Marine Nature Conservation Review

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

edited by

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Part 2

Reviews within MNCR Coastal Sectors

Chapter 1: Shetland (MNCR Sector 1)*

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Synopsis

The Shetland Isles are the most northerly part of Britain and have a coastline of about 1,450 km in length. The inshore marine habitats present are predominantly rocky and range from those exposed to severe wave action to extremely sheltered situations within the many firths, voes and sounds. Sublittoral regions include both rocky and sedimentary habitats with the variety of sediment types particularly notable. Although surface salinity in enclosed areas might be significantly reduced by rainfall, there are no estuarine habitats present. However, brackish conditions exist in houbs and vadills within or at the heads of voes. Rocky shore communities are very varied because of the differences in wave exposure and include some especially well-developed examples of exposed coast communities. In the sublittoral, rock surfaces have extensive kelp forests but grazing reduces the diversity and abundance of many species. However, grazing by sea urchins in shallow depths is reduced by wave action on exposed coasts while urchins are uncommon in extreme shelter so that richer communities may exist in these situations. The wide range of conditions of tidal current strength are important after wave action in determining the types of communities present in the sublittoral zone. Sediment habitats are generally restricted to a few pocket beaches in the intertidal and the communities are not extensively developed. However, large sandy beaches occur at wave exposed locations in the south of Shetland and hold low-diversity communities typical of disturbed sediments. Many of the sublittoral sediment communities are very rich. Isolated and generally small beds of seagrass *Zostera marina* occur in shallow depths in some voes and the brackish-water seagrass *Ruppia* spp in isolated waters. Beds of horse mussels occur extensively in tide-swept areas. Maerl (predominantly *Phymatolithon calcareum* and some *Lithothamnion glaciale*) occurs in some of the sounds. Extensive caves in some locations, especially Papa Stour and Fair Isle, have characteristic communities. Northern species which are rarely or not found elsewhere in Britain occur in Shetland. These include the sea urchin *Strongylocentrotus droebachiensis* and the sea cucumber *Cucumaria frondosa*. The coastal waters around Shetland support large populations of common and grey seals and of otters.

1.1 Introduction and historical perspective

The Shetland Islands (Figure 1.1) are the most northerly part of the British Isles, lying at the northern entrance to the North Sea on a similar latitude to Bergen in Norway. Fair Isle is some 40 km south-west of Sumburgh Head, the most southerly point of mainland Shetland, and is separated from Orkney by a deep (121 m) channel, the Fair Isle Channel. The island of Foula is approximately 20 km to the west of Shetland while to the north, the Faeroe Channel, which is over 1,000 m deep, separates the Shetland archipelago from the Faeroe Islands. Shetland consists of numerous large and small islands with a highly indented coastline of approximately 1,450 km in length and no part of the archipelago is more than 5 km from the coast (Flinn 1974). The coastline, which is predominantly rocky, has some of the most spectacular wave-exposed coastal scenery in the British Isles, with high cliffs, caves and long, steep-walled narrow inlets called 'geos'. Deep water occurs close inshore, particularly along the east coast where the 80 m depth contour follows the coastline at a

* An initial review was undertaken from published sources of information on benthic habitats and communities as well as interviews with relevant workers up to 1990 (Hiscock & Johnston 1990). Information has been substantially revised by the present author to take account of major additional studies up to the end of 1994 and some further additions have been made up to the end of 1996 by the series editor. This chapter does not include benthic survey information summarised for or published in the MNCR *Regional Reports* series or work now being undertaken to map biotopes in candidate Special Areas of Conservation. For information on conservation status and an analysis of rare and scarce seabed species, the reader is referred to the *Coastal Directories* series.

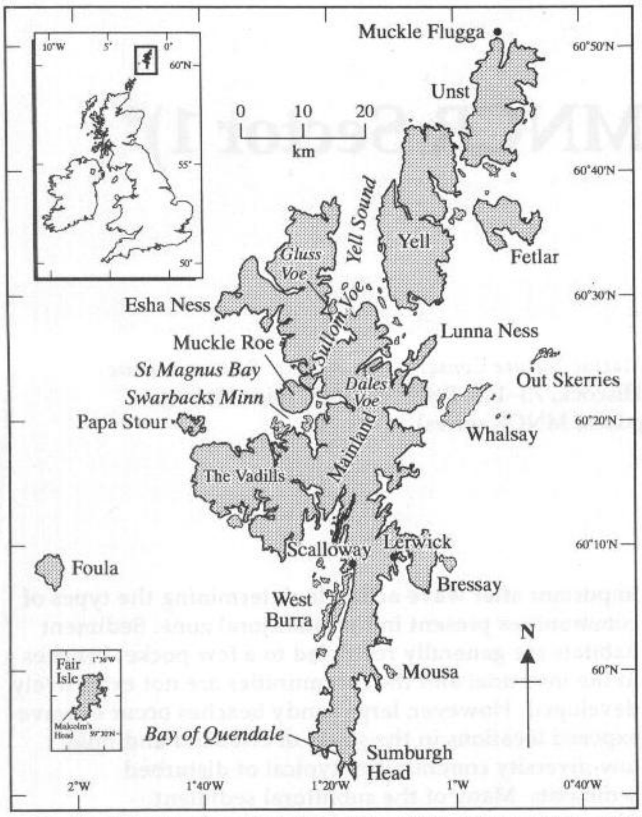

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Figure 1.1. The Shetland islands showing places mentioned in the Introduction.

distance of less than 3 km in places. On the west coast, a basin in St Magnus Bay reaches a depth of 200 m. The few areas of littoral sediment occur as shingle at the heads of voes, as pocket beaches on sheltered areas of coast and as more extensive sandy beaches backed by dunes on parts of the more exposed coastline. Shetland has about 116 inlets described as 'voes' or 'firths'. Almost all of these are flooded valleys without an entrance sill and without significant freshwater input. Their hydrographic characteristics and those of the many firths and sounds have been catalogued using information obtained from Admiralty charts and Ordnance Survey maps (Dixon 1987a). Further characteristic features of the voes are the lagoonal structures known as 'houbs' and 'vadills'. These, together with the generally broken nature of the coastline, provide extensive sheltered littoral and sublittoral habitats with the seabed grading from rock to coarse shelly sand to mud.

Shetland is one of the most wind-swept areas of the British Isles and thus the open coasts are frequently exposed to strong wave action, predominantly from the south and west. This, combined with the depth of the water, means that there are deep rocky habitats available around much of the open coast. Hence the Shetland Islands have a transition from some of the most wave-exposed rocky habitats in the British Isles to some of the most sheltered rocky and sediment shores. Tidal streams also play an important part in structuring the habitats available. There is a considerable variation in size and depth of the numerous channels between islands and across sills. The strength of the streams thus ranges from negligible up to speeds of several knots.

The North-East Atlantic Drift, which flows up the west coast of the British Isles past Shetland has some influence on seawater temperatures in the area. Although these are low for the British Isles, with mean bottom temperatures ranging from 7 °C in winter to 11 °C in summer, this range is less than that experienced by more southern coasts of the North Sea where temperatures ranging from 5 °C to 16 °C are recorded (British Oceanographic Data Centre 1992). However, this wide temperature range is in large part due to the shallow enclosed nature of the North Sea whereas Shetland lies in more stable oceanic water. Rainfall in Shetland is high, averaging 1,117 cm per annum (Shetland Islands Council 1988) and some voes will be subject to reduced surface salinity following heavy rain (Dixon 1987b; Edwards & Sharples 1986). Brackish conditions occur in many of the shallow houbs and vadills, but there are few areas of extensive estuarine conditions due to the absence of large rivers.

The location of Shetland in the far north of Great Britain suggests that the islands are likely to include representatives of a northern fauna and flora. Maggs (1986) collated information available from Shetland in a major review of the Scottish marine macroalgae, listing 281 species as occurring in the islands and discussing their distribution patterns. The ratio of Rhodophycota: Chromophycota (red algae: brown algae), which is often used for comparing regional flora and which generally decreases towards northern latitudes, was lower than that for Orkney and higher than in Faeroe. Some 71 southern species reached Shetland but not Faeroe, while only two species reached their southern limits in Shetland. This illustrated the accepted phenomenon of a reduction in species-richness with increasing latitude and the increasing importance of brown algae in more northern floras. The most important floristic discontinuity in the area was considered to be that between Shetland and Faeroe with a secondary one between Shetland and Orkney, and both of these were related to possible environmental factors (Maggs 1986).

The earliest published records of marine species from Shetland were those of Montagu who, in 1811, described a gastropod and two species of brachiopod collected from the south coast of Shetland by Fleming when he was minister on Bressay (Jeffreys 1864). Fleming subsequently published more of his discoveries in his *History of British animals* (Fleming 1828, quoted in Jeffreys 1864). More systematic studies of the marine biology of Shetland extend back to 1839 when Edward Forbes dredged there and so impressed the British Association for the Advancement of Science with his finds that a Dredging Committee was established to "thoroughly examine the invertebrates of the deep sea" off Shetland (Norman 1869). The results of those extensive dredging surveys carried out in the mid-1800s are reported by Forbes (1851) and in a volume edited by Jeffreys (1869). The final dredging reports were presented in 1868 and described dredging activities in the deep water of St Magnus Bay and off the east coast of Shetland. A series of papers gave the results pertaining to particular taxonomic groups and dealt primarily with lists of species, new records and geographic distributions (Jeffreys 1869; M'Intosh 1869; Norman 1869; Waller 1869). Amongst these, M'Intosh (1869) included records from the east of Shetland and from the shore at Hillswick, and Norman (1869) included Whalsay, Out Skerries and Unst, again giving some littoral records. In his notes, Norman (1869) states "The marine fauna of Shetland has proved to be extremely rich. The sea there would seem to be in an especial manner the meeting place of northern and southern types". The work resulted in the addition of 204 species to the British marine fauna of which 40 were new to science. Some zoological work was carried out in the vicinity of the Shetland Islands as a by-product of fisheries research (Stephen 1933a, 1933b) but, for almost 100 years after the Dredging Committee's work, there were very few marine zoological studies undertaken in the islands.

This period of natural history studies in Shetland is of both historic interest and considerable zoological importance and a number of common strands ran through the work. First was the exploration of a new fauna and the compilation of a species list, including the description of many new species. These taxonomic and distributional records were incorporated into a number of monographs dealing with major groups of marine invertebrates during the second half of the 19th century, several of which remain as standard texts today. Bowerbank, for example, while not participating in the dredging expeditions, identified and described sponges which were sent to him from Shetland (Bowerbank 1864, 1866, 1874, 1882). The success of this exercise was such that relatively few species have been added to the Shetland marine fauna during more recent studies, and many of the species found during the 19th century have rarely, if ever, been seen since. Certainly, a number of species recorded in the area at the time, such as the zooanthid anemone *Parazoanthus anguicomus*, do not appear to have been recorded on Shetland in recent years although they are known from elsewhere on the British coastline. A second strand of interest was the high species diversity that continued to attract these naturalists to the islands, reflected in the extensive species lists produced. Although high diversity is present in sediments, more recent studies of inshore rocky habitats have been found to indicate low species diversity. The high habitat diversity of the islands does, however, contribute to an overall rich environment. Thirdly, early workers, collecting at the northern extremity of the British Isles, were able to develop theories of biogeography which have since been amplified and modified by more recent work (Alvarez *et al.* 1988). These 19th century studies thus laid very solid foundations for subsequent ecological studies and should not be overlooked.

In contrast to the intense zoological activity, there was little in the way of botanical research in Shetland during the same period, although those dredging in the area did make a few incidental botanical observations. The only systematic account of the marine algae at that time appears to be that of Edmondston, a young and very talented Shetland botanist. He published *A Flora of Shetland* which included records of some 90 species of marine algae (Edmondston 1845). It was over 50 years before any additional records were published by Børgesen (1903; Børgesen & Jonsson 1908) who collected algae in Shetland during a brief stop *en route* to the Faeroe Islands. He sampled at Lerwick and Bressay and, at the entrance to Yell Sound, on Muckle Holm and in Burra Voe. Several botanists visited Shetland in the 1950s and 1960s, notably Powell (1954a, 1954b, 1957a, 1957b, 1963) and Irvine (1962, 1974a, 1974b, 1980).

It was the development of the oil industry at Sullom Voe in the 1970s that prompted the majority of more recent ecological studies (Institute of Terrestrial Ecology 1975a; Foxton 1981; Dunnet 1995). The growth of fish farming in the 1980s led to further studies (Dixon 1986, 1987a, 1987c; Hiscock 1989; Rostron 1989) while with the start of the Nature Conservancy Council's Marine Nature Conservation Review in 1987, broad scale marine ecological surveys were commissioned (Hiscock 1986, 1988; Howson 1988). Connor (1994) included Shetland in a discussion of the sublittoral ecology of Scottish islands. More recently, work has been carried out as a result of the wreck of the *Braer* oil tanker in January 1993, which resulted in the release of over 84,000 tonnes of fuel and bunker oil. Later sections of this chapter deal in more detail with the various publications mentioned above.

1.2 General marine biological surveys during the 20th century

1.2.1 Introduction

The first major multi-disciplinary survey was conducted by the Institute of Terrestrial Ecology (ITE) with the help of the Scottish Marine Biological Association (SMBA) for the marine parts of the work (Institute of Terrestrial Ecology 1975a, 1975b). Additionally, studies of littoral rocky areas were undertaken by staff and students of University College Swansea and included 80 sites. Thirty-six nearshore sublittoral sites were surveyed by diving by Dr R. Earll and C. Lumb. These wide-ranging surveys were concentrated on the central mainland around Sullom Voe although they incorporated sites throughout Mainland Shetland, on Unst and on the Out Skerries. The marine elements of this work incorporated studies of rocky and sedimentary shores and the sublittoral biota (Institute of Terrestrial Ecology 1975c, 1975d, 1975e). The coastline was classified by the ITE on the basis of its physical characteristics, taking information from maps and aerial photographs (Institute of Terrestrial Ecology 1975b). This aimed to provide a framework for survey site selection and descriptions of the coastal biology. Eight coastal groups were identified ranging from the most sheltered shingle and boulder shores in houbs and voes to the very exposed bedrock platforms and cliffs of locations such as Foula and Fair Isle. Sites from these groups were then chosen for biological investigation. Further general surveys were carried out by the Marine Conservation Society (Moss & Ackers 1987) and for the MNCR (Hiscock 1986, 1988; Howson 1988).

1.2.2 Littoral surveys

Eight types of rocky shore were identified by the ITE, ranging from very exposed bedrock through several categories of intermediate exposure to very sheltered shores (Institute of Terrestrial Ecology 1975c). Forty-three rocky shore sites were surveyed from a wide variety of locations as a part of the monitoring programme for Sullom Voe (Hiscock 1981). The studies described zonation patterns and abundance for 10 lichens, 82 algae and 91 animals from open shore habitats. As a result of MNCR studies, Howson (1988) described 17 littoral habitat and community types including rockpools and tidal pools. In sheltered conditions, littoral rock was dominated by the alga *Ascophyllum nodosum* and fucoids with a relatively low diversity of species. Where these sheltered shores were a mixture of boulder and sediment, there were large numbers of littorinid molluscs, mussels and barnacles. Irvine (1974a) noted that no *Ascophyllum nodosum* f. *mackaii* had been found in Shetland, although it has since been recorded from particularly sheltered situations in The Vadills at Brindister (Bunker, Bunker & Perrins 1994). On more exposed shores, *Fucus vesiculosus* was the dominant mid-shore fucoid, becoming the evesiculate *Fucus vesiculosus* f. *linearis* in very exposed conditions, and eventually being replaced as the dominant by barnacles *Semibalanus balanoides*, limpets *Patella vulgata* and mussels *Mytilus edulis*. *Fucus spiralis* f. *nana* appeared on the upper shore in these conditions while *Himanthalia elongata* became increasingly abundant on the lower shore. Concomitantly, several species of red algae became more frequent with increasing exposure and species such as *Gelidium pusillum* were found in crevices (Irvine 1974a). Most workers have observed that species diversity was greatest in conditions of intermediate exposure (Howson 1988; Institute of Terrestrial Ecology 1975c; Irvine 1974a; Powell 1975) and Powell (1975) commented that rocky shores were dominated by similar species, particularly fucoids, to other parts of Scotland.

The most exposed bedrock shores, where the kelp *Alaria esculenta* was present in the sublittoral fringe, supported relatively few species, particularly animals. These shores were found on the outermost locations such as Muckle Flugga and Out Skerries (Institute of Terrestrial Ecology 1975c). *Himanthalia elongata* was absent in such exposed conditions while on the other hand *Porphyra* spp., *Fucus distichus*, *Fucus spiralis* f. *nana* and *Blidingia minima* were characteristic (Irvine 1974a). Howson (1988) recognised two categories of animal-dominated exposed rocky shores on which the only fucoid was *Fucus distichus*. Irvine (1974a) noted some seasonal variations, observing that in late autumn the upper shore became covered with *Porphyra linearis*, *Bangia fuscopurpurea* (now *Bangia atropurpurea*) and various species of filamentous green algae. A variety of rockpools illustrated the principle that an increase in exposure raises the height at which species occur on the shore (Howson 1988; Irvine 1974a). The walls of caves and geos on exposed rocky coastlines supported rich lower shore communities dominated by encrusting sponges, ascidians and bryozoans in their inner reaches and barnacles, mussels *Mytilus edulis* and hydroids on their outer walls (Howson 1988).

Sediment shores were surveyed at several sites on Shetland Mainland during the ITE surveys (Institute of Terrestrial Ecology 1975d) and each shore was described individually. The fauna of these was considered to be fairly uniform and again comparable with similar locations on mainland Scotland and in the Western Isles. Two main species associations were recognised. The first was characterised by the tellin *Macoma balthica* with the lugworm *Arenicola marina*, and the bivalves *Cerastoderma edule* and *Mya arenaria*, and occurred on muddy sand in the littoral and shallow sublittoral. The second association, found on clean littoral sand, was characterised by the tellin *Tellina* (now *Angulus*) *tenuis* with *Arenicola marina* and razor clams *Ensis* spp. It was noted that there was much intergrading between the two types. Work carried out on sediment shores of north Mainland (Jones & Jones 1981) showed that many of the shores in areas near to the Sullom Voe oil terminal were composed of coarse sands and/or gravels with only small areas of fine and medium sand containing infauna populations. The fauna from two of these, from fine sand and very fine sand in Dales Voe and fine sand in Gluss Voe, is listed in Table 1.1. Stephen, in work carried out much earlier with the Fisheries Board for Scotland, recognised two similar habitats in his littoral zone, one of four zones into which he divided the North Sea (Stephen 1933a, 1933b). Pearson, Coates & Duncan (1994) also identified versions of the *Macoma balthica* community which they considered to be widespread throughout northern European boreal areas. They described two variants of this, one in sediments with a high shell content and containing the polychaetes *Fabricia sabella* and *Tubificoides benedeni*, and the second in sediments with more fine sand containing the polychaete *Travisia forbesii*, the bivalve *Crenella decussata* and the isopod *Eurydice pulchra*. Polychaetes and bivalves characteristic of certain physical conditions were also listed by the Institute of Terrestrial Ecology. For example, *Nereis* (now *Hediste*) *diversicolor* and *Mya arenaria* usually indicated slightly brackish conditions whereas the bivalve *Venerupis pullastra* (now *Venerupis senegalensis*) was found in gravel (Institute of Terrestrial Ecology 1975d).

