack of intense urchin-grazing was considered in part responsible for rich exposed-coast communities, and the barnacle *Balanus crenatus* was noted as predominant on shallow rock habitats around Tiree. Woodward (1985) reviewed the distributional records of the fan shell *Pinna* (now *Atrina*) *fragilis* in Scotland, including a record from Coll's south-east coast.

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