Some sedimentary beaches at the heads of voes were included at the sheltered extreme of the Institute of Terrestrial Ecology rocky shore descriptions and were characterised by *Nereis* (now *Hediste*) *diversicolor*, and the decapods *Pagurus bernhardus* and *Carcinus maenas* (Institute of Terrestrial Ecology 1975c). Howson (1988) surveyed sheltered muddy sand shores dominated by *Arenicola marina*. Exposed clean sand in Bay of Quendale had few species and no obvious dominant, although the isopod *Eurydice pulchra*, and the amphipods *Talitrus*

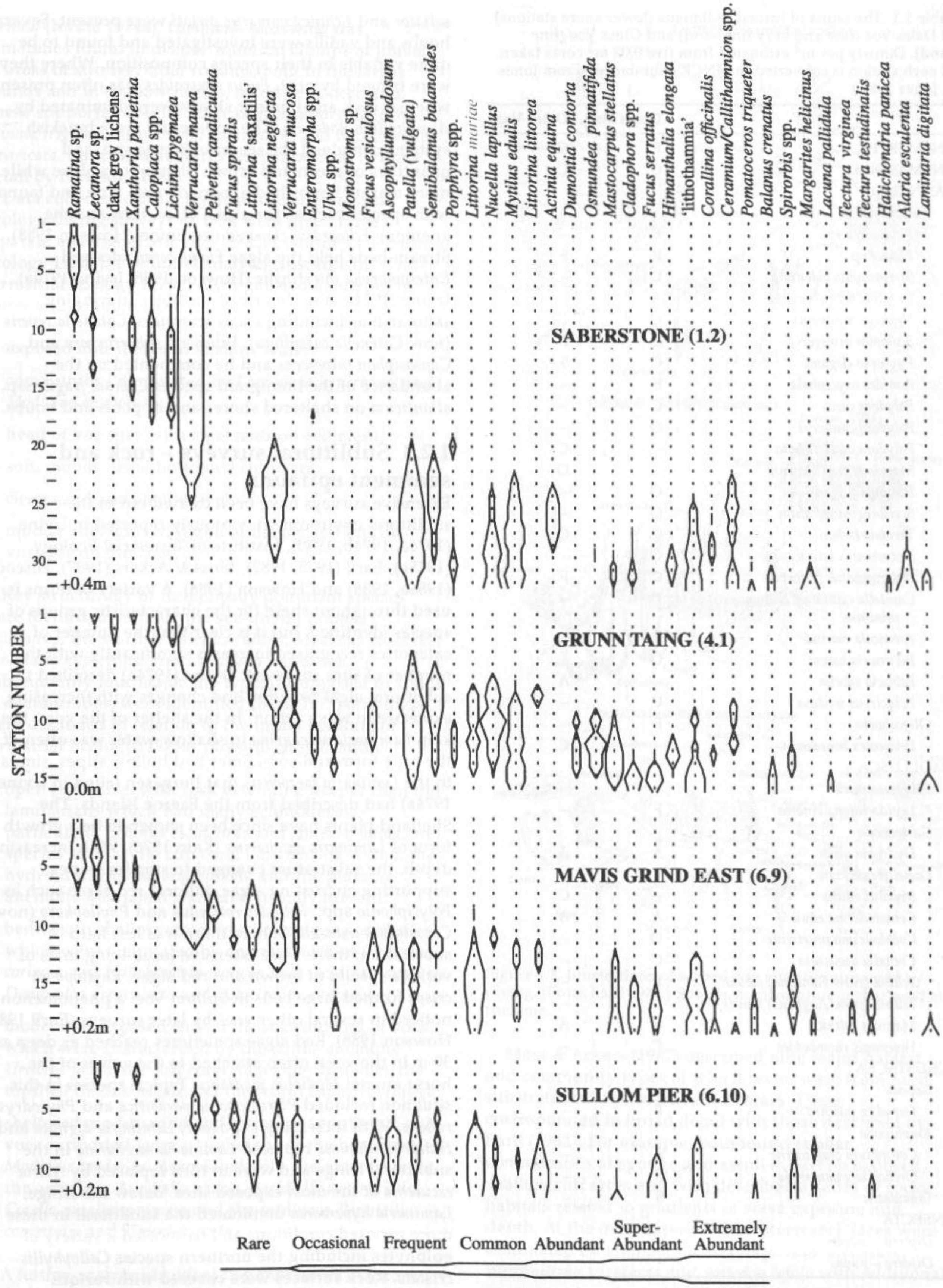

Figure 1.2. The vertical distribution and abundance of widely distributed rocky shore species at four sites in the region of Sullom Voe. Saberstone is an exposed site. Grunn Taing is a sheltered bedrock site within Sullom Voe. Mavis Grind is a very sheltered site at the head of Sullom Voe, and Sullom Pier is a very sheltered site mostly on loose-lying stones. Stations are located at vertical intervals of 20 cm. The height of the lowest station above chart datum is shown. (Based on Hiscock 1981 and using most recent nomenclature.)

Table 1.1. The fauna of littoral sediments (lower shore stations) at Dales Voe (fine and very fine sand) and Gluss Voe (fine sand). Density per m^2 estimated from five 0.02 m^2 cores taken at each station is converted to MNCR abundance. (From Jones & Jones 1981.)

	Gluss Voe	Dales Voe
NEMERTEA	F	C
NEMATODA	C	C
ANNELIDA		
Polychaeta		
Phyllodoce sp	F	–
Eteone sp	F	F
Streptosyllis bidentata	C	–
Exogone hebes/brevipes	A	–
Nephtys hombergii	O	O
Scoloplos armiger	C	F
Pygospio elegans	C	S
Aonides oxycephala	F	–
Polydora caeca	C	–
Polydora caulleryi	O	–
Polydora quadrilobata	–	C
Magelona papillicornis	–	O
Paraonis fulgens	O	–
Scalibregma inflatum	O	–
Travisia forbesii	C	O
Notomastus latericeus	O	–
Heteromastus filiformis	C	F
Capitella capitata/Capitomastus minimus	F	–
Arenicola marina	F	O
Pectinaria koreni	O	–
Fabricia sabella	–	A
Polycirrus medusa	C	–
Oligochaeta	F	–
Peloscolex benedeni	–	C
MOLLUSCA		
Polyplacophora		
Lepidochitona cinerea	F	–
Gastropoda		
Hydrobia ulvae	A	A
Lamellibranchiata		
Mytilus edulis	–	C
Cerastoderma edule	A	A
Cochlodesma praetenue	O	–
Crenella decussata	C	–
Tellina (now *Fabulina*) *fabula*	F	–
Tellina (now *Angulus*) *tenuis*	C	–
Macoma balthica	–	A
Venerupis rhomboides	C	–
CRUSTACEA		
Isopoda		
Eurydice pulchra	F	–
Amphipoda		
Corophium crassicorne	S	–
Orchestia gammarella	F	–
Tanaidacea	S	–
INSECTA		
Diptera – larvae	O	C
Diptera – pupae	–	F

saltator and *Echinogammarus pirloti* were present. Several houbs and vadills were investigated and found to be quite variable in their species composition. Where they were fringed by peat, *Fucus muscoides* was often present whereas rock and boulder shores were dominated by *Ascophyllum nodosum*. The apparently more brackish systems contained the seagrass *Ruppia* spp. and quantities of green and brown filamentous algae while more marine houbs had a more diverse flora and fauna with species such as the alga *Chorda filum* and the anemone *Edwardsia claparedii* common (Howson 1988). Stream-beds held the algae *Fucus ceranoides* and *Enteromorpha intestinalis* (Howson 1988; Irvine 1974a). Irvine (1974a) also described the algae in fringing saltmarsh as including *Fucus muscoides*, *Catenella repens* (now *Catenella caespitosa*), *Vaucheria sphaerospora* and *Capsosiphon fulvescens* and he commented on the abundance of the immigrant species *Codium fragile* ssp. *atlanticum* on sheltered shores and in pools and houbs.

1.2.3 Sublittoral surveys – rock and sediment epifauna

Extensive surveys have been carried out in the sublittoral environment, variously reported in Irvine (1974a, 1974b, 1980), Institute of Terrestrial Ecology (1975e), Earll (1975, 1982), Moss & Ackers (1987), Hiscock (1986a, 1988) and Howson (1988). A variety of terms is used throughout these for the characteristic groups of species identified, but it is clear that the number of categories recognised increases significantly with the number of sites surveyed. Irvine (1974a) described the sublittoral algal zonation and changes with increasing exposure to wave action. In the shelter of the voes, the kelp *Laminaria saccharina* in shallow water was often of the cape form and sometimes had hollow stipes, similar to the *Laminaria faeroensis* that Børgesen (cited in Irvine 1974a) had described from the Faeroe Islands. The Shetland plants have since been shown to be a growth form of *Laminaria saccharina* (Kain 1976). With increasing depth, the substratum changed to smaller stones supporting encrusting algae, filiform red algae such as *Polysiphonia* spp., *Polyides rotundus* and *Phyllophora* (now *Coccotylus*) *truncata*. Where there was less hard substratum, there were extensive loose-lying mats of various species of brown and red algae. *Phyllophora crispa* formed large beds in Sullom Voe, a phenomenon noticed in several other voes by later surveys (Earll 1982; Howson 1988). Red algae sometimes reached as deep as 30 m in the voes, often attached to the valves of the horse mussel *Modiolus modiolus*. Typical species in this situation included *Pterosiphonia parasitica* and *Phycodrys rubens*. With increasing exposure, *Laminaria digitata* and *Halidrys siliquosa* replaced *Laminaria saccharina* in the sublittoral fringe and were in turn replaced by *Alaria esculenta* at the most exposed sites. Below the fringe, *Laminaria hyperborea* dominated the sublittoral in these more exposed conditions and supported a variety of epiphytes including the northern species *Callophyllis cristata*. Rock surfaces were covered with various encrusting coralline algae including *Lithothamnion glaciale*, *Leptophytum laeve*, *Phymatolithon lenormandii* and *Phymatolithon rugulosum* and foliose red algae such as *Halarachnion ligulatum*, *Porphyra miniata* and *Dilsea* *carnosa* (Irvine 1974a). *Laminaria saccharina* was sometimes found in deeper water on clumps of gravel. In areas of stronger tidal streams, both in the larger sounds and in shallow rapids, maerl beds occurred. These supported species such as *Scinaia turgida* (now *Scinaia trigona*), *Apoglossum ruscifolium* and *Rhodophyllis divaricata*. Both these features were described in more detail by Howson (1988).

Data collected during the Institute of Terrestrial Ecology diving surveys of 1974 were given three separate analyses (Earll 1975, 1982; Institute of Terrestrial Ecology 1975e). The initial analysis (Institute of Terrestrial Ecology 1975e) distinguished a number of zones and communities:

- exposed and sheltered shallow water;
- communities dominated by *Laminaria hyperborea* and *Modiolus modiolus;*
- head of voe sites with algal mats on sediment;
- soft, mobile, level-bottomed substrata;
- clean sand and shell-gravel;
- muddy shell-gravel, found at deeper stations in virtually all the voes.

Key structurally or numerically dominant species were identified, notably the sea-urchin *Echinus esculentus*, the starfish *Asterias rubens, Modiolus modiolus, Laminaria hyperborea* and *Laminaria saccharina*. Subsequently four major site types, as opposed to zones or communities, were identified (Earll 1975) and these were discussed in relation to the initial Institute of Terrestrial Ecology (1975a) physical classification:

- open coast sites with rock extending deeper than the laminarians which had many echinoderms, particularly *Echinus esculentus* and *Antedon bifida*, and species such as the cup coral *Caryophyllia smithii*, the hydroid *Kirchenpaueria pinnata* and the plumose anemone *Metridium senile* also usually present;
- bedrock in shallow water in extremely exposed sites which were dominated by sponges such as *Clathrina coriacea* and *Halichondria panicea* and ascidians such as *Dendrodoa grossularia* and *Polyclinum aurantium;*
- moderately exposed sites at the seaward end of voes which were characterised by the dahlia anemone *Urticina felina*, the soft coral *Alcyonium digitatum*, the topshell *Gibbula magus* and the worm *Lanice conchilega;*
- sheltered muddy sand and gravel deeper than 5 m in voes supported large populations of the horse mussel *Modiolus modiolus*. Associated with the mussels were the ascidians *Ascidiella scabra, Ascidiella aspersa* and *Corella parallelogramma* and the molluscs *Turritella communis* and *Timoclea ovata*.

A further analysis identified 13 communities in the shallow sublittoral (Earll 1982) and again highlighted the widespread occurrence and importance around Shetland of dense beds of *Modiolus modiolus*. Three of the communities described by Earll (1982) are shown in Figure 1.3.

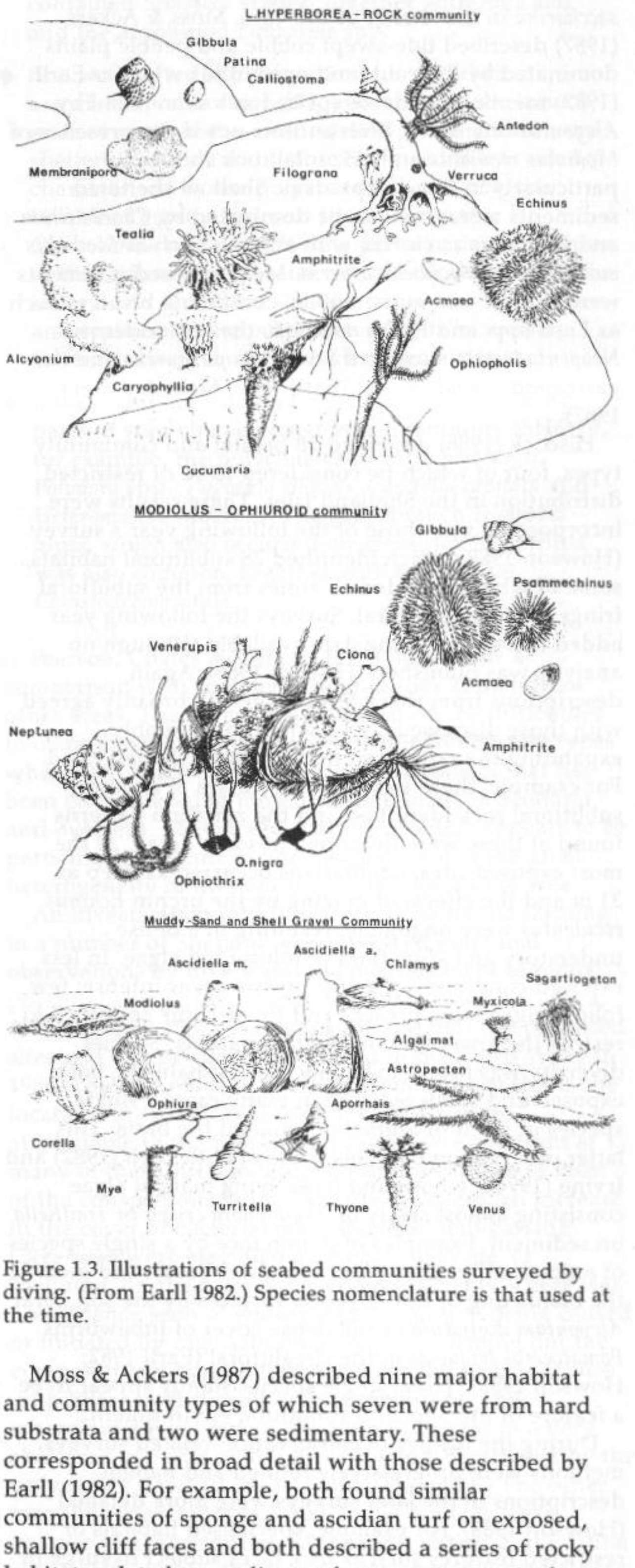

Figure 1.3. Illustrations of seabed communities surveyed by diving. (From Earll 1982.) Species nomenclature is that used at the time.

Moss & Ackers (1987) described nine major habitat and community types of which seven were from hard substrata and two were sedimentary. These corresponded in broad detail with those described by Earll (1982). For example, both found similar communities of sponge and ascidian turf on exposed, shallow cliff faces and both described a series of rocky habitats related to gradients of wave exposure and depth. At the most exposed sites, steep rock faces were dominated by animals such as *Alcyonium digitatum, Parasmittina trispinosa* and *Antedon bifida* with additional species such as *Leptasterias muelleri* and *Kirchenpaueria pinnata*. Less steeply inclined rock supported a *Laminaria hyperborea* forest in the more exposed situations, with a park extending to about 24 m depth, and *Laminaria* *saccharina* in the shelter of the voes. Moss & Ackers (1987) described tide-swept cobble and pebble plains dominated by hydroids and ophiuroids whereas Earll (1982) mentioned tide-swept bedrock dominated by *Alcyonium digitatum*. Both authors noted the presence of *Modiolus modiolus* on horizontal rock surfaces, particularly in tide-swept areas. Shallow sheltered sediments were found to be dominated by *Chorda filum* and *Laminaria saccharina* with animals such as *Modiolus modiolus* and *Ascidiella aspersa*. More exposed sediments were coarser and more mobile, containing bivalves such as *Ensis* spp. and *Pecten maximus*, the echinoderms *Neopentadactyla mixta* and *Spatangus purpureus* and the gastropod *Gibbula magus* (Earll 1982; Moss & Ackers 1987).

Hiscock (1986) described 16 habitat and community types, four of which he considered to be of restricted distribution in the Shetland Isles. These results were incorporated into those of the following year's survey (Howson 1988) which identified 28 sublittoral habitats, some of which included all zones from the sublittoral fringe to the circalittoral. Surveys the following year added more sites to the data available although no analysis was published (Hiscock 1988). Again, descriptions from these MNCR surveys broadly agreed with those discussed above while considerably expanding the range and detail of habitats described. For example, there were several classes of exposed sublittoral rock identified and the zonation patterns found at these were described in some detail. At the most exposed sites, laminarians occurred as deep as 31 m and the effects of grazing by the urchin *Echinus esculentus* were negligible, resulting in a dense understory and stipe flora of foliose red algae. In less exposed conditions, grazing pressure was intense; few foliose algae were present and the urchins appeared to restrict the lower limit of the laminarians. Species diversity was found to be low in most habitats, both exposed and sheltered, and in many cases a single species of plant or animal dominated the biota. This latter observation parallels those of both Earll (1982) and Irvine (1974a) who found loose-lying mats of algae consisting almost solely of *Phyllophora crispa* or *Trailliella* on sediment. Examples of dominance by a single species of animal rather than plant can also be seen and include the blanketing of tide-exposed surfaces by the soft coral *Alcyonium digitatum* or the dense cover of tubeworms *Pomatoceros triqueter* in the circalittoral (Earll 1982; Howson 1988). These single species stands appear to be a feature of the Shetland sublittoral environment.

During the history of conservation-related surveys, methods were progressively refined and habitat descriptions in the later surveys were more detailed (Howson 1988). For example, specialised habitats or restricted features such as rock faces subject to surge in caves and geos, tide-swept habitats, and sheltered houbs were increasingly recognised as of potential nature conservation importance and closer attention was paid to the variety of sediment types. Rock walls in geos were found to have a compressed depth zonation with *Alaria esculenta* and *Laminaria hyperborea* found to a depth of 1–4 m bcd, followed by a band of foliose red algae, another of *Alcyonium digitatum* and dwarf *Metridium senile* and then by a diverse animal turf. More abraded areas were covered by *Pomatoceros triqueter* and bryozoan crusts (Howson 1988). Tide-swept areas showed considerable variability between sites, but four major habitat types were distinguished (Howson 1988). These ranged from bedrock dominated by *Alcyonium digitatum* and the barnacle *Balanus crenatus*, as described by Earll (1982) to pebble and gravel beds with species such as *Porphyra miniata*, brittlestars including *Amphiura securigera*, and hydroids. *Modiolus modiolus* formed beds in several of these habitats and the holothurian *Cucumaria frondosa* was often found. Nine sedimentary habitats were described on the basis of diving surveys and four from infaunal samples collected by dredge (Howson 1988). These are considered in more detail later as the faunal data were re-analysed by Pearson, Coates & Duncan (1994), but certain points based on epifaunal observations are relevant here. Numerous examples were found of sheltered infralittoral sand with *Chorda filum* and *Arenicola marina*, and of sheltered muddy sediments with beds of *Modiolus modiolus*, which corresponded to the descriptions of Earll (1982) and Moss & Ackers (1987). At the latter group of sites, in shallow water, the cape form of *Laminaria saccharina* and *Laminaria hyperborea* was normally present. Coarse exposed sand had a reasonably varied epifauna with species such as the molluscs *Colus islandicus*, *Pecten maximus*, *Neptunea antiqua* and *Ensis* sp. while coarse muddy shell-gravel at the entrance to voes had the sea pens *Virgularia mirabilis* and *Pennatula phosphorea*. There was soft mud in the inner basins of voes with the anemone *Sagartiogeton* sp., the decapod *Liocarcinus depurator* and the gastropod *Aporrhais pespelecani*. Deoxygenated sediment with dead bivalves and a bacterial film was also found in some of these inner basins. In contrast, beds of maerl on coarse shell-gravel were found at several locations at which a diverse associated fauna and flora was recorded, while the seagrass *Zostera marina* was found on muddy sand at two sites (Howson 1988). The historical and recent distribution of *Z. marina*, *Ruppia maritima*, *Ruppia cirrhosa* and *Ruppia spiralis* were described by Scott & Palmer (1987). *Z. marina*, known locally as 'marlie', was common and widespread until a decline during the 1930s, while *Ruppia* spp. are still found in many of the brackish systems in Shetland.

1.2.4 Infauna of sublittoral sediments

In his work with the Fisheries Board for Scotland, Stephen (1933a, 1933b) divided the North Sea into four main areas on the basis of its mollusc and echinoderm fauna. In addition to the littoral zone mentioned above, he distinguished a coastal zone, again with two separable sediment types, an offshore zone and, in the deep north-eastern section of the northern North Sea, a *Thyasira*-Foraminiferan zone. The coastal zone, from 2 to 20 fathoms (3.6-36.5 m), included both sandy sediments with the bivalves *Fabulina fabula*, the brittlestars *Ophiura ophiura* and *Ophiura albida* and muddy sediments which were dominated by the bivalves *Abra alba* and *Abra nitida*. Many of the Shetland voes fell into this latter group. The Department of Agriculture and Fisheries for Scotland (DAFS) collected grab samples from 14 areas around Shetland in 1962 and from St Magnus Bay in 1963. The infauna from these were identified but the data remained unpublished until they were incorporated into a retrospective analysis of samples from several benthic surveys (Pearson, Coates & Duncan 1994), discussed below.

Results of the Institute of Terrestrial Ecology surveys of the benthic sediments in both shallow water and the deeper parts of the voes revealed that the voes had a rich infauna (Pearson 1975 in ITE 1975e; SMBA 1975 in ITE 1975e). Shallow submerged peat was found to have an abundant fauna including large numbers of the echinoderm *Echinocardium cordatum*. Horse mussels *Modiolus modiolus* were again found to be common on mixed sediments in shallow water as well as in the deeper parts of the voes. Survey sites were described individually and these are included in later sections of this chapter.

Infaunal data sets from a variety of sources and a range of sediments were amalgamated and then analysed by Pearson, Coates & Duncan (1994) in order to identify the community types present. The data sets involved were from samples collected during the general surveys by the DAFS and the MNCR (Hiscock 1988; Howson 1988), during monitoring work related to the Sullom Voe oil terminal (Institute of Offshore Engineering 1982; Jones 1984; May, Kippen & Smith 1991) and from a conservation assessment of Whiteness Voe (Hiscock 1989; Rostron 1989). Six communities were described within the structures of the MNCR community classification (Hiscock & Connor 1991). These were primarily related either to the presence of the epifaunal horse mussel *Modiolus modiolus*, or to a particular range of sedimentary particle sizes. Up to four variants or facies of each were identified and their distribution within the Shetland Islands described. Lists of characteristic species were given for each community and its facies. The six communities identified were:

- the *Modiolus* community (SH1) which was widespread at all depths on the sheltered and semi-sheltered sediments but was particularly abundant in Swarbacks Minn and Sullom Voe. It was identifiable on the basis of the presence of the horse mussel *Modiolus modiolus*, and the fauna of its four facies were related to the nature of the underlying sediment;
- the shell-sand and gravel community (SH2) which was widely distributed in moderately exposed deeper parts of the outer voes, sound and bays, and typically on the west coast where the polychaete *Pisione remota*, the bivalve mollusc *Abra prismatica* and the sea urchin *Echinocyamus pusillus* were found;
- the muddy sand and gravel community (SH3) which was one of the most widely distributed communities in intermediate depths and was dominated by a variety of different species, the polychaete *Scoloplos armiger* and the phoronid *Phoronis* sp. being amongst the most numerous;
- the shallow muddy sand community (SH4), which occurred in the sheltered inner areas of voes and also contained *Scoloplos armiger* together with *Abra alba* and the amphipod *Dexamine* spp;
- fine well-sorted silt/clay sediments and their associated community (SH5) occurred at the inner ends of some of the most extensive voes and in very sheltered sounds and firths. These sediments were characterised by the polychaete *Glycera alba*, the bivalves *Thyasira* spp. and the solenogaster *Chaetoderma nitidulum*. Where periodic deoxygenation of the sediment and water column occurred, as in the inner basin of Sullom Voe, the fauna was less diverse and typified by the polychaetes *Capitella capitata*, *Pectinaria koreni* and the bivalve *Abra nitida*;
- littoral sand and shell gravel beaches in the inner parts of voes characterised by a community (SH6) of, for example, the polychaetes *Nephtys hombergii*, *Polydora* spp., *Pygospio elegans*, *Capitella capitata* and *Heteromastus filiformis*. The prosobranch *Hydrobia ulvae*, which also occurred on areas rich in detritus, was also common, together with the bivalve *Cerastoderma edule*.

Pearson, Coates & Duncan (1994) also made a comparison with sediment communities known from other areas. The authors commented on the difficulties in distinguishing between even major community types when such comparisons are made, a problem that has been encountered in most sheltered inlets in Scotland and overseas. They noted that the problem appears to be particularly extreme in Shetland because of the great heterogeneity of the sediments throughout the area.

An investigation into the effects of salmonid farming in a number of Shetland voes involved epifaunal observations by divers and the measurement of redox potential along a 50 m transect line (Dixon 1986, 1987a, 1987c; Fowler 1987). A total of 25 cage sites, six proposed sites and two ex-sites were visited in the initial study in 1986. The infauna was analysed from three of these, the locations of which were confidential. Changes attributable to the presence of cages were apparent at many of these sites, including a disappearance of most of the conspicuous fauna towards the cages, an increase in the cover of bacterial mats and sediment gassing. Cage sites were classified as 'clean', 'average' or 'polluted' on the basis of observed gradients. There was no evidence seen of widespread stagnation being caused or initiated by cage salmon *Salmo salar* farming but the comparatively rapid deterioration of the seabed at sites with little water movement was apparent. The macrofauna from one of the older cage sites in a very sheltered voe was of low diversity and dominated by the polychaete *Capitella capitata* and nematodes. The other two sites were more exposed and sediments were coarser and more mixed. At the most exposed, the fauna was dominated by the amphipod *Corophium crassicorne* with polychaetes such as *Polydora ?ciliata* and *Capitomastus minimus* and the bivalve *Cochlodesma praetenue*. The more sheltered site was polychaete-dominated with *Capitomastus minimus* predominant. At both of these sites, diversity decreased towards the cages with the polychaete *Capitella capitata* appearing in high numbers. This was particularly apparent at the more sheltered site where *Malacoceros fuliginosus*, another polychaete indicative of organic enrichment, was also found at the stations closest to the cage. A further survey the following year (1987) (Dixon 1987c) concurred with the findings of the previous year, that effects on the seabed from salmon cages were apparent within a radius of 15 m or so from the cage, and that such effects were more pronounced at sites with limited water circulation. This was particularly noticeable at one site included in the second survey, where the paucity of the animal life indicated an environment occasionally subject to periods of hypoxia. Whether or not organic waste from the salmon farm contributed to this was open to speculation.

1.2.5 Studies of particular species or groups

Many studies of marine algae have been undertaken separately from more general surveys. Irvine (1962) noted the northern affinities of the flora, comparing it with neighbouring areas such as Orkney and Faeroe. A British Phycological Society field meeting collected material from seven regions of Shetland Mainland and produced a species list incorporating previous published and unpublished records. This included several new records for the islands (Dixon 1963). A more extensive botanical survey in 1973 resulted in a series of publications describing the marine vegetation (Irvine 1974a, 1974b), discussing particular species of note (Irvine *et al.* 1975) and listing over 300 species recorded (Irvine 1980). Although much of this work was concentrated in Sullom Voe, collections were made from as wide a variety of environmental conditions and localities as possible, enabling zonation patterns of the flora around Shetland and changes with increasing wave exposure to be described (Irvine 1974a). The effectiveness of mapping species distributions in marine ecological studies was discussed by Norton (1978). The examples he used included several species with distributions including the Shetland Islands. A checklist of the British marine macroalgae, with particular emphasis on Scottish records (Pagett 1983), was superseded by that prepared by Maggs (1986).

The biology of *Fucus distichus* was studied in some detail by Powell at sites around Scotland including Fair Isle, Scalloway and Lerwick in Shetland (Powell 1954a, 1957a, 1957b, 1963; Powell & Lewis 1952). He established four subspecies, *distichus*, *anceps*, *edentatus* and *evanescens* (Powell 1957a), although the last of these was not found in the British Isles. *Fucus distichus* ssp. *edentatus* appeared to be widespread in Shetland in polluted harbour areas and on semi-exposed shores, ssp. *distichus* was found in rockpools and ssp. *anceps* was considered rare in the islands (Powell 1963). The ecology of two of these subspecies, *anceps* and *distichus*, was described in detail with descriptions of particular locations (Powell 1957b).

The ecology of *Fucus distichus*, considered to be endangered by oil-related developments, was examined in more detail by Russell (1974). He considerably extended the known range of *F. distichus* ssp. *distichus*, finding plants to be larger and healthier than those reported by Powell (1963). More recently, Rice & Chapman (1985) reviewed the taxonomy of the species using numerical classification techniques and taking into account environmental factors. They showed that there were two distinct species involved rather than four subspecies. *Fucus distichus* included the subspecies *distichus* and *anceps* and was found in pools and on open rock on the upper shore of both sheltered and exposed sites. *Fucus evanescens* encompassed the subspecies *evanescens* and *edentatus* and occurred from the mid-shore to the sublittoral, again in both sheltered and exposed locations. The occurrence of *F. distichus* in two such extreme habitats, polluted harbours and exposed rocky shores, may represent the success of a species at the southern edge of its geographical range surviving in environments where competition from other species is reduced (Wilkinson 1992).

Several workers have studied aspects of the biology of certain animal species or groups within the Shetland archipelago as a whole. Stephen (1936) reviewed the taxonomy and known distribution, including new records, for all the species of echiuran, sipunculan and priapulid known from Scottish waters, including several records from Shetland. Powell (1954b) described the distribution of the barnacle *Chthamalus stellatus* on Shetland Mainland and Fair Isle, giving new northern limits for the known range of the species. He suggested that its distribution was linked to the survival of the planktonic larvae rather than the adult barnacle. Crothers (1979) looked at the shell shape of the dog whelk *Nucella lapillus* around Shetland and concluded that a model relating shell shape to shore exposure, derived from Mongstad in Norway, could not be applied in Shetland. A later survey found that shell shapes did vary around the coast and that two separate models were needed to relate shell shape and exposure. This implied that there were two separate populations of dog whelks in Shetland, possibly due to geographical separation during the last ice age (Crothers 1992). Woodward (1985) listed records of the fan shell *Pinna fragilis* (now *Atrina fragilis*) from around Scotland, giving five records from various locations around Shetland from 1803 to 1949. Smith (1988) collected molluscs around the islands during a Marine Conservation Society survey and compiled a list of the species she collected. This contained new records of several living species.

Sand-eels (Ammodytidae), which are a benthic species with a major fishery in the North Sea, have been the subject of considerable interest around the Shetland Islands partly because of massive breeding failures of large populations of seabirds which feed on sand-eels (Heubeck 1989). Langham (1971) listed the main Scottish spawning periods and grounds, including several around Shetland, of five species of sand-eel and described the distribution and abundance of their larvae. The major sand-eel fishing grounds around Shetland were mapped by Gammack & Richardson (1980) and more recently by Gauld (1990).

There are large breeding populations of both grey seals *Halichoerus grypus* and common seals *Phoca vitulina* around Shetland (Anderson 1974, 1981; Gubbay 1988; Thompson 1992). In the mid-1980s, Shetland had a population of an estimated 3,500 grey seals, approximately 4% of the Scottish total of 89,000 (Gubbay 1988). In 1989, the number of grey seals in Scotland was estimated at 79,000 animals, which was 92% of the British and 40% of the world population (Thompson 1992). Counts of common seals are less reliable and probable underestimates because of behavioural differences between grey and common seals. However, the Scottish population in the mid-1980s was at least 20,000 animals, 4,700 of which were from Shetland (Gubbay 1988: Thompson 1992). In 1973, the Shetland common seal stock was estimated at 1,800 animals (Bonner, Vaughan & Johnston 1973). Grey seal breeding sites are found around the whole of the Shetland coastline (Anderson 1974, 1981); Gammack & Richardson (1980) mapped these and the distribution of aggregations of both grey and common seals.

An ecological study of the porpoise *Phocoena phocoena* around Shetland was undertaken in 1992 (Evans *et al.* 1993), extending earlier smaller-scale studies. Systematic land-based watches supplemented by boat transects confirmed that porpoises were widely distributed around Shetland, but with regular concentrations on the east and south coasts of Mainland Shetland. Areas with porpoise concentrations coincided with known sand-eel fishing grounds, with two areas, Mousa Sound and south Noss Sound, particularly important. Both these areas supported high aggregations of sand-eels and gadoids, while Mousa Sound also supported high concentrations of herring *Clupea harengus*. However, a detailed comparison of porpoise and prey distribution on a seasonal basis showed little correlation.

The population of otters in Shetland, estimated at 700-900 individuals, is considered to be of international importance although it may be vulnerable because of its small size and isolation (Kruuk *et al.* 1989). Relatively high concentrations of mercury occur naturally in fish in Shetland, but food shortage, with contributory effects from mercury and PCBs, appears to be the ultimate cause of most otter deaths (Kruuk & Conroy 1991). The mean life expectancy of an adult otter was 3.1 years but the greatest recorded age of a Shetland otter was 10 years (Kruuk & Conroy 1991).

1.3 East coasts of Unst and Yell including Bluemull Sound and Fetlar

1.3.1 Introduction

The north and east-facing coastlines of Unst and Yell including Fetlar (Figure 1.4) are generally exposed to strong wave action but not to prevailing winds. Burra Firth, Balta Sound, Nor Wick and Harolds Wick are the major inlets on Unst while on Fetlar there are two large bays, Wick of Gruting and Wick of Tresta. On the east coast of Yell are Basta Voe and Mid Yell Voe, with two more open inlets, Ay Wick and Otters Wick. There are numerous small sandy beaches in the area and several examples of depositional features such as tombolos and bars. Several of the voes and bays contain dune and machair systems (NCC 1976). Strong tides run through the major sounds, Colgrave and Bluemull Sounds.

1.3.2 Littoral

Many of the shores are semi-exposed or sheltered, showing a transition from semi-exposed with *Fucus vesiculosus* to very sheltered ones dominated by *Ascophyllum nodosum* (Institute of Terrestrial Ecology 1975c). At Swinna Ness, there was an extensive boulder plain in the lower shore with dense beds of kelp *Laminaria digitata* and *Laminaria hyperborea* while bedrock on Linga Sound near Gutcher had typical sheltered shore communities dominated by *Ascophyllum nodosum* and *Fucus serratus* (Howson 1988). A shore at Burra Firth on Unst was dominated by the barnacle *Semibalanus balanoides* and mussels *Mytilus edulis* in the mid-shore (Berryman & Clark 1982). Repeat surveys of these shores in Burra Firth in subsequent years showed little change in the community structure (Bott, Salt & Tindale 1981; Williams, Cohen & Boyce 1983). In Balta Harbour on the east coast of Unst, the lower shore consisted of muddy gravel and pebbles and had a rich infauna of large

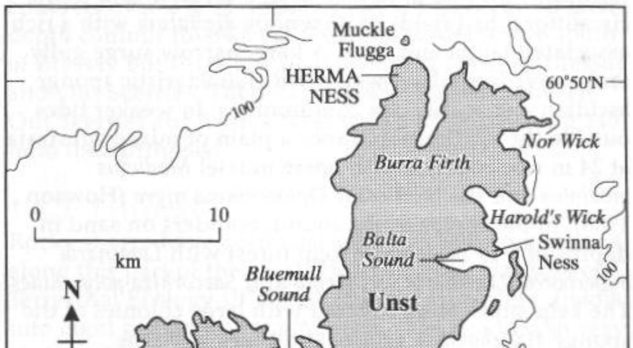

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Figure 1.4. Unst, Yell and Fetlar.

bivalves, polychaetes, nemerteans, sipunculans and the anemone *Edwardsia claparedii* (Howson 1988).

1.3.3 Sublittoral

On the north coast of Unst, steep, moderately exposed bedrock towards the entrance to Burra Firth gave way to boulders and shelly sand at 18 m and a rippled barren sand-plain at 22 m. Several long narrow caves at the entrance to, and within, the voe of Burra Firth had rich sponge, ascidian, bryozoan and tubeworm *Salmacina dysteri* communities in their middle reaches. Boulders in the caves and crevices held anemones and crustacea, and there were dense beds of foliose algae at the entrance. *Laminaria hyperborea* forest extended to 21 m but the rock was heavily grazed and the only foliose alga present in any abundance was *Dictyota dichotoma* (Howson 1988). Coarse, clean sediments with shell-gravel and pebbles were found in Sandwick, Harolds Wick and Nor Wick. These supported the razor clam *Ensis arcuatus*, the brittlestar *Ophiura affinis* and the sea pen *Virgularia mirabilis*. In South Balta Sound there was finer sand with maerl while in the more sheltered Balta Voe there was muddy gravel with few species (Howson 1988).

Tidal streams of up to 6 knots (3 m s^{-1}) run through Bluemull Sound creating a variety of tide-swept habitats and communities. Steep and vertical bedrock at the northern entrance extended to at least 28 m and in the circalittoral had fields of *Alcyonium digitatum* with a rich associated fauna and flora. A long, narrow surge gully and a cave in shallow water had characteristic sponge, ascidian and anthozoan communities. In weaker tides outside the northern entrance a plain of mixed substrata at 24 m was covered with horse mussel *Modiolus modiolus* and the brittlestar *Ophiocomina nigra* (Howson 1988). In the centre of the sound, boulders on sand in depths of 5 to 14 m had a kelp forest with *Laminaria hyperborea, Laminaria saccharina* and *Saccorhiza polyschides*. The kelp stipes were covered with large colonies of the sponge *Halichondria panicea* and there were the anemones *Urticina felina* and *Cereus pedunculatus* in the sand. In deeper water, pebbles and cobbles were covered with the hydroid *Sertularia argentea* which supported caprellids and other amphipods while dense colonies of *Alcyonium digitatum* grew on bedrock outcrops (Moss & Ackers 1987). A tide-swept cobble and bedrock slope was also found in the southern entrance in 16 to 24 m with *Modiolus modiolus, Alcyonium digitatum* and the brittlestar *Ophiothrix fragilis* (Howson 1988).

Basta Voe had little hard substratum in the sublittoral but muddy sand in shallow water supported *Chorda filum* and various species of unattached algae, often as loose mats, with *Phyllophora crispa, Trailliella, Enteromorpha* sp. and *Asperococcus* spp. predominating. The snake blenny *Lumpenus lampretaeformis* was found occasionally.

In slightly deeper water, the surface of clean sand was covered with patches of diatoms, and the lugworm *Arenicola marina*, the razor-clam *Ensis arcuatus*, and the echinoderms *Astropecten irregularis, Trachythyone elongata* and *Amphiura brachiata* were all present (Hiscock 1986). Coarse sediments in Basta Voe supported beds of *Modiolus modiolus*. South of Burra Ness were rich fine sand and shell-gravel communities with counterparts in the Wick of Tresta and Colgrave Sound. Coarse, clean sediments with maerl fragments were widely distributed in the area and particularly in the centre of the channels and the sounds. There were maerl beds on the south and east sides of Burra Ness in 13 to 27 m of water with a bed of *Modiolus modiolus* closer inshore on the eastern side. This area had extremely rich muddy shell-gravel communities. The houb at Gutcher in north-east Yell contained a bed of the sea-grass *Ruppia maritima* (Howson 1988).

The Shetland sediment community analysis carried out by Pearson, Coates & Duncan (1994) identified three major sediment communities with variants around the northern islands:

- Beds of *Modiolus modiolus* on muddy shell-gravel were recorded from the Wick of Tresta and Basta Voe (SH1). A much coarser sediment with shell, pebble and maerl, also supporting some *Modiolus modiolus*, was found in the Wick of Tresta and at Burra Ness, and this held species such as the crustacean *Ebalia tuberosa*, the brittlestar *Ophiopholis aculeata*, the polychaetes *Nephtys ciliata, Nereimyra punctata*, and *Kefersteinia cirrata* and the crustacean *Eumida sanguinea* (SH1, Facies 2).
- Sediments deeper than 15 m in Basta Voe were siltier and here species such as the gastropod *Turritella communis*, the amphipod *Cheirocratus intermedius*, the bivalve *Hiatella arctica*, the polychaetes *Notomastus latericeus* and *Myriochele heeri* were associated with *Modiolus modiolus* (SH1, Facies 4).
- Shelly sand and gravel occurred at several sites to the east of the northern islands in 20 to 50 m of water. This contained a community characterised by the bivalve *Abra prismatica*, the polychaete *Pisione remota* and the urchin *Echinocyamus pusillus* with in addition the polychaete *Aonides pauchibranchiata*, the bivalve *Moerella pygmaea* and the amphipod *Urothoe elegans* (SH2, Facies 1).
- In 20 to 30 m in the Wick of Gruting and Wick of Tresta, more mixed sediment with stones and shells supported a similar community but showed some signs of organic enrichment with the polychaete *Magelona mirabilis*, the bivalve *Chamelea gallina*, the amphipod *Perioculodes longimanus* and the polychaete *Chaetozone setosa* (SH2, Facies 3).
- In shallow muddy sand in 12 m in Mid Yell Voe and 20 m in Basta Voe there was the polychaete *Scoloplos armiger*, the bivalve mollusc *Abra alba* and amphipod *Dexamine* sp.

1.4 East Mainland including Out Skerries

1.4.1 Introduction

The east coast of Mainland Shetland, from Lunna Ness to Sumburgh Head (Figure 1.5), is highly indented with several large voes and offshore islands. The coastline is exposed, although perhaps less so than the west coast which faces the prevailing winds and seas. The Out Skerries are a group of small islands and rocks lying about 15 km east of Lunna Ness. The other major islands are Whalsay which is inshore from the Out Skerries and separated from the mainland by Lunning and Linga Sound, Bressay, which is separated from Lerwick by Bressay Sound, Noss off the east coast of Bressay and Mousa, with Mousa Sound between the island and mainland. Strong tidal streams run through the sounds and around headlands, particularly Sumburgh Head. Among the larger voes and embayments are Vidlin and Dury Voes in the north of the area and South Nesting Bay, Cat Firth, Wadbister Voe, Lax Firth and Dales Voe north of Lerwick. There are cliffs along much of the coastline, particularly along the stretch from Lerwick and Bressay to Sumburgh Head which is formed of Old Red Sandstone. The sandstone cliffs around Noss have been eroded into an impressive range of arches, caves and offshore stacks. The coastline also has a wide range of depositional features, such as ayres and tombolos, with particularly good examples being present between Dury Voe and Dales Voe (NCC 1976). Examples of houbs and pools include the Pool of Virkie, near Sumburgh, which holds a sheltered intertidal mudflat, a rare habitat in Shetland, and large rocky tidal pools on Mousa in which seals haul out. A storm beach at Grutness is one of the biggest boulder beaches in Shetland and has boulders over 2 m in diameter (NCC 1976). The 80 metre depth contour follows the coastline close inshore south of Bressay but there is a shallower area between Bressay and Out Skerries. There is deep water again between Out Skerries and Lunna Ness with a basin reaching 140 m to the north-east.

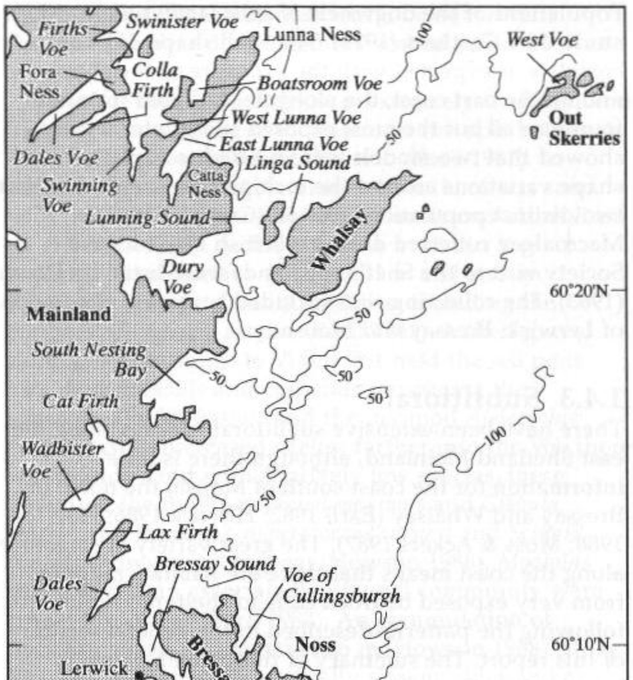

Figure 1.5. The east coast of Mainland Shetland.

1.4.2 Littoral

Rocky shores have been surveyed at scattered locations along this part of the coast (Howson 1988; Institute of Terrestrial Ecology 1975c). Shetland shores were divided into eight categories ranging from very exposed to very sheltered, and examples from all categories were found on the east coast (Institute of Terrestrial Ecology 1975c). The most exposed bedrock shores, with limpets *Patella vulgata* and barnacles *Chthamalus stellatus* on the mid and upper shore and the algae *Alaria esculenta* and *Corallina officinalis* in the sublittoral fringe, were found on Out Skerries, the southern end of Bressay and on Lunna Ness. In contrast, the most sheltered shores, with dense *Ascophyllum nodosum*, were found in Vidlin Voe and Dales Voe and at South Nesting (Institute of Terrestrial Ecology 1975c). At Masti Geo on Mousa there is a cave about 150 m in length (Howson 1988). The outer walls held communities similar to nearby exposed shores and were dominated by barnacles and mussels *Mytilus edulis*, while the inner walls supported the soft coral *Alcyonium digitatum*, sea-urchins *Echinus esculentus* and the anemone *Sagartia elegans*. Rockpools in the splash zone on Mousa were dominated by the green alga *Enteromorpha* sp. and contained three-spined sticklebacks *Gasterosteus aculeatus*. Other pools lower on the shore held a much greater variety of species and were dominated by encrusting coralline algae and *Corallina officinalis*. Mousa has a series of larger tidal pools which are connected to the sea by a shallow tidal rapids. The pools are floored by large slate boulders and seals haul out in them. In shallow water in the west pool there were the algae *Codium fragile*, *Fucus serratus* and *Cladophora rupestris* with *Himanthalia elongata* and *Laminaria saccharina* in deeper water. Boulders beneath the canopy were encrusted with coralline algae and dense *Corallina officinalis* and there was a wide variety of other species present. Steep boulder sides in the east pool were covered with *Laminaria saccharina*. The entrance channel was floored with shell-gravel and cobble, and was dominated by filamentous green algae, the lugworm *Arenicola marina*, *Laminaria saccharina* and *Codium fragile* while boulders in the west entrance held *Fucus serratus*, *Himanthalia elongata* and *Cladophora rupestris*. Shores at the Pool of Virkie near Sumburgh consisted of pebble and cobble overlying muddy gravel and were covered by dense fucoids with *Mytilus edulis*, the barnacle *Semibalanus balanoides* and littorinids (Howson 1988).

In the shelter of Lerwick Harbour, stone walls supported fucoids with a zonation pattern including *Fucus evanescens*, which formed a mid-shore band between *Fucus spiralis* above and *Fucus serratus* below (Powell 1957b). In this situation it replaced *Fucus vesiculosus* and *Ascophyllum nodosum*. *Fucus evanescens* was still present in abundance on a nearby shore but disappeared within a few hundred metres of the harbour. It was suggested that *Fucus evanescens* was more tolerant of pollution in the harbour than either *Fucus vesiculosus* or *Ascophyllum nodosum* (Powell 1957b). This population has been included in several papers describing the taxonomy and ecology of the species (Powell 1957a, 1957b, 1963; Rice & Chapman 1985; Russell 1974). A fucoid-dominated sheltered shore with *Porphyra umbilicalis* around the high water mark was described from Bressay by Børgesen (1903) who observed *Enteromorpha* sp., large bushes of *Pilayella littoralis*, *Chorda filum*, *Laminaria saccharina* and *Laminaria digitata* just below low water. On a shore south-east of Lerwick, *Prasiola crispa* was present several feet above high water mark with crusts of *Verrucaria marina* (Børgesen 1903). *Fucus ceranoides* was found in a stream running across the shore at Lax Firth together with *Enteromorpha* sp., *Ascophyllum nodosum* and *Fucus muscoides* (Howson 1988).

There are several small sediment shores in voes and embayments along this coastline. Well-drained white sand in South Nesting Bay at Lingness and West Voe of Skellister contained a sparse fauna which included the polychaetes *Arenicola marina* and *Nephtys hombergii*, the bivalves *Chamelea gallina* and *Angulus tenuis* and the holothurian *Leptosynapta inhaerens* (Institute of Terrestrial Ecology 1975d). Sand at the Ayre of Dury was covered by a layer of peat and the infauna held a polychaete/oligochaete assemblage (Howson 1988). A population of cockles *Cerastoderma edule* from this site was included in an allometric study of Shetland populations of *Cerastoderma edule* (Jones & Jones 1981); the cockles were found to be infested with the entocommensal nemertean *Malacobdella grossa* (Jones, Jones & James 1979). A similar community was found in muddy sand and gravel at The Vadills, South Nesting (Howson 1988). A more extensive sand flat in the Pool of Virkie was worked by *Arenicola marina* with approximately 25 animals per m^2. Large areas of diatom film and filamentous green algae on the sediment suggested some mild organic input. The infauna here was dominated by oligochaetes with *Chamelea gallina*, *Scoloplos armiger*, *Cerastoderma edule* and the amphipod *Ampelisca brevicornis* present (Howson 1988).

Specimens of *Elminius modestus*, an Australasian barnacle, were found at several east Mainland locations including Vidlin Voe, East Lunna Voe, Cat Firth, Lerwick Harbour and Brei Wick but the only sizeable population was in Vidlin Voe (Hiscock, Hiscock & Baker 1978). Populations of the dogwhelk *Nucella lapillus* were studied by Crothers (1979). The shell shape did not correlate as expected with the exposure of the shore, and on the east coast, the elongate sheltered form was found on all but the most exposed sites. Later work showed that two models were needed to explain the shape variations around the archipelago, suggesting that two distinct populations existed (Crothers 1992). Macroalgae collected during a British Phycological Society visit to the Shetland Islands were listed by Dixon (1963). The collecting sites included several in the region of Lerwick, Bressay and Mousa.

1.4.3 Sublittoral

There have been extensive sublittoral surveys along the east Shetland Mainland, although there is little information for the coast south of Mousa, the north of Bressay and Whalsay (Earll 1982; Hiscock 1986; Howson 1988; Moss & Ackers 1987). The great variety of structure along the coast means that there are habitats ranging from very exposed bedrock cliffs to sheltered sediments, following the patterns described in the general section of this report. The summary of these given below is based primarily on Howson (1988) with additional details from the other surveys.

Exposed bedrock at Out Skerries, which was surveyed to 42 m depth, supported a kelp *Laminaria hyperborea* forest to 28 m with circalittoral rock covered by encrusting coralline algae and *Parasmittina trispinosa* beyond this. Overhangs on infralittoral cliffs had a well developed sponge-ascidian community. The echinoderms *Hippasteria phrygiana* and *Ophiura sarsi* were found in this area (Earll 1982; Hiscock 1986). On the east coast of Lunna Ness, a bedrock cliff supported the ascidians *Ciona intestinalis* and *Ascidiella aspersa*, while gravel here consisted almost entirely of tubes of *Pomatoceros triqueter* (Howson 1988). Bedrock and boulders were present to 27 m depth at Catta Ness, with *Laminaria hyperborea* to 20 m in the infralittoral and the urchin *Echinus esculentus*, ophiuroids and the featherstar *Antedon bifida* in the circalittoral. A barren pebble and cobble plain was found at 36 m. Farther south at Gletness, moderately steep bedrock on the skerries supported laminarians to 21 m. From about 22 m there was a gently sloping seabed of mixed substrata. Horse mussels *Modiolus modiolus* and the urchin *Strongylocentrotus droebachiensis* were present in the circalittoral and below 26 m, the brittlestar *Ophiocomina nigra* was dominant. The algae *Chorda filum* and *Asperococcus turneri* were found on a shallow clean sand-plain behind a skerry (Howson 1988).

The southern ends of Bressay and Noss and the coast of Mousa are exposed, with steep and vertical bedrock on Mousa reaching a level floor of bedrock and boulders at 30 m depth. Arches and overhangs around the Giant's Leg had vertical walls to 20 m. The laminarians extended to 25 m, with *Laminaria saccharina* replacing *Laminaria hyperborea* at 22 m and communities were typical of exposed conditions. Foliose algae were abundant in the infralittoral, reflecting the lower level of grazing at more exposed sites, while rock in the circalittoral supported the soft coral *Alcyonium digitatum*, the tubeworm *Pomatoceros triqueter* and coralline crusts. A turf of hydroids and bryozoans was found on some walls. *Ophiocomina nigra* dominated the seabed below 30 m at Mousa (Howson 1988).

West Voe on Out Skerries was extremely sheltered and had soft mud with bedrock outcrops; the opisthobranch *Akera bullata* was found on the mud (Earll 1982). In slightly more exposed conditions here there was sand with the lugworm *Arenicola marina* and razor-clams *Ensis* sp. (Hiscock 1986). A cliff at Lunna in Vidlin Voe supported laminarians to about 21 m and had an unusually diverse circalittoral fauna including the featherstar *Antedon petasus* (Earll 1982). A shell-gravel slope at the entrance to Vidlin Voe held the sea pens *Virgularia mirabilis* and *Pennatula phosphorea*, the anemone *Peachia hastata* and the decapod *Atelecyclus rotundatus*. In increased shelter farther into the Voe there was muddy sand with relatively few species, these including the molluscs *Pecten maximus* and *Gibbula magus*, and the algae *Asperococcus turneri* and *Scinaia turgida* (now *Scinaia trigona*) (Howson 1988). *Modiolus modiolus* and an associated epifaunal community were present in places (Earll 1982). An accumulation of decaying algae was noted at 26 m (Howson 1988). Dury Voe was shallow with gradually sloping sides and a seabed of mixed rock and sand. *Laminaria hyperborea* grew on the boulders with *Ophiocomina nigra* on the fronds (Earll 1982).

In the strong tidal streams of Lunning Sound, unbroken bedrock was found to a depth of 42 m and this supported *Laminaria hyperborea* and *Laminaria saccharina* to 25 m. In deeper water, the rock was blanketed by *Alcyonium digitatum* with a band of *Modiolus modiolus* on the rock at 30 to 35 m. In a more sheltered location nearby, maerl was present on a seabed of clean shelly sand with various grades of hard substrata. The associated community contained the urchin *Strongylocentrotus droebachiensis*, *Gibbula magus*, the ascidian *Molgula occulta* and the alga *Scinaia turgida* (now *Scinaia trigona*). Clean sand at 12 m in Noss Sound was bordered by sand-covered rock which supported *Halidrys siliquosa* and other sand-tolerant algae. Below 14 m there were heavily grazed large boulders and bedrock outcrops. Mousa Sound had bedrock to a depth of 13 m where it was replaced by a mixture of cobbles, coarse sand and shell-gravel which supported *Modiolus modiolus* with *Ophiocomina nigra*. At a depth of 36 m in the centre of the channel there was very barren, clean, shelly sand. Bedrock around the edges of the sound supported sand-tolerant algae between 15 and 18 m (Howson 1988). Mixed sediments in Bressay Sound supported *Modiolus modiolus* with associated epifauna while there were *Arenicola marina* mounds and drift laminarians on soft, sandy mud at the northern end of the channel (Barnett *et al.* 1975 in ITE 1975e; SMBA 1975 in ITE 1975e).

Sediments in several voes on the east Mainland were sampled by the DAFS in 1963 and the faunal lists from these were included in a general analysis of the Shetland sedimentary environment (Pearson, Coates & Duncan 1994). Of the six community types identified in Shetland, three were recorded from the east coast.

- In the Voe of Cullingsburgh on Bressay, maerl and fine silt at 17 m were mixed with shell-sand and gravel (SH2, Facies 2) and there was a community characterised by the polychaetes *Nephtys cirrosa* and *Eumida sanguinea*, the bivalves *Ensis* sp. and *Abra prismatica*, and the amphipods *Ampelisca brevicornis* and *Ampelisca tenuicornis*.
- A variant of the shell-sand and gravel community was found in deeper water (20–30 m) in Wadbister Voe, Voe of Sound and Gulber Wick where the sediment was more mixed with larger stones and broken shells were present. Species characteristic of this sediment included the polychaetes *Magelona mirabilis* and *Exogone hebes*, the bivalves *Chamelea gallina* and *Moerella pygmaea*, and the amphipod *Perioculodes longimanus* (SH2, Facies 3).
- Muddy sand and gravel, one of the most widespread sedimentary habitats in the Shetland voes, was recorded from 12–35 m in Wadbister Voe and Lax Firth (SH3). Although it was generally characterised by the polychaete *Myriochele* sp., the bivalve *Clausinella fasciata* and the amphipod *Urothoe elegans*, a wide variety of other species could also predominate depending upon the characteristics of the sediment at a given locality.
- Sediment with a higher proportion of silt at 12 m in Lax Firth held a variant of this community with the polychaete *Scoloplos armiger*, the bivalve *Fabulina fabula* and the cumacean *Diastylis rugosa* found (SH3, Facies 3).
- In depths of about 20 m in Dury Voe fine, silty sand was found with a community characterised by *Scoloplos armiger*, *Abra alba* and amphipods *Dexamine* spp. (SH4).

Modiolus modiolus was sampled in Cat Firth as part of an allometric and population study of the species (Comely 1981). The populations were found to be similar to those in Scottish sealochs with considerable variation between sites. The seabed in Cat Firth varied from gravelly sand with shell and silt to a fairly clean, coarse sand and gravel. The distribution of *Modiolus modiolus* was patchy and this influenced the distribution of other species. For instance, the scallop *Aequipecten opercularis* was found only in the areas where *Modiolus modiolus* were present and the mussels from Cat Firth were found to be particularly heavily infested with the boring sponge *Cliona* spp. (Comely 1981).

1.5 South-west Mainland

1.5.1 Introduction

The coastline from the western point of the Walls peninsula to Sumburgh Head in the south (Figure 1.6) is fully exposed to the south and west, the direction of the prevailing wind and sea. The coastline is broken by a series of voes and islands which run more or less north–south and several of these penetrate a considerable distance into the centre of the island behind the Walls peninsula. The effect of this is to protect large stretches of this coast from the west and in some cases, such as Gruting Voe, there is additional shelter afforded from the south by islands and headlands. Therefore, while the southern and western sections are extremely exposed, some of the central section of this area is very sheltered. Much of the outer part of the exposed coastline is bounded by cliffs, and the highest cliffs on the mainland of Shetland are found at Fitful Head in the south-west. These are 280 m high and they have a series of associated stacks and skerries offshore. This part of the coast has several major inlets which include Gruting Voe and Vaila Sound in the west at Walls, The Firth, Sandsound Voe, Weisdale Voe, Stromness Voe and Whiteness Voe in the centre and, south of Scalloway, Clift Sound, West Burra Firth and West Voe. Stromness Voe has a very narrow silled entrance to the open sea and at its head is Loch of Strom which joins the voe via another narrow rocky channel. Despite its simple elongate shape and large size, Loch of Strom is comparable with a vadill or houb.

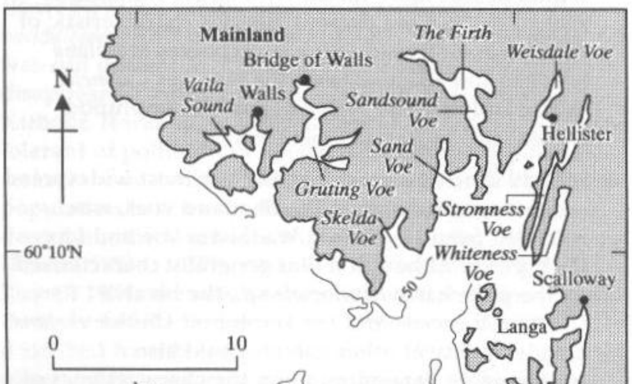

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Figure 1.6. South-west Mainland.

There are a number of depositional features of interest along the coast, notably St Ninian's Tombolo, a shell-sand tombolo connecting St Ninian's Island to the Shetland Mainland. It has been built by wave action from both the north and south and is unstable, changing in size depending on sea conditions. It is of national importance as the largest example of such a structure in Britain (NCC 1976). There are tidal pools or houbs at Hellister on Weisdale Voe and Bridge of Walls and a vadill at the head of Whiteness Voe. At the Bay of Scousburgh a sand-bar has cut off a basin at the head of the Bay to form Loch of Spiggie; this no longer has any marine input but there is a well developed beach, dune and machair system. The largest area of sand in Shetland is at Bay of Quendale in the south of the island. The dune ridge, which is over 10 m high, is relatively stable and is backed by a large area of machair (NCC 1976). In January 1993, the oil tanker *Braer* went aground on the rocky headland of Garth's Ness, to the west of Bay of Quendale.

1.5.2 Littoral

Open rocky shores throughout the area supported communities typical of exposed or very exposed conditions. They were similar to those in the north-west with the kelp *Alaria esculenta* and coralline algae on the lower shore and sublittoral fringe, and the alga *Porphyra umbilicalis*, the barnacle *Semibalanus balanoides*, mussels *Mytilus edulis*, limpets *Patella vulgata*, the alga *Mastocarpus stellatus* and occasional non-native barnacles *Elminius modestus* in the mid and upper shore levels (Covey & Hill 1993; Environment & Resource Technology 1994; Fuller & Donnan 1993; Institute of Terrestrial Ecology 1975c). *Chthamalus stellatus* was first found in this area by Powell (1954b). Rocky shores at Scatness had mixed stands of fucoids *Fucus distichus* and *Fucus spiralis* f. *nana* with the latter also forming a dense band above the *Fucus distichus*. The main associated species here included *Porphyra umbilicalis* and *Blidingia minima* (Russell 1974). *Fucus distichus* was also recorded over a 1 km stretch of exposed shore at West Burra in coralline rockpools with *Mastocarpus stellatus*, *Ceramium rubrum* (now *Ceramium nodulosum*) and *Enteromorpha* sp. (Russell 1974).

The broken coastline meant that examples of most of the seven categories of shore type described by Institute of Terrestrial Ecology (1975c) were found in the area, illustrating transitions from very exposed to very sheltered conditions. Among the most sheltered shores, dominated by *Ascophyllum nodosum*, were sites in Vaila Sound and Gruting Voe. Sheltered shingle shores have been described from East Voe of Scalloway and Skelda Voe (Institute of Terrestrial Ecology 1975d) and the Firth (Howson 1988). At these sites, boulders and cobbles on sediment supported fucoids, including *Ascophyllum nodosum*, and *Mytilus edulis* with lugworms *Arenicola marina* in areas of open sediment. *Fucus ceranoides* was found in streams running across the shore. Sandy gravel at low water in Skelda Voe was found to contain the polychaetes *Nephtys hombergii*, *Polycirrus* sp. and *Nereis* (now *Hediste*) *diversicolor* and the bivalves *Cerastoderma edule* and *Mya arenaria* (Institute of Terrestrial Ecology 1975d). A wide clean sand beach in Sand Voe with *Alaria esculenta* on rocks at the eastern end had a sparse fauna with *Angulus tenuis*, and the polychaetes *Arenicola marina* and *Scolelepis squamata* (Institute of Terrestrial Ecology 1975d). There was also a clean sand beach in the south-facing Bay of Quendale with the isopod *Eurydice pulchra* and the amphipods *Talitrus saltator* and *Echinogammarus pirloti* (Howson 1988).

Several rocky shores were surveyed in the aftermath of the *Braer* oil spill (Covey & Hill 1993; Fuller & Donnan 1993). The most obvious effect of the spill, seen at Garth's Ness, the shores nearest to the site of the spill, was the absence of grazing molluscs, particularly *Patella vulgata* and littorinids, although limpet scars were abundant in rockpools. On rocky shores in the Bay of Quendale, there were no littorinids but *Patella vulgata* was rare rather than absent. Both *Littorina littorea* and *P. vulgata* were found in small numbers on the west side of the Bay. Shores farther from the spill site were unaffected. It was predicted that the absence of grazers would result in a flush of green algae on the affected shores in the spring (Fuller & Donnan 1993) and indeed this was observed the following autumn (Environment & Resource Technology 1994). The latter study also found a higher mortality of the barnacle *Semibalanus balanoides* in the vicinity of the wreck than elsewhere.

1.5.3 Sublittoral

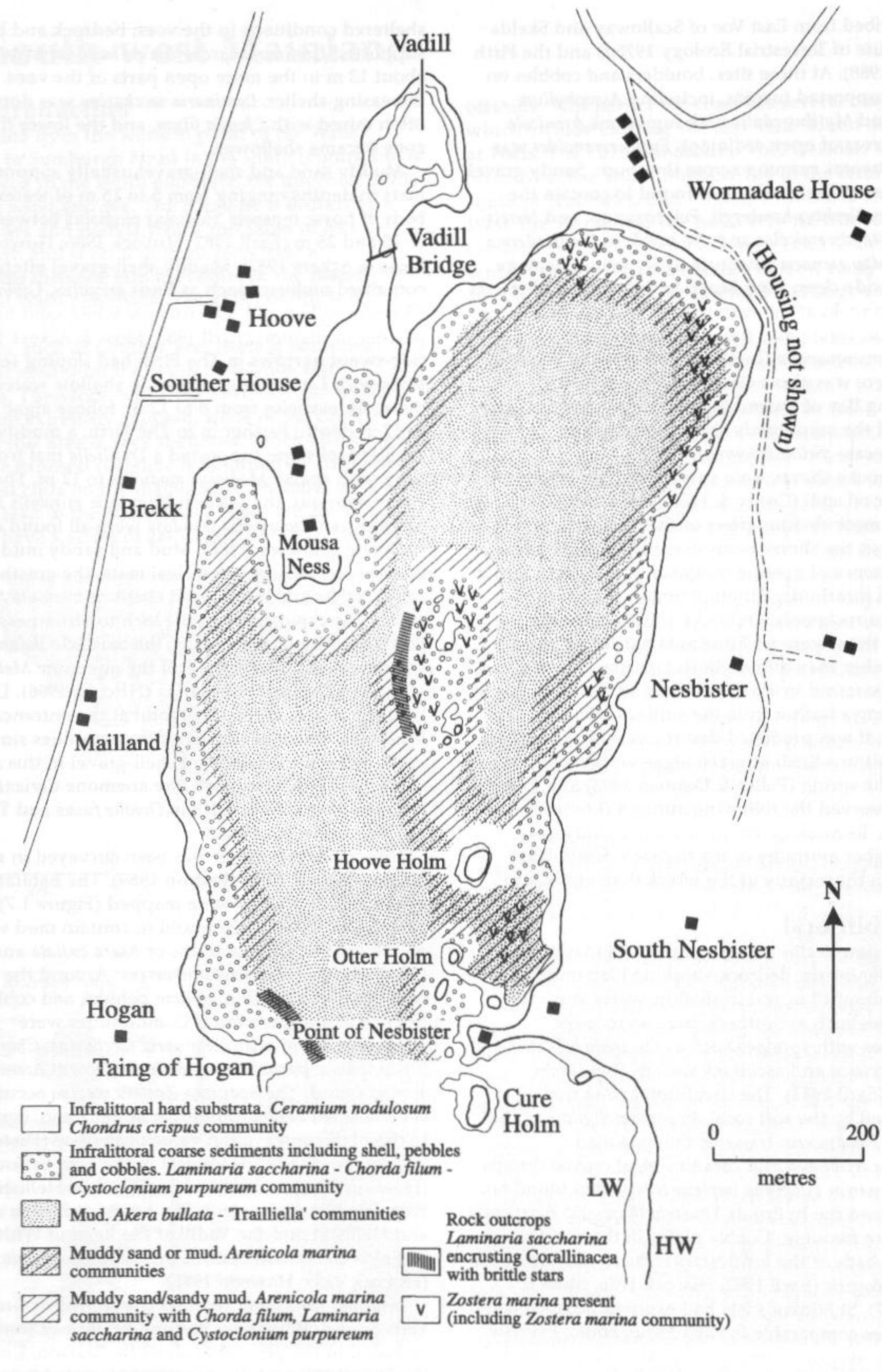
The open coast in this area was similar to that north of the Walls peninsula. Bedrock supported laminarians to depths of about 15 m and in shallow water at very exposed sites such as Scatness there were surge communities with sponges such as *Oscarella lobularis* and *Clathrina coriacea* and ascidians such as *Polyclinum aurantium* (Earll 1982). The circalittoral zone was characterised by the soft coral *Alcyonium digitatum*, the tubeworm *Pomatoceros triqueter*, the bryozoan *Parasmittina trispinosa* and coralline algal crusts; clumps of the tubeworm *Filograna implexa* were often found on rock walls and the hydroids *Thuiaria thuja* and *Abietinaria abietina* were frequent. Cobble plains in the circalittoral had sparse beds of the brittlestars *Ophiocomina nigra* and *Ophiothrix fragilis* (Earll 1982; Hiscock 1986; Moss & Ackers 1987). St Ninian's Isle had exposed bedrock with communities comparable to Papa Stour, Foula, Fair Isle and Muckle Flugga. Foliose algae, particularly *Odonthalia dentata* and *Delesseria sanguinea* extended to approximately 25 m depth and vertical walls supported *Alcyonium digitatum* and the tubeworm *Salmacina dysteri*. On the sheltered side of the island, bedrock and boulders changed to shell-gravel at 12 m which supported no obvious infauna (Howson 1988). In more sheltered conditions in the voes, bedrock and boulders supported *Laminaria saccharina* or *Laminaria hyperborea* to about 12 m in the more open parts of the voes. With increasing shelter, *Laminaria saccharina* was dominant, often mixed with *Chorda filum*, and the lower limit of this zone became shallower.

Muddy sand and shell-gravel usually supported algal mats in depths ranging from 5 to 15 m of water with beds of horse mussels *Modiolus modiolus* between depths of 15 and 25 m (Earll 1982; Hiscock 1986; Howson 1988; Moss & Ackers 1987). Muddy shell-gravel often contained molluscs such as *Ensis arcuatus*, *Gibbula magus*, *Chamelea gallina* and *Mya truncata* while sand had patches of diatoms (Earll 1982; Moss & Ackers 1987). The tide-swept narrows in The Firth had sloping sediment sides with *Laminaria saccharina* in shallow water and dense *M. modiolus* from 8 to 12 m; foliose algae extended to 17 m depth. Farther in to The Firth, a muddy shell-gravel slope supported a *Trailliella* mat from 3 to 10 m with sparse *Modiolus modiolus* to 17 m. The scallop *Pecten maximus*, the sea pen *Virgularia mirabilis* and the holothurian *Cucumaria frondosa* were all found on the sediment (Howson 1988). Mud and sandy mud in the Loch of Strom supported algal mats, the opisthobranch *Akera bullata* and many dead shells of mussels *Mytilus edulis*. The rapids joining the loch to Stromness Voe were dominated by *Mytilus edulis*, the barnacle *Balanus crenatus*, dwarf individuals of the anemone *Metridium senile* and *Laminaria saccharina* (Hiscock 1986). Limestone bedrock occurs in the sublittoral at the entrance to Whiteness Voe and supported communities similar to other rocky sites. Sand and shell-gravel in this area supported *Pecten maximus*, the anemone *Cerianthus lloydii*, and the holothurians *Thyone fusus* and *Thyone roscovita* (Howson 1988).

Upper Whiteness Voe has been surveyed in some detail (Hiscock 1989; Rostron 1989). The habitats and communities present were mapped (Figure 1.7) and the centre of the basin was found to contain mud with a mat of *Trailliella* and populations of *Akera bullata* and the holothurian *Leptosynapta inhaerens*. Around the edges, sediments graded from coarse pebbles and cobbles to finer sand and then mud. Communities were algal-dominated with *Laminaria saccharina*, *Chorda filum*, *Cystoclonium purpureum* and the lugworm *Arenicola marina* found. The seagrass *Zostera marina* occurred in several small beds around this upper basin, contributing to the high conservation value of the Voe (Hiscock 1989). *Zostera marina* was also found in the area in South Voe (Howson 1988) and in the large houb at Hellister on Weisdale Voe (pers. obs.). The houbs at Bridge of Walls and Hellister and the Vadill at the head of Whiteness Voe also all contain beds of the seagrass *Ruppia maritima* (Hiscock 1989; Howson 1988).

Infaunal data from sediments sampled in Gruting Voe, Vaila Sound, Whiteness Voe and Scalloway were included in the general analysis by Pearson, Coates & Duncan (1994) and the communities noted below were identified.

- Gruting Voe and Vaila Sound both contained good examples of the *Modiolus modiolus* community (SH1). In areas with more silt, a variant of SH1 was



Based on Admiralty chart 3294 and the 1981 Ordnance Survey 1:25,000 map (sheet HU 44/45). © Crown copyright.

Figure 1.7. Sublittoral communities at the head of Whiteness Voe (from Hiscock 1989).

characterised by the presence of the molluscs *Turritella communis* and *Hiatella arctica* and the polychaete *Notomastus latericeus* (SH1, Facies 4).

- Other parts of Gruting Voe and Vaila Sound where *Modiolus* did not occur and the seabed east of Langa near Scalloway had muddy sand and gravel in depths of 12 to 42 m with the polychaete *Myriochele* sp., the bivalve *Clausinella fasciata* and the amphipod *Urothoe elegans* (SH3). A shellier variant of this sediment was found in 13 to 30 m in Sand Voe near Scalloway, containing the polychaete *Platynereis dumerilii*, the chiton *Lepidochitona asellus* and the brittlestar *Ophiura affinis* (SH3, Facies 1).
- Muddy sand in a depth of 5 m in Whiteness Voe held the polychaete *Scoloplos armiger*, the bivalve *Abra alba* and amphipods *Dexamine* spp. (SH4). At 10 m depth there was more silt in the sediment and the polychaete *Scalibregma inflatum* and the bivalves *Fabulina fabula* and *Corbula gibba* were also present (SH4, Facies 1).
- A silt/clay community was also found in Whiteness Voe in very sheltered conditions with elements characteristic of deeper areas, but with the addition of herbivorous species such as the gastropod *Roxania utriculus* and the detrivorous amphipods *Ampelisca tenuicornis* and *Corophium acherusicum* (SH5, Facies 3).

The inner basin of Whiteness Voe was described by Rostron (1989). Mud in the centre of the basin contained a moderately diverse community dominated by the polychaete *Mediomastus fragilis*, the bivalve *Mysella bidentata* and nematodes, whereas muddy sand had a dense population of the polychaete *Polydora ?caeca* and was much less diverse. There were many epifaunal species among seagrass *Zostera marina* while coarse sand in a bed of *Zostera* contained the polychaete *Protodorvillea kefersteini*, the amphipod *Phtisica marina*, and the bivalves *Mysella bidentata*, *Musculus costulatus* and *Venerupis senegalensis* (Rostron 1989).

Sublittoral studies to investigate the impact of the *Braer* oil spill in south-west Shetland were carried out towards the end of 1993 (Environment & Resource Technology 1994). Of the sediment samples tested, none proved highly toxic, although there was some evidence that a recovery had occurred between April and November 1993. In the absence of any pre-spill data, evidence of any impact to the coastal macrobenthos appeared to be limited to an increase in the number of the polychaetes *Capitella* spp. in Banna Minn and, to a lesser extent, Bigton Wick and Inner West Voe of Sumburgh. There was no visible evidence of effects in the rocky sublittoral.

1.6 North-west Mainland including Papa Stour, North-west Yell and Unst

1.6.1 Introduction

The Shetland Mainland coastline from the north-western point of the Walls peninsula to Ramna Stacks (Figure 1.8) and then the similar north-west coasts of Yell and Unst to Muckle Flugga (Figure 1.4) is extremely varied. The Muckle Flugga group of small islands and rocks is the most northerly point of the British Isles. The open rocky coast is very exposed and includes the impressive cliffs of the headland at Esha Ness and of the island of Papa Stour which has stacks, arches, sea caves, tunnels and storm beaches. Several major voes are found on this stretch of coast. Ronas Voe in the north is one of the longest in Shetland, has two sills and reaches a maximum depth of 42 m in the extremely sheltered inner basin. South and west of the island of Muckle Roe, Swarbacks Minn leads into a complex of deep, sheltered voes which includes Busta Voe, Olna Firth and Aith Voe, which at 68 m, is the deepest voe in Shetland. The island of Vementry separates Swarbacks Minn from Brindister Voe and the Voe of Clousta, and at the head of Brindister is a complex and extremely sheltered system of shallow basins, the Vadills. Whale Firth on the west coast of Yell is one of the longest voes in Shetland but reaches a maximum depth of only 27 m. There are strong tides around the headlands and through the Sound of Papa and deep water in St Magnus Bay, which reaches a depth of 140 m in its centre.

1.6.2 Littoral

The inaccessible and exposed nature of much of the open coastline has restricted littoral surveys in this area. The west-facing coasts of Esha Ness, the Walls peninsula, Papa Stour and those of north-west Unst and of Muckle Flugga rank among the most exposed in Shetland, and the rocky shore communities were comparable with those of Foula and Fair Isle (Hiscock 1981, 1988; Howson 1988; Institute of Terrestrial Ecology 1975c). Even in calm weather these shores were subject to a continuous large swell and littoral zones were raised to a considerable height above high water mark. The algae *Alaria esculenta* and *Corallina officinalis* blanketed the lower shore up to mid-tide level and *Fucus distichus* was found in the upper mid-shore. *Porphyra umbilicalis*, *Enteromorpha* sp. and the barnacle *Semibalanus balanoides* provided almost 100% cover in the upper mid-shore and there were scattered *Chthamalus stellatus* at these sites (Hiscock 1981; Howson 1988; Institute of Terrestrial Ecology 1975c). *Fucus distichus* was also recorded from an exposed shore at Sandness on the Sound of Papa (Russell 1974). In slightly less exposed conditions near Hillswick, south-east of Esha Ness, *Fucus vesiculosus* f. *linearis* was present (Hiscock 1981).

Shores in voes or sheltered by islands were dominated by fucoids, with *Fucus vesiculosus* on the mid-shore towards the entrance to voes, often mixed with *Ascophyllum nodosum* (Hiscock 1981; Howson 1988) which dominated very low-diversity shores in the greatest

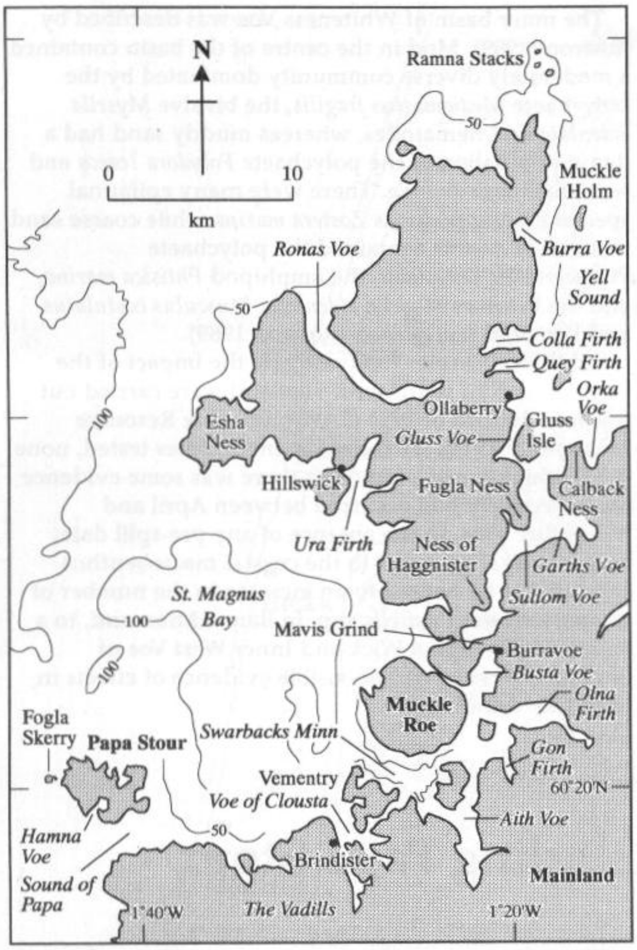


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Figure 1.8. North-west Mainland.

shelter at the heads of voes (Institute of Terrestrial Ecology 1975c). Surveys in Whale Firth on Yell described communities from exposed bedrock at the entrance to the voe where *Laminaria digitata* and *Alaria esculenta* occurred in the sublittoral fringe and a lower shore zone of the algae *Porphyra umbilicalis*, *Cladophora rupestris* and *Mastocarpus stellatus* was present. Farther into the voe, *Fucus serratus*, *Cystoclonium purpureum* and various small red algae were common on the lower shore and *Fucus vesiculosus* and *Ascophyllum nodosum* became increasingly common. Littorinids, *Semibalanus balanoides* and *Patella vulgata* were generally common on these sheltered shores (Whatley & Williams 1978). A similar pattern was also well illustrated by a mapping exercise along the shores of Brindister Voe and the Vadills where *Fucus vesiculosus* was dominant only in the seaward part of the voe (Bunker, Bunker & Perrins 1994). Other fucoids also showed similar distribution patterns. *Fucus spiralis* and *Pelvetia canaliculata* occurred from the voe entrance to the entrance to the Vadills but were absent from the most sheltered rock. Of particular interest in the Vadills were several small beds of the free-living *Ascophyllum nodosum* f. *mackaii* in embayments, the first report of this growth-form in the Shetland Islands. *Fucus ceranoides* was found at the inner end of the southern arm of the system where salinities may have been reduced (Bunker, Bunker & Perrins 1994).

There are few published descriptions of soft sediment shores in the area. A sheltered intertidal flat at East Burra Firth in Aith Voe was found to have shingle lying on sand across much of the shore with sand and peat fragments on the lower shore. The shingle supported fucoids and mussels *Mytilus edulis* while the sand contained the lugworm *Arenicola marina*, a polychaete/oligochaete assemblage, and the bivalves *Mya arenaria* and *Cerastoderma edule* (Howson 1988; Institute of Terrestrial Ecology 1975d). Gravel with shell debris in Busta Voe held *Cerastoderma edule* (Jones & Jones 1981) while a very shallow tidal pool at Saltness contained the seagrass *Ruppia maritima* (Howson 1988). The pool was fringed by peat and saltmarsh and had a sand and pebble shore with fucoids including *Fucus muscoides*, *Chorda filum*, the gastropod *Littorina saxatilis* and *Arenicola marina*. Small patches of littoral sediment in the Vadills held a filamentous brown and green algal assemblage (Bunker, Bunker & Perrins 1994).

1.6.3 Sublittoral

There appears to be little information for large stretches of the open coast in this area as much of it is very exposed and has only limited access. Sites around St Magnus Bay were surveyed by Moss & Ackers (1987), who found rugged terrain with sublittoral cliff faces, gullies and boulder slopes with bedrock and boulders reaching depths greater than 26 m. Kelp forests of *Laminaria hyperborea* were usually replaced by *Saccorhiza polyschides* and *Laminaria saccharina* and these laminarians extended to depths of 24 m. Circalittoral rock was dominated by the soft coral *Alcyonium digitatum*, encrusting coralline algae and the tubeworm *Pomatoceros triqueter*. Groups of the anemone *Urticina felina* occurred on ledges and at breaks of slope while boulders often supported the brittlestars *Ophiothrix fragilis* and *Ophiocomina nigra*. Many of these sites appeared grazed by urchins *Echinus esculentus* (Moss & Ackers 1987). A gully in shallow water on the south of the Esha Ness peninsula had walls covered by *Dendrodoa grossularia*, *Polyclinum aurantium* and other ascidians and bryozoans (Earll 1982). Gullies in deeper water off the Ness of Hillswick were broken by numerous crevices with squat lobsters *Galathea strigosa*, the brittlestar *Ophiopholis aculeata* and the crab *Cancer pagurus* while the walls supported *Alcyonium digitatum*, the anemone *Corynactis viridis* and the tubeworm *Filograna implexa*. These sites appeared less heavily grazed than others in the area (Moss & Ackers 1987).

The open west coast of Papa Stour, which is very exposed, had *Alaria esculenta* to a depth of 5 m, dense *Laminaria hyperborea* with a luxuriant sub-flora to 21 m and kelp (*Laminaria hyperborea* and *Laminaria saccharina*) to a maximum depth of 28 m (Howson 1988). The circalittoral was very similar to sites in St Magnus Bay with *Alcyonium digitatum*, the featherstar *Antedon bifida*, encrusting coralline algae and *Pomatoceros triqueter*. Caves on Fogla Skerry were very exposed and had dense *Odonthalia dentata* (a red alga) at the entrance while the inner walls were blanketed with a rich ascidian, sponge, hydroid and bryozoan turf; this included the anemone

Phellia gausapata. The nationally scarce alga *Schmitzia hiscockiana* was found on boulders in a cave entrance. The Sound of Papa, which has strong tidal streams, had boulders and gravel at about 18 m with the hydroid *Abietinaria abietina* on the sides of boulders, and rock ridges at 25 m dominated by algal crusts and *Ophiocomina nigra*. The seabed was heavily grazed with *Echinus esculentus, Antedon bifida* and *Pomatoceros triqueter* abundant (Howson 1988).

Muckle Flugga has steep and very exposed bedrock in the sublittoral which drops to a slope of coarse sediment at 34 m depth. Communities were similar to those on Foula, Fair Isle and Papa Stour (Howson 1988). Dense kelp *Laminaria hyperborea* dominated to 17 m, *Laminaria saccharina* to 28 m and the red alga *Delesseria sanguinea* to 34 m. There were few urchins and foliose algae were abundant in the sub-flora and on the kelp stipes. Beds of the anemone *Corynactis viridis*, the soft coral *Alcyonium digitatum* and colonial ascidians blanketed vertical rock and the open parts of kelp forests while the anemone *Urticina felina* covered gully floors (Howson 1988). The open west coast of Unst was broadly similar, although grazing by the sea urchin *Echinus esculentus* was more apparent and thus there was less foliose algae and *Alcyonium digitatum* dominated the circalittoral (Moss & Ackers 1987).

The sheltered communities in this area are better known than those of exposed coasts (Earll 1982; Hiscock 1986; Howson 1988; Institute of Terrestrial Ecology 1975e). Ronas Voe is extremely sheltered along most of its length and, unlike other voes, has a significant sill. The deep inner basin is subject to periods of anoxic conditions; the mud here was covered with a bacterial film (Hiscock 1986). The inner basin of Ronas Voe and Olna Firth both had bedrock outcrops from a mud plain with similar communities. In the infralittoral, these supported cape-form *Laminaria saccharina, Chorda filum* and *Aurelia aurita* scyphistomae. In the circalittoral, the ascidian *Ascidiella aspersa, Antedon bifida*, the anemone *Sagartiogeton laceratus* and the polychaete *Myxicola aesthetica* were present (Hiscock 1986; Howson 1988). Other communities were similar throughout most of the large voes. There was often relatively little hard substrata in shallow water, although at some sites boulders extended to depths as great as 15 m along the voe sides. Muddy sand and stones in shallow water usually had *Laminaria saccharina* and *Chorda filum* to about 5 m depth and a filamentous algal mat to about 14 m (Earll 1982; Howson 1988). Beds of horse mussel *Modiolus modiolus* and associated epifauna such as *Ascidiella aspersa* and the bivalve *Aequipecten opercularis* were almost ubiquitous on muddy sand and gravel throughout these voes and were particularly abundant at depths of about 15 m (Earll 1982; Hiscock 1986; Howson 1988; Moss & Ackers 1987). However, they were less frequent on cleaner, more exposed sediments; Comely (1981) found none on coarse shelly sand in Ura Firth and few on clean coarse sand towards the entrance of Ronas Voe. The varied epifaunal communities that the *Modiolus modiolus* supported has been described in some detail by Earll (1982), Howson (1988) and Pearson, Coates & Duncan (1994).

Surveys by Leicester Polytechnic (Berryman 1981; Berryman & Clark 1982; Berryman & Young 1979) in Whale Firth found that the *Laminaria hyperborea* forest extended to a depth of 10 m but had been replaced by *Laminaria saccharina* by the bend about half-way up the voe. A surge gully at the entrance to the Firth supported a rich sponge and ascidian community. A plain of the anemone *Sagartiogeton laceratus* and the polychaete *Myxicola infundibulum* was found on mud in the inner arm of the voe and there was *Ensis* sp. in sandier sediment in the outer arm. *Modiolus modiolus* was common on rock below the lower infralittoral (Berryman 1981; Berryman & Young 1979). The surveys were repeated over several years and, although changes were observed, it was felt that these were due to normal fluctuations in the populations of individual species (Berryman 1983; Berryman & Clark 1982).

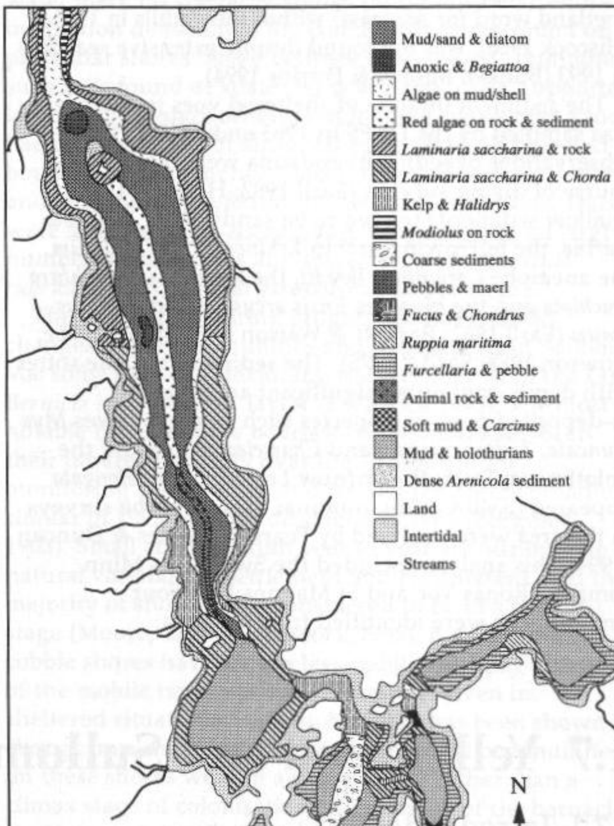

Figure 1.9. Map of the sublittoral communities in Brindister Voe and the Vadills (from Bunker, Bunker & Perrins 1994).

Sublittoral communities present in Brindister Voe and the Vadills have recently been described and mapped (Bunker, Bunker & Perrins 1994; Figure 1.9) and illustrate many of the features outlined above. The outer Voe shows a clear zonation of communities both with increasing shelter and with depth, while the effect of increased tidal flow through the narrow entrance to the Vadills can be seen in the presence of species such as *Laminaria hyperborea* and *Halidrys siliquosa* in this area. The structure of the system with numerous basins and connecting channels and sills means that a great variety of habitats and communities were present in a small area. Of particular interest were the basins filled with soft mud containing the holothurians *Leptosynapta inhaerens* and *Trachythyone* (now *Leptopentacta*) *elongata* and, around the fringes, the alga *Furcellaria lumbricalis*. The seagrass *Ruppia maritima* was found in the innermost basins but *Zostera marina*, recorded from Marlee Loch ('Marlee' is the Shetland word for seagrass) within the Vadills in 1985 (Hiscock 1986), was not found despite extensive searches in 1993 (Bunker, Bunker & Perrins 1994).

The sediment infauna of sheltered voes in this area was sampled by the DAFS in 1963 and SMBA (1975). Observations of sediment epifauna were made in the course of diving surveys (Earll 1982; Howson 1988). Shallow sediments tended to be sandy, with *Arenicola marina*, the burrowing urchin *Echinocardium cordatum*, the anemone *Cerianthus lloydii*, the brittlestar *Amphiura brachiata* and the bivalves *Ensis arcuatus* and *Angulus tenuis* (Earll 1982; Barnett & Watson 1975 in ITE 1975e; Howson 1988; SMBA 1975). The sediment became softer with depth, containing significant amounts of re-deposited peat, and species such as the bivalves *Mya truncata*, *Zirfaea crispata* and *Chamelea gallina* and the holothurian *Trachythyone* (now *Leptopentacta*) *elongata* appeared (SMBA 1975). Infaunal data from the surveys in the area were analysed by Pearson, Coates & Duncan (1994); this analysis included the Swarbacks Minn complex, Ronas Voe and St Magnus Bay. Four communities were identified from the area:

- The most widespread was *Modiolus modiolus* on poorly sorted muddy substrata (SH1). In the shallow water of Ronas Voe, *Modiolus modiolus* on muddy sand supported the gastropod *Gibbula cineraria* and the bivalves *Modiolarca tumida* and *Hiatella arctica* (SH1, Facies 3). In deeper water in Aith Voe and others in the Swarbacks Minn complex, siltier sediment held the gastropod *Turritella communis*, the bivalve *Hiatella arctica* and the polychaete *Notomastus latericeus* (SH1, Facies 4);
- In open areas of Swarbacks Minn and St Magnus Bay in depths beyond 70 m, clean shell-sand and gravel contained a community characterised by the polychaete *Pisione remota*, the bivalve *Abra prismatica* and the urchin *Echinocyamus pusillus* (SH2);
- Muddy sand and gravel, which was widespread between 11 and 95 m in Swarbacks Minn and at about 30 m in Ronas Voe appeared organically enriched and held the bivalves *Mysella bidentata* and *Crenella decussata*, the polychaetes *Prionospio malmgreni* and *Ophiodromus flexuosus* and the phoronid *Phoronis* sp. (SH3, Facies 2);
- In fine silt and clay in Swarbacks Minn, Aith Voe and Olna Firth, the polychaete *Glycera alba* and the molluscs *Thyasira* sp. and *Chaetoderma nitidulum* were present (SH5) A variant of SH5 was found in Ronas Voe, where a higher organic content was indicated by the presence of the polychaetes *Mediomastus fragilis*, *Protodorvillea kefersteini* and *Chaetozone setosa* (SH5, Facies 1).

The findings of this analysis (Pearson, Coates & Duncan 1994) supported earlier observations that the deep sheltered basins of Ronas Voe, Olna Firth, Gon Firth and Aith Voe were likely to suffer intermittent periods of anoxia and would thus be vulnerable to any increase in organic loading of the system (Barnett *et al.* 1975 in ITE 1975e; SMBA 1975 in ITE 1975e).

1.7 Yell Sound and Sullom Voe

1.7.1 Introduction

Yell Sound is one of the major channels in the Shetland Islands, separating Mainland Shetland from Yell. It runs for 28 km more or less north to east from the rocks of Ramna Stacks at its northern entrance to the peninsula of Lunna Ness in the east. It has a rocky coastline with numerous small islands and rocks and tides of up to 7 knots (3.5 m s^{-1}) run through the sound, being particularly strong in the eastern section (Syratt & Richardson 1981). There are cliffs along much of the northern part of the sound and several areas of boulder and shingle beach but very little soft sediment although there are six sandy shores in the area. There are several voes along the length of Yell Sound, particularly on the Mainland shore. These include Sullom Voe, one of the longest and deepest in Shetland, Gluss and Orka Voes at the entrance to Sullom Voe, Quey Firth and Colla Firth to the north and Dales Voe, Colla Firth and Swining Voe to the south-east, as well as several smaller voes. Dales Voe is separated from Swinister Voe by the triple bar houb at Fora Ness and there are other large houbs at Fugla Ness and Scatsta in Sullom Voe, Quey Firth and the Ness of Galtagarth in Hamna Voe on Yell. Sullom Voe reaches a depth of 51 m at its entrance and 49 m at its head. It has a sill of 12 m depth between Ness of Haggrister and Voxter Ness separating the deep inner basin from the main part of the Voe. There are several small subsidiary arms and embayments in the Voe, including Voxter and Garths Voes and the Bight of Haggrister. The Sullom Voe Oil Terminal is situated on the southern side of Calback Ness at the entrance to the voe. Depths reach over 30 m in the jetty area.

The marine biology of Yell Sound and Sullom Voe is perhaps better known than that of any other part of

Shetland. Intensive work in this area began in 1974 when, with the imminent arrival of the oil industry in the islands, baseline surveys in several marine biological disciplines were initiated, involving several different organisations. A major multi-disciplinary project was instigated by the Institute of Terrestrial Ecology for the then NCC (Institute of Terrestrial Ecology 1975a). Although the general findings of this work have been discussed in earlier sections of this chapter, the results pertaining to Sullom Voe and Yell Sound are included here. The Sullom Voe Environmental Advisory Group (SVEAG) was established in 1974 when it began to commission baseline and monitoring studies in the Sullom Voe area (Foxton 1981). The Shetland Oil Terminal Environmental Advisory Group (SOTEAG) replaced SVEAG in 1977, shortly before the terminal became operational in 1978, and since then has overseen an annual monitoring programme (Foxton 1981; Dunnet 1995). Much of the available information on the marine environment of Sullom Voe and the impact of oil developments has been drawn together in two symposium volumes (Pearson & Stanley 1981; Dunnet & McIntyre 1995). A large oil-spill in Sullom Voe at the end of 1978 from the *Esso Bernicia* and the resultant clean-up operations necessitated further work to look at the recovery of habitats in the area.

1.7.2 Littoral

1.7.2.1 Rocky shores

The earliest descriptions of rocky shores in this area were those of Børgesen (1903) from steep, exposed rock on Muckle Holm at the entrance to Yell Sound and sheltered rock platforms in the nearby Burra Voe, although the first large-scale survey was carried out during the Institute of Terrestrial Ecology programme (Powell 1975). Following this, the Field Studies Council Oil Pollution Research Unit (OPRU) was commissioned by SVEAG in 1976 to survey the rocky shores, and 34 sites were described in Sullom Voe, Yell Sound and reference areas. These were surveyed using semi-quantitative recording along transects (Baker *et al.* 1976). Additional sites were surveyed in 1977 and repeat surveys were carried out in subsequent years (Hiscock 1981; Moore, Taylor & Hiscock 1995). This sequence of work included a survey of the effects of the *Esso Bernicia* spill (Hiscock & Cartlidge 1979). By this stage, a total of 50 sites had been surveyed and 23 selected as primary monitoring sites. During the same period as the OPRU studies, several shores in Yell Sound were surveyed independently, but using OPRU methods, by expeditions from Leicester Polytechnic (Bott, Salt & Tindale 1981; Whatley & Williams 1978; Williams, Cohen & Boyce 1983). Descriptions below have been compiled from these various sources.

Shores in Yell Sound and Sullom Voe range from steep exposed bedrock to more gradually sloping and extremely sheltered bedrock, boulders and cobble in the heads of voes and houbs, although even in sheltered conditions rocky shores were often relatively steep (Powell 1975). The most exposed sites were dominated by barnacles and mussels *Mytilus edulis* in the mid-shore with patches of red algae such as *Callithamnion* spp., *Ceramium* spp. and *Laurencia* (now *Osmundea*) *pinnatifida* and on the upper shore *Porphyra umbilicalis*, *Urospora penicilliformis* and *Bangia fuscopurpurea* (now *Bangia atropurpurea*). The sublittoral fringe at these exposed sites had the kelps *Alaria esculenta* and *Laminaria digitata* while many supported *Fucus vesiculosus* f. *linearis*. With increasing shelter, several species became less frequent or disappeared; these included the algae *Himanthalia elongata* and *Porphyra umbilicalis*, the gastropod *Littorina neritoides*, the barnacle *Semibalanus balanoides*, *Mytilus edulis* and the anemone *Actinia equina*. Conversely, fucoids appeared with increasing shelter and mid and lower shore littorinids became more abundant. *Pelvetia canaliculata* and *Fucus serratus* were found on both semi-exposed and sheltered shores whereas *Ascophyllum nodosum* was confined to the most sheltered situations. *Halidrys siliquosa* was sometimes abundant near low water mark on sheltered shores (Børgesen 1903). Shore inclination determined the community composition on particular shores. Steep bedrock in sheltered conditions, such as is found at Voxter Ness in Sullom Voe, supported large *Mytilus edulis* whereas more gradually sloping rock had a dense cover of algae (Hiscock 1981). Shingle and boulder shores generally had a very shallow inclination and were normally found in sheltered conditions. These were dominated by *Ascophyllum nodosum* and had large numbers of littorinids and the amphipods *Ampithoe rubricata* and *Orchestia gammarellus* under stones.

The OPRU monitoring programme has enabled changes in the communities and populations in Sullom Voe to be followed, including the recovery from the *Esso Bernicia* spill (Moore, Taylor & Hiscock 1995). The most notable feature of the bedrock communities has been their inherent stability over the 15 years of the monitoring programme, and indeed they were broadly similar in 1992 to those described in 1903 (Børgesen 1903). Small changes from year to year are attributable to natural variation in settlement and recruitment, and the majority of shores were considered to be in a climax stage (Moore, Taylor & Hiscock 1995). Boulder and cobble shores have shown less stability, largely because of the mobile nature of the substratum. Even in sheltered situations, the beach profile has been shown to change on a more or less annual basis and communities on these shores were in a successional rather than a climax stage of colonisation. Populations of the barnacle *Semibalanus balanoides* were found to be more stable at exposed rather than sheltered sites, the latter showing considerable fluctuation in settlement and recruitment from year-to-year. Dogwhelks *Nucella lapillus* numbers mirrored the barnacle populations on most shores, remaining fairly high until 1989. In 1990, numbers were observed to fall, particularly around the terminal area, and they appear to have been affected by tributyltin (TBT) (Taylor *et al.* 1992; Moore, Taylor & Hiscock 1995).

Sullom Voe shores have been affected to a small degree by the presence of the oil terminal and by oil spills. Following the *Esso Bernicia* spill, communities on untreated or hand-cleaned shores were found to be broadly similar to the pre-spill situation, although the numbers of littorinids and limpets had decreased (Hiscock & Cartlidge 1979). However, most species had returned to their pre-spill densities within two or three years (Moore, Taylor & Hiscock 1995). In contrast, by 1992 those shores which had been cleaned by bulldozers and mechanical diggers had still not returned to their 1978 community structure. These shores, which were primarily boulder or cobble, were rapidly colonised by *Fucus vesiculosus*, *Fucus serratus* and *Fucus spiralis*; however, *Pelvetia canaliculata* and *Ascophyllum nodosum* took much longer to become re-established (Moore, Taylor & Hiscock 1995).

1.7.2.2 Sediment shores

There are few soft sediment shores in the area and these are generally situated at the heads of voes or in houbs. Several were included in the ITE programme: Garths Voe, Gluss Voe, Scatsta Voe, Houb of Scatsta, Houb at Garths Ness and Bay of Ollaberry (Institute of Terrestrial Ecology 1975d). Others were surveyed for SOTEAG with a view to establishing monitoring sites (Jones 1976) and shores at Dales Voe, Gluss Voe, Swining Voe and Scatsta Voe, and the houbs at Scatsta and Fugla Ness were selected for this latter purpose (Jones 1981). The substratum at any one site tended to be variable and poorly-sorted, with a preponderance of coarse sand, gravel and shell debris. Peat fragments were often an important component of the sediment, sometimes forming an upper layer as much as 5 cm deep (Jones 1981). There were localised areas of finer sand which usually held a richer fauna; stones and gravel on the upper shore were often afaunal (Institute of Terrestrial Ecology 1975d; Jones & Jones 1981). Sand in the more sheltered situations such as the Houb of Scatsta held species such as the bivalves *Macoma balthica*, *Cerastoderma edule* and *Mya arenaria*, and the lugworm *Arenicola marina*, whereas more exposed, cleaner sand in the Voe of Scatsta and Bay of Ollaberry held the bivalves *Angulus tenuis*, *Fabulina fabula*, *Ensis siliqua*, *Ensis arcuatus*, the polychaete *Magelona papillicornis* (now *Magelona mirabilis*) and the holothurian *Leptosynapta inhaerens* (SMBA 1975). The shore at Dales Voe was dominated by molluscs and spionids with *Pygospio elegans*, *Polydora quadrilineata*, *Cerastoderma edule*, *Macoma balthica* and *Fabricia sabella* particularly common. In contrast in Gluss Voe, crustaceans and molluscs were dominant with annelids diverse but of low density (Jones & Jones 1981). The amphipod *Corophium crassicorne* was the most abundant animal at the latter site with the bivalves *Angulus tenuis*, *Fabulina fabula*, *Paphia* (now *Venerupis*) *rhomboides* and *Crenella decussata*, a predominantly sublittoral species, present. The Houb of Scatsta seemed to be a highly productive environment although there were relatively few species present, but there were particularly large quantities of the cockles *Cerastoderma edule* (Barnett *et al.* 1975 in ITE 1975e). These cockle populations were an unusual feature of the houbs as they were living on the sediment surface (Jones & Jones 1981). The stonier sediments at these sites generally supported little infauna but sometimes had fucoids and mussels on the surface, although large numbers of the sand-eel *Ammodytes tobianus* were found in otherwise barren gravel at the Bay of Ollaberry (Barnett *et al.* 1975 in ITE 1975e).

The annual monitoring programme for SOTEAG produced a series of reports, but was discontinued in 1985. The study involved transect surveys in Dales Voe and Gluss Voe and population studies of *Cerastoderma edule* at all seven locations, listed above, and of *Macoma balthica* in the Houb of Scatsta and Dales Voe (Jones & Jones 1981; Jones 1995). Recruitment was found to be sporadic in both species and growth rates varied between sites, probably due to inter-site differences in food availability. There was generally little annual change with any differences being attributable to natural causes. A decline in the growth rate of *Cerastoderma edule* was observed at most sites but pre-dated the arrival of the oil industry in Shetland (Jones 1982). However, the effective loss in 1983 of the population of *Macoma balthica* from the monitoring site at the Houb of Scatsta was considered to be a continuing effect of the *Esso Bernicia* spill (Jones 1984).

1.7.3 Sublittoral

1.7.3.1 Hard substrata

Macroalgal communities in Sullom Voe were first described in broad terms by Irvine (1974a) and in more detail by Tittley, Irvine & Jephson (1976) (Tables 1.2 and 1.3). Their sites were revisited about ten years later (Tittley *et al.* 1985a, 1985b) and again in 1993. As a consequence, the marine algae of the Voe are now well known. Sites in Sullom and nearby voes were surveyed by ITE and SMBA (Earll 1982; Institute of Terrestrial Ecology 1975e) and around Calback Ness for SOTEAG (Hiscock & Hainsworth 1976). Since 1978, British Petroleum have commissioned annual surveys around the diffuser site at Calback Ness (IOE 1982, 1988). More recently, surveys for the MNCR have included the inner basin of Sullom Voe, the Houb at Fora Ness, Lunna Ness and Yell Sound (Hiscock 1986; Howson 1988) while fish farm studies for the NCC investigated sites at Swinister, Boatsroom and West Lunna Voes (Dixon 1986). Leicester Polytechnic included a few sites in Yell Sound in their annual expeditions to Shetland between 1979 and 1983 (Berryman 1981, 1983).

Around Calback Ness and in the outer parts of Sullom Voe, bedrock to a depth of 10 m was dominated by *Laminaria hyperborea*, with *Saccorhiza polyschides* replacing this at the rock-sand boundary and a band of *Laminaria digitata* in the sublittoral fringe. With increasing shelter, *Laminaria hyperborea* was replaced by *Laminaria saccharina* which was the dominant macroalga in the inner voe, with hollow-stiped plants in the most sheltered locations (see Kain 1976 for a discussion of this growth form). Less stable substrata, such as stones, shells and sand, supported *Laminaria saccharina* in the more exposed situations and *Chorda filum* in shelter (Hiscock & Hainsworth 1976; Tittley, Irvine & Jephson 1976). At Calback Ness, the sub-flora and fauna of the kelp forest and circalittoral were sparse, a result of grazing by *Echinus esculentus*. However, there was a richer flora on sand and gravel in shallower water, partly due to the presence of a range of summer annuals (Hiscock & Hainsworth 1976). Most macroalgae found in Sullom Voe occurred throughout the Voe, although some species were restricted to the entrance and others, particularly those associated with unstable substrata, to the inner voe. A wide variety of species occurred as deep as 15 m

Table 1.2. Vertical distribution of algal species in Sullom Voe. (Based on Tittley, Irvine & Jephson 1976 and using most recent nomenclature.)

Species not found below 6 m	Species not found below 15 m	Species found below 15 m
Acrothrix gracile	*Ahnfeltia plicata*	*Aglaozonia* phase of *Cutleria multifida*
Chondrus crispus	*Asperococcus compressus*	*Aplogossum ruscifolium*
Corallina officinalis	*Asperococcus turneri*	*Brongniartella byssoides*
Cutleria multifida	*Bulbocoleon piliferum*	*Callocolax neglectus*
Enteromorpha ramulosa	*Ceratocolax hartzii*	*Callophyllis cristata*
Furcellaria lumbricalis	*Chorda filum*	*Callophyllis laciniata*
Giffordia granulosa	*Chylocladia verticillata*	*Ceramium nodulosum*
Gononema aecidioides	*Desmarestia viridis*	*Coccotylus truncata*
Halidrys siliquosa	*Dictyota dichotoma*	*Desmarestia aculeata*
Laminaria digitata	*Dumontia contorta*	*Dilsea carnosa*
Mastocarpus stellatus	*Ectocarpus fasciculatus*	*Griffithsia corallinoides*
Membranoptera alata	*Erythrotrichia carnea*	*Laminaria saccharina*
Palmaria palmata	*Heterosiphonia plumosa*	*Lomentaria clavellosa*
Plumaria elegans	*Hypoglossum hypoglossoides*	*Peyssonelia* sp.
Stictyosiphon griffithsianus	*Laminaria hyperborea*	*Phycodrys rubens*
Stictyosiphon tortilis	*Phyllophora pseudoceranoides*	*Plocamium cartilagineum*
	Pseudolithoderma extensum	*Polyides rotundus*
	Rhodomela confervoides	*Polysiphonia elongata*
	Saccorhiza polyschides	*Polysiphonia stricta*
	Spermatochnus paradoxus	*Pterothamnion plumula*
	Sphacelaria radicans	*Rhodomela lycopodioides*
	Stictyosiphon soriferus	*Rhodophyllis divaricata*
	Trailliella – phase of *Bonnemaisonia hamifera*	*Sphacelaria plumigera*
	Ulva lactuca	

with a few, such as *Polysiphonia elongata*, *Phycodrys rubens*, *Phyllophora crispa* and *Lomentaria clavellosa*, growing as deep as 22 m. In the inner voe, few algae grew below 6 m (Tittley, Irvine & Jephson 1976). Communities on floating structures in Sullom Voe were found to be comparable with those on similar structures on other British North Sea coasts (Tittley & Fletcher 1984). Above the water line there were wave-washed green algae such as *Urospora* spp. and *Ulothrix* spp. Brown algae characterised the waterline communities, and there were laminarians below water level. Communities on fixed hard substrata were similar to those of natural rocky habitats (Tittley & Fletcher 1984).

Five characteristic algal associations were recognised from the voe (Tittley, Irvine & Jephson 1976) and were recorded again ten years later and were judged to be very stable (Tittley *et al.* 1985a). However, in the later study, several species were added to the Sullom Voe and Shetland lists and the beds of *Phyllophora crispa* and fine, filamentous algae were reported to be more widespread than previously. There appeared to be a strong resemblance between the associations found in Shetland and a classification developed by Børgesen for the Faeroe Islands (Tittley *et al.* 1985b). The associations are described below.

- Association 1 in shallow water comprised an algal turf of predominantly red species which covered firm substrata. This was particularly diverse in the outer voe and resembled Børgesen's '*Corallina* formation'.
- Association 2 was of epiphytes on *Laminaria hyperborea* stipes. In the outer voe, this flora was reasonably abundant, with species such as *Callophyllis cristata*, *Cryptopleura ramosa* and *Myriogramme* (now *Haraldiophyllum*) *bonnemaisonii* found. The association corresponded to Børgesen's '*Laminaria hyperborea* formation'. However, the association was poorly developed in the inner voe as there were few *L. hyperborea* and they were small with the most frequent epiphytes being *Audouinella purpurea* and *Polysiphonia urceolata* with other species especially including *Membranoptera alata*, *Phycodrys rubens* and *Rhodomela lycopodioides*.
- Association 3 consisted of unstable substrata containing shells and sand shallower than 10 m supporting a blanketing layer of soft vegetation dominated by brown algae such as *Asperococcus compressus* and *Asperococcus turneri*. This was equivalent to Børgesen's '*Stictyosiphon* association'.
- Association 4 was a red algal association characterised by *Phycodrys rubens*, *Phyllophora crispa* and *Polysiphonia elongata*; this was Børgesen's 'Florideae formation'. In Shetland this had three facies:

1. A particularly diverse assemblage beneath *Laminaria hyperborea*;
2. *Chorda filum*, *Palmaria palmata* and *Ahnfeltia plicata* were present where *Laminaria hyperborea* was absent and there were additional species such as *Scinaia turgida* (now *Scinaia trigona*);
3. Deeper than 18 m dominated by *Phyllophora crispa*, the lingulate form of *Phycodrys rubens* and the crusts *Aglaozonia* (phase of *Cutleria multifida*) and *Pseudolithoderma extensum*. Stones and debris in deeper water in the outer voe were included in this last facies and also supported *Callophyllis cristata*, *Halarachnion ligulatum* and *Ulva lactuca*. In 15 m *Phyllophora crispa* formed extensive,

Table 1.3. Infralittoral algal associations in Sullom Voe. Bold indicates dominant species of an association. Associations 2 and 5 include few species and are described in the text. (Based on Tittley, Irvine & Jephson 1976 and using most recent nomenclature.)

Association 1	Association 3	Association 4		
		Facies A	Facies B	Facies C
Aglaozonia phase of *Cutleria multifida*	*Acrothrix gracilis*	*Ahnfeltia plicata*	*Aglaozonia* phase of *Cutleria multifida*	*Aglaozonia* phase of *Cutleria multifida*
Ahnfeltia plicata	*Aglaozonia* phase of *Cutleria multifida*	*Aglaothamnion roseum*	*Rhodothamnionella floridula*	***Phycodrye rubens***
Ceramium nodulosum	*Asperococcus compressus*	*Aglaozonia* phase of *Cutleria multifida*	*Callithamnion* sp.	***Phyllophora crispa***
Chondrus crispus	*Asperoccus turneri*	*Asperococcus turneri*	*Callophyllis cristata*	***Polysiphonia elongata***
Chorda filum	*Callithamnion* spp.	*Brongniartella byssoides*	*Delesseria sanguinea*	*Pesudolithoderma extensum*
Chylocladia verticillata	*Ceramium nodulosum*	*Callocolax neglectus*	*Erythrocladia irregularis*	
Corallina officinalis	*Chaetomorpha capillaris*	*Callophyllis cristata*	*Halurus equisetofolius*	
Cystoclonium purpureum	*Chorda filum*	*Callophyllis laciniata*	*Heterosiphonia plumosa*	
Delesseria sanguinea	*Chylocladia verticillata*	*Ceramium deslongehampsii*	*Hypoglossum hypoglossoides*	
Derbesia marina	*Cladophora* sp.	*Ceramium nodulosum*	*Lomentaria clavellosa*	
Dictyosiphon foeniculaceus	***Dictyosiphon foeniculaceus***	*Ceratocolax hartzii*	*Lithothamnion glaciale*	
Dilsea carnosa	***Desmarestia viridis***	*Chaetomorpha melagonium*	***Phycodrys rubens***	
Dumontia contorta	*Ectocarpus siliculosus*	*Chorda filum*	***Phyllophora crispa***	
Enteromorpha intestinalis	*Enteromorpha ramulosa*	*Cladophora* sp.	*Coccotylus truncata*	
Fucus serratus	*Giffordia granulosa*	*Delesseria sanguinea*	*Plocamium cartilagineum*	
Fucus vesiculosus	*Griffithsia corallinoides*	*Desmarestia aculeata*	*Polyides rotundus*	
Furcellaria lumbricalis	*Lithothamnion glaciale*	*Dictyosiphon foeniculaceus*	***Polysiphonia elongata***	
Gigartina stellata	*Gononema aecidioides*	*Erythrocladia irregularis*	*Polysiphonia stricta*	
Lithothamnion sp.	*Peyssonelia* sp.	*Halurus equisetifolius*	*Pseuolithoderma extensum*	
Membranoptera alata	*Phymatolithon lenormandii*	*Heterosiphonia plumosa*	*Pterosiphonia parasitica*	
Phyllophora pseudoceranoides	*Plocamium cartilagineum*	*Hypoglossum hypoglossoides*	*Rhodophyllis divaricata*	
Plumaria elegans	*Polyides rotundus*	*Lomentaria clavellosa*	*Scinaia trigona*	
Polyides rotundus	*Polysiphonia elongata*	*Nitophyllum punctatum*	*Sphacelaria plumigera*	
Polysiphonia elongata	*Polysiphonia stricta*	*Palmaria palmata*	*Sphacelaria radicans*	
Polysiphonia fucoides	*Pseudolithoderma extensum*	*Peyssonnelia* sp.	*Ulva lactuca*	
Polysiphonia urceolata	***Spermatochnus paradoxus***	***Phycodrys rubens***	*Xenococcus crouanii* ssp. *roseus*	
Pseudolithoderma extensum	*Sphacelaria plumigera*	***Phyllophora crispa***		
Rhodomela confervoides	*Sphacelaria radicans*	*Plocamium cartilagineum*		
Rhodomela lycopodioides	***Stictyosiphon soriferus***	*Polyides rotundus*		
Rhodophyllis divaricata	***Stictyosiphon tortilis***	***Polysiphonia elongata***		
Sphacelaria plumigera	*Trailliella* – phase of *Bonnemaisonia hamifera*	*Polysiphonia fibrata*		
Sphacelaria radicans	*Ulva lactuca*	*Polysiphonia stricta*		
Ulva lactuca	*Ulva rigida*	*Pseudolithoderma extensum*		
		Pterosiphonia parasitica		
		Rhodophyllis divericata		
		Seirospora interrupta		
		Spermothamnion repens		
		Sphacelaria cirrosa		
		Sphacelaria plumigera		
		Trailliella – phase of *Bonnemaisonia hamifera*		
		Ulva lactuca		
		Ulva rigida		

loose-lying meadows on the sediment surface at Scatsta Ness, and at 23 m this species was the only alga found.

- Association 5 was one of fine filamentous species binding mud and silt in deeper water; the principal species involved were *Audouinella floridula*, *Oscillatoria rosea* and *Trailliella*.

The component species for Associations 1, 3 and 4 at inner voe locations are listed in Table 1.3.

Strong tidal streams run through Yell Sound, and in the sublittoral the islands here have bedrock and stable boulder slopes which drop to a cobble and gravel seabed at about 27 m depth. *Laminaria hyperborea* in the upper infralittoral was replaced by *Desmarestia aculeata* at 17 to 20 m and, as the urchin *Echinus esculentus* was abundant in the infralittoral, there were few foliose algae in the sub-flora (Howson 1988). *Laminaria saccharina* and *Saccorhiza polyschides* occurred sporadically in the lower infralittoral (Berryman 1981; Howson 1988). The circalittoral was heavily grazed with dominant species including encrusting coralline algae, the tubeworms *Pomatoceros triqueter* and *Salmacina dysteri*, the bryozoan *Parasmittina trispinosa*, and the soft coral *Alcyonium digitatum*. In the centre of Yell Sound, the channel floor at 20 to 25 m consisted of very mixed substrata, ranging from bedrock outcrops to cobble, coarse sand and pebble. This area was dominated by horse mussel *Modiolus modiolus* and brittlestars *Ophiocomina nigra* with beds of *Ophiothrix fragilis* from about 30 m downwards. Associated with the *Modiolus modiolus* were a range of hydroids and echinoderms, and the red alga *Phycodrys rubens* blanketed the mussels at Bigga Ruins in the sound.

The southern entrance to Yell Sound is more wave exposed but tidal streams are weaker; communities to the north and south of the entrance were similar. A rock in the entrance had a vertical face dropping to a sand-plain at 50 m. This was dominated by *Alcyonium digitatum*, *Pomatoceros triqueter* and the featherstar *Antedon bifida*. Nearby, a bedrock, boulder, cobble and gravel plain at 20 m was dominated by *Ophiocomina nigra* and *Echinus esculentus* with *Alcyonium digitatum* on the bedrock and the anemone *Metridium senile* and the cushion-star *Porania pulvillus* conspicuous. At these entrance sites, the lower limit of foliose algae was recorded at about 23 m and upward-facing surfaces were grazed and scoured; thus in the infralittoral, erect species were sparse, whereas in the circalittoral these animals were clustered around crevices and projections (Howson 1988).

In the *Laminaria saccharina* forest at the head of Sullom Voe, boulders and coarse sediment supported the urchin *Psammechinus miliaris*, the bryozoan *Scrupocellaria scruposa*, encrusting Bryozoa and the ascidian *Ascidia mentula* (Hiscock 1986). The horse mussel *Modiolus modiolus* is one of the commonest epifaunal organisms in the Voe and is distributed widely throughout Shetland voes (Barnett *et al.* 1975 in ITE 1975e; Pearson, Coates & Duncan 1994). The mussels occur on all substrata at all depths but are most abundant at about 15 m. Their shells provide a stable, hard substratum for a great variety of other epifaunal organisms, such as the brittlestars *Ophiothrix fragilis*, *Ophiocomina nigra* and *Ophiopholis aculeata*, sponges such as *Cliona celata*, ascidians, and particularly *Ascidiella aspersa*, and various species of hydroid, bryozoan and mollusc, particularly the bivalve *Aequipecten opercularis* (Pearson & Eleftheriou 1981). A burrowing holothurian *Thyone fusus* is often associated with the *Modiolus modiolus* beds (Hiscock 1986). The communities associated with these beds and its distribution within Sullom Voe were described in detail in Pearson & Eleftheriou (1981) and Pearson, Coates & Duncan (1994). Growth rates and the biochemical condition of the *Modiolus modiolus* populations in Sullom Voe were described by Comely (1981).

1.7.3.2 Sedimentary substrata

Shallow sand at the heads of the voes in this area had relatively little epifauna. Queen scallops, *Aequipecten opercularis*, the hermit-crab *Pagurus bernhardus* and the starfish *Asterias rubens* were generally common and swimming crabs, the brittlestars *Ophiura albida* and *Ophiura ophiura* and the burrowing starfish *Astropecten irregularis* were often found. Orka, Tofts and Firths Voes had coarse sand and gravel at their heads while Dales and Swining Voes and Colla Firth were more sheltered and muddier. Swining Voe had the greatest variety of epifaunal organisms with additional species such as the spider-crab *Hyas coarctatus*, the gastropod *Neptunea antiqua* and the anemone *Sagartiogeton laceratus* recorded (Barnett *et al.* 1975 in ITE 1975e). The infauna included the bivalves *Fabulina fabula*, *Dosinia lupinus*, *Thracia* spp., the burrowing urchin *Echinocardium cordatum* and holothurian *Labidoplax digitata* at sandier sites, and the bivalves *Arctica islandica* in Dales Voe and *Zirfaea crispata* from Garths Voe and Voxter Voe.

The infauna of Sullom Voe has been subject to baseline surveys (Addy & Griffiths 1976; Pearson 1975 in ITE 1975e; Stanley & Pearson 1976; Pearson & Eleftheriou 1981) and an annual monitoring programme under the auspices of SOTEAG (Addy 1981; May & Pearson 1995; Westwood, Dunnet & Hiscock 1989; Dunnet 1995). The results of separate surveys in Sullom Voe have been documented in a series of limited-circulation reports to SOTEAG. The benthos in an area off Calback Ness where the terminal effluent discharge diffuser is situated has similarly been monitored on an annual basis since 1974 for British Petroleum (Institute of Offshore Engineering 1982, 1988). Benthic samples from Sullom Voe and other voes in the area were collected during a grab sampling programme by DAFS (1963) and these data with some of the above were included in a wider analysis of Shetland infaunal communities by Pearson, Coates & Duncan (1994).

The deep inner basin of Sullom Voe has a high organic content and is subject to intermittent periods of anoxic conditions. This is reflected in the low diversity of the fauna in the deepest parts of this basin and the dominance of the polychaetes *Capitella capitata*, *Scalibregma inflatum* and *Pectinaria koreni*, species characteristic of organic enrichment (Pearson & Eleftheriou 1981). The communities in this basin corresponded with Facies 1 and 2 of the silt/clay community (SH5) defined by Pearson, Coates & Duncan (1994) (May & Pearson 1995). *Modiolus modiolus* occurred on the shallower sides of this basin on muddy sand and gravel and this community corresponded to Facies 3 of the *Modiolus* community (SH1) described by Pearson, Coates & Duncan (1994). The central part of the voe, from Voxter Ness to Calback Ness – Gluss Isle, supported high densities of the epifaunal *Modiolus modiolus* (Pearson & Eleftheriou 1981). The sediment beneath the patches of mussels had a higher silt content than the surrounding open sediment which is sandier and more mixed. Communities here were dominated by the polychaete *Apistobranchus tullbergi*, the oligochaete *Tubificoides benedeni*, and the bivalves *Corbula gibba*, *Thyasira flexuosa* and *Abra alba* in shallower water, Community SH4 of Pearson, Coates & Duncan (1994), whereas in deeper muddy sand and gravel, Community SH3 was widely distributed. Both of these communities were widespread in other parts of the area including Dales Voe, Colla Firth, Swining Voe, Gluss Voe, Garths Voe and off Calback Ness (Pearson, Coates & Duncan 1994).

The outer part of Sullom Voe had shell-sand with *Modiolus modiolus* (SH1) and around Calback Ness, organically enriched shell-sand and gravel (SH2) with species such as *Capitella capitata*, *Mediomastus fragilis*, *Corophium crassicorne* and *Ampelisca typica* present (Pearson, Coates & Duncan 1994). Pearson & Eleftheriou (1981) found fewer *Modiolus modiolus* in parts of this outer area, a preponderance of surface deposit feeders and a greater variety of fish, particularly the long rough dab *Hippoglossoides platessoides*. The area around Calback Ness was divided into four sediment and community types (Addy 1981). Very fine sand held the polychaete *Prionospio malmgreni*, and the bivalves *Thyasira flexuosa*, *Phaxas pellucidus* and *Myrtea spinifera*. Areas of rock and boulders supported horse mussels *Modiolus modiolus* beds with the brittlestars *Ophiothrix fragilis*, *Ophiopholis* *aculeatus* and *Ophiocomina nigra*, coarser mixed sediments held *Urothoë* spp. and *Glycera ?alba* while medium sediments in Orka Voe and west of Mio Ness had the amphipods *Ampelisca* spp. and *Harpinia* spp. and *Phaxas pellucidus*.

In general, communities within Sullom Voe have been stable over the monitoring period although there have been significant changes in a few areas such as the inner basin, where intermittent eutrophication is a naturally occurring phenomenon. In Garths Voe, however, there have been significant changes in the faunal composition over the years of sampling with a continued presence and change in distribution patterns of opportunist species (e.g. Westwood, Little & Dodd 1986). These changes have been attributed to a combination of physical disturbance from shipping and organic enrichment (May & Pearson 1995). Communities and hydrocarbon measurements in Orka Voe have also shown some evidence of mild contamination (May & Pearson 1995).

1.7.4 Marine mammals

Lunna Ness has an otter *Lutra lutra* population, with about one adult per kilometre of coast (Kruuk & Moorhouse 1991). The females lived in groups of up to four while there were fewer males with larger ranges, overlapping those of the females. The otters fished within about 100 m of the shore, the males spending more time on the exposed parts of the coast than the females (Kruuk & Moorhouse 1991). This coastline has a mixture of exposed headlands and sheltered embayments with either *Ascophyllum nodosum*, *Fucus vesiculosus* and *Laminaria saccharina* or *Himanthalia elongata*, *Mastocarpus stellatus* and *Laminaria hyperborea*. The otters fished amongst the algae, preferring areas where there were open spaces enabling access to the algal forests. They spent most of their time fishing in depths of 0–3 m (Nolet, Wansink & Kruuk 1993). As a result, their prey was mostly bottom-dwelling, inshore fish, with the viviparous blenny *Zoarces viviparus* being the most frequent prey species, followed by rockling *Ciliata mustela*, scorpion fish *Taurulus bubalis*, butterfish *Pholis gunnellus* and the fifteen-spined stickleback *Spinachia spinachia*. The blennies were caught more frequently in the sheltered sites; rockling were taken more on the open coast. There were also seasonal variations in the prey caught. It was estimated that the otters took a substantial proportion of the *Ciliata mustela* population (Kruuk & Moorhouse 1990). The main prey species were inactive at the time of day that the otters hunted, hiding under stones and amongst algae. It also seemed that if an area was fished out, it was repopulated from adjacent areas within 24 hours (Kruuk, Wansink & Moorhouse 1990). There was a strong correlation between the abundance of the main prey species in July and August and the subsequent number of otter cubs.

Grey seals *Halichoerus grypus* and common seals *Phoca vitulina* feed and breed in the area and there are important seabird breeding colonies. Yell Sound is a cetacean migration route; there have been many whale sightings reported and small schools of porpoise *Phocoena phocoena* are often observed (Sullom Voe Oil Spill Advisory Committee 1992).

1.8 Fair Isle

1.8.1 Introduction

Fair Isle (Figure 1.6) lies about 40 km south of Sumburgh Head, mid-way between Shetland and Orkney. It is separated from Orkney by the Fair Isle Channel, which is over 100 m in depth, and lies with the rest of the Shetland Island group on a shallower platform of rock. It has an exposed rocky coastline with numerous promontories, geos and stacks. Inlets on the east side, North and South Haven, are protected by the dual headlands of Ba Ness, and landing sites are located in these bays. There are steep cliffs on the north and west coasts while the south-east is lower-lying. Most of the island is extremely exposed to wave action although the east coast is less exposed than the Atlantic west coast. Tidal streams are of moderate strength around headlands but are negligible elsewhere. A list of the marine algae of Fair Isle was published by Burrows (1963).

1.8.2 Littoral

Exposed rocky shores on Fair Isle had an algal zonation with bands of macroalgae growing at up to 8 m above sea level, although the tidal range is only about 2 m (Burrows *et al.* 1954; Howson 1988; Powell 1957b; Figure 1.10). This considerable upward extension of the littoral zone was attributed to a combination of continual swell and damp climatic conditions (Burrows *et al.* 1954). The dominant algae on an exposed rocky headland at North Gavel were *Blidingia minima*, *Porphyra umbilicalis* and *Fucus spiralis* f. *nana* in the upper shore zones, *Fucus distichus* in the mid-shore and *Mastocarpus stellatus*, *Alaria esculenta* and coralline crusts on the lower shore and in the sublittoral fringe. The mid-shore was animal rather than plant-dominated, with barnacles *Semibalanus balanoides*, mussels *Mytilus edulis* and limpets *Patella aspersa* (Powell 1957b). The adjacent North Haven was sheltered and included areas of sand, boulders, a concrete slipway and rock walls around the sides. The algae here were more characteristic of sheltered shores and on the slipway there was a band of the more unusual *Fucus evanescens* in the mid and lower shore. The upper shore supported *Blidingia minima* and *Fucus spiralis*, the mid-shore had *Ascophyllum nodosum* and *Fucus vesiculosus* and the lower shore *Fucus evanescens* and *Fucus serratus* (Burrows *et al.* 1954; Powell 1957b). Several more shores were surveyed in 1987 by the MNCR when very similar patterns were found and more detail was given on the animal populations of the shores (Howson 1988). The less exposed shores in North and South Haven had the kelps *Laminaria digitata* and

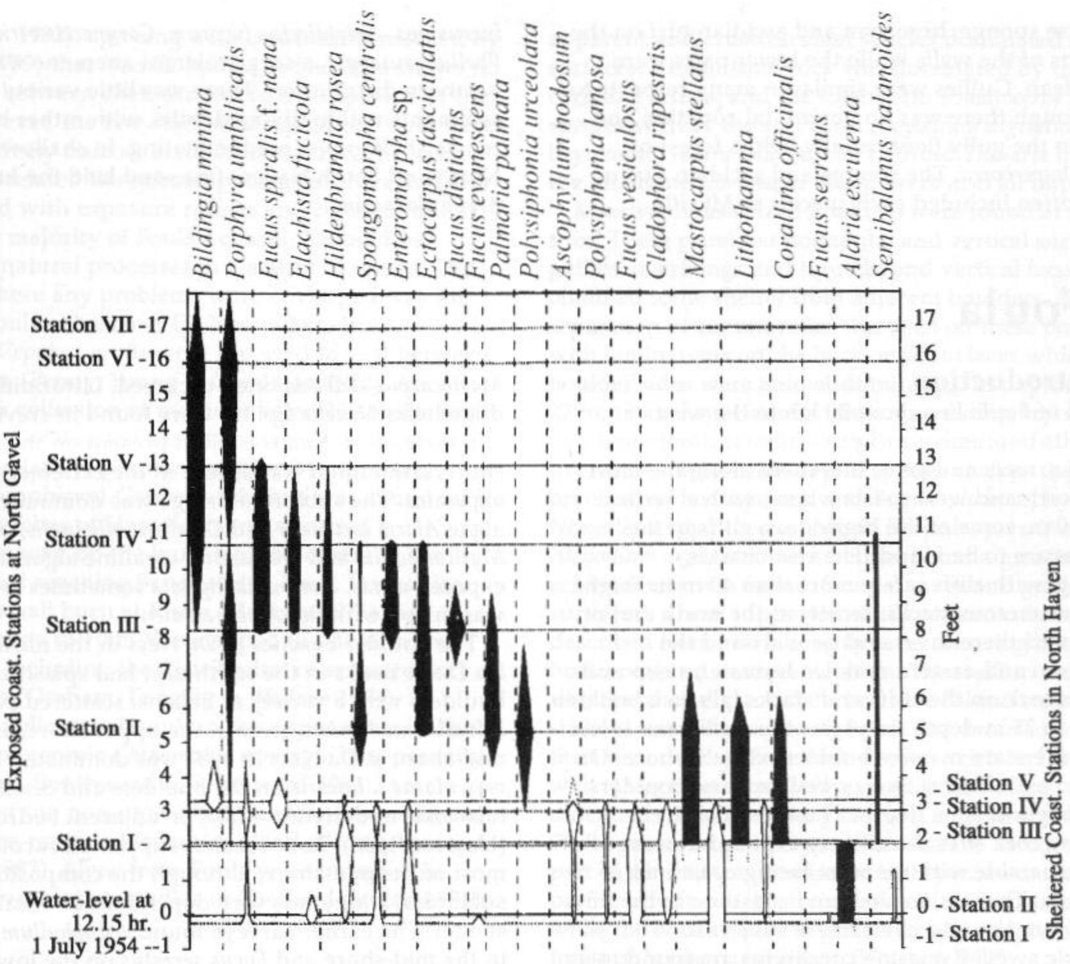

Figure 1.10. Occurrence and zonation of intertidal algae at two locations on Fair Isle. North Gavel (black kites) is very exposed to wave action and North Haven is sheltered. Heights are in feet. Based on Burrows *et al.* (1954) and using most recent nomenclature.

Laminaria hyperborea in the sublittoral fringe, rather than *Alaria esculenta*, and *Fucus vesiculosus* f. *linearis* was found in South Haven. A headland at Tail of Uran, on the exposed south-west corner of the island, had enabled the development of communities ranging from the most exposed, barnacle dominated rock to the most sheltered, with *Ascophyllum nodosum* in the mid-shore (Howson 1988). Scattered barnacles *Chthamalus stellatus* were found on the upper mid-shore at exposed sites (Howson 1988; Powell 1954b); these and other records in Shetland represent the northern limits of the species' known range (Powell 1954b). In June, there were few of the summer annual algae normally found on other British shores; it was suggested that this was attributable to the later onset of summer at this latitude (Burrows *et al.* 1954). However, subsequent workers in Shetland have commented on the generally lower species diversity in the islands (Maggs 1986).

1.8.3 Sublittoral

Surveys of the sublittoral zone of Fair Isle appear to be limited to those reported by Howson (1988) and the following descriptions are based entirely on that report. Steep bedrock continues around the north and west coasts into the sublittoral, being replaced at about 38 m depth by rippled shell-gravel with bedrock outcrops and boulders. On the south coast, this boundary occurs at 31 m and on the east coast at 24 to 28 m (Howson 1988). *Alaria esculenta* in the sublittoral fringe extended to a depth of 12 m while kelps reached 22 m on the east of the island and at least 30 m elsewhere. *Laminaria hyperborea* in the infralittoral was often replaced by *Laminaria saccharina* and *Saccorhiza polyschides* in the lower infralittoral. At most sites, there was a dense understory and stipe flora with little grazing by the urchin *Echinus esculentus* in the exposed conditions. Exposed cliff faces supported the soft coral *Alcyonium digitatum*, the tubeworm *Pomatoceros triqueter* and the bryozoan *Parasmittina trispinosa*, as did tide-swept bedrock and boulders. Sheets of the jewel anemone *Corynactis viridis* were found amongst the *Alcyonium digitatum* in the latter situation.

Caves, arches, gullies and geos were particular features of the shallow sublittoral around Fair Isle and these supported a range of surge-tolerant organisms. Dense algae were usually found on boulders at the cave entrances where there was adequate light, with species such as *Polysiphonia urceolata* (now *Polysiphonia stricta*), *Odonthalia dentata*, *Plocamium cartilagineum* and *Desmarestia aculeata* common. The walls supported the barnacle *Balanus crenatus*, *Alcyonium digitatum* and the anemone *Metridium senile*. Farther inside the caves, there was a dense sponge, bryozoan and ascidian turf on the upper parts of the walls while the lower parts were abraded clean. Gullies were similar in many respects to caves although there was no horizontal zonation and boulders in the gully floor usually held a forest of *Laminaria hyperborea*. The sponge and ascidian turf on the walls often included such species as *Myxilla incrustans*, *Amphilectus fucorum*, *Corynactis viridis* and *Phellia gausapata*, a surge-tolerant anemone with a northern distribution. There was little variety of sediments within diving depths, with rather barren coarse shell-gravel predominating. In shallow water in North and South Haven, fine sand held the lugworm *Arenicola marina*.

1.9 Foula

1.9.1 Introduction

The island of Foula lies about 20 km to the west of Shetland. Its impressive rocky coastline is dominated by cliffs, stacks, reefs and geos. It is sheer along the most exposed north and west coasts where, with a vertical drop of 360 m, some of the highest sea cliffs in the British Isles are to be found. The east coast is lower-lying, with cliffs rarely more than 40 m in height. There are numerous stacks, mostly at the north end of the island and there caves and geos around the south-eastern and eastern end. Underwater, steep and vertical bedrock on the cliffs and stacks falls to a boulder floor at 30 to 35 m depth. In places the sublittoral is less steep and there are massive boulders close inshore. On the north coast off Arva Skerry, bedrock and boulders extend to beyond 50 m depth. These west and north-facing rock sites are all very exposed to wave action, comparable with the west facing coastlines of other islands. There is no sheltered coastline as the only inlet is at Ham Voe and even this is subject to considerable swell. Estuarine conditions are found in a small area of the Voe where Ham Burn enters the sea and sand, boulders and a small amount of mud are present (Penny, Young & Goodman 1982). There are moderate tidal streams around the headlands and on the east coast. A few kilometres off the east coast lies Shaalds Reef, an area of shallow water with a strong tidal flow.

1.9.2 Littoral

The shores of Foula are inaccessible, except by boat, along the cliffs of the north and west coasts, and so no biological data are available for these. The remaining shoreline consists of smaller exposed rocky cliffs, shelving reefs, gullies and boulder beaches and the descriptions given below of the communities they supported have been compiled from Howson (1988) and Penny, Young & Goodman (1982). Results of the latter's work in 1980 were summarised by Wilson (1980) and in 1981 by Penny & Brook (1981). The lichen *Verrucaria maura* and the gastropod *Littorina saxatilis* extended well up into the splash zone. A band of blue-green algae was found at some sites in the littoral fringe, and the upper shore usually supported a band of *Porphyra umbilicalis*, often with the barnacles *Semibalanus balanoides* and *Chthamalus stellatus*, limpets *Patella vulgata*, and the alga *Cladophora rupestris*. There was normally a distinct band of *Semibalanus balanoides*, mussels *Mytilus edulis* and limpets *Patella vulgata* in the mid-shore, although communities could be patchy and dense stands of the algae *Palmaria palmata*, *Porphyra umbilicalis* and *Mastocarpus stellatus* often occurred. Littorinids and dogwhelks *Nucella lapillus* were found in crevices. *Himanthalia elongata* was often present on the lower shore, although it was absent in the extremes of wave exposure. The sublittoral fringe was dominated by the algae *Alaria esculenta* and *Corallina officinalis*, mussels *Mytilus edulis* and encrusting coralline algae. In less exposed areas, *Laminaria digitata* sometimes replaced or was mixed with the *Alaria esculenta*.

The boulder beaches at Da Ness in the north-east and Da Doon Banks in the south-east had splash zone boulders with a variety of lichens; scattered patches of *Pelvetia canaliculata* grew in the upper shore, and the mid-shore at Da Ness in 1987 was dominated by *Fucus vesiculosus* f. *linearis* on the boulders and *Semibalanus balanoides* and *Mytilus edulis* on adjacent bedrock (Howson 1988). Both beaches supported fucoids across most of the mid-shore, although the composition of the sublittoral fringe was very dependent on localised shelter. The earlier surveys found *Ascophyllum nodosum* in the mid-shore and *Fucus serratus* on the lower shore (Penny, Young & Goodman 1982). Boulders on the lower shore supported the sponges *Halichondria panicea* and *Hymeniacidon perleve* together with the anemones *Urticina felina* and *Actinia equina*. *Laminaria digitata* and *Laminaria saccharina* grew in the sublittoral fringe at Da Doon Banks although *Alaria esculenta* was dominant a short distance away. It was felt that the communities on the boulder storm-beaches might be prone to damage in winter and so may be variable from year to year (Davies *et al.* 1990; Howson 1988).

At Trolli Geo, the effects of some freshwater run-off from a marsh and a small amount of sewage from a croft were apparent (Penny, Young & Goodman 1982). The sublittoral fringe and lower shore were typical of exposed rocky shore communities but the mid-shore had extensive cover of green algae and there were mats of *Vaucheria* sp. on upper shore boulders. In estuarine conditions at Sloag Burn and Ham Voe there was a range of green algal species including *Ulothrix* spp., *Enteromorpha* spp. and *Blidingia minima*. *Fucus serratus* and *Fucus spiralis* f. *nana* were present at Sloag Burn. There are numerous rockpools on the shores, some of which are quite large. These supported a wide range of species including sticklebacks, conger eels *Conger conger* and the eel *Anguilla anguilla* and were often lined with coralline crusts. They illustrated the principle that an increase in wave exposure raises the height at which species are found on the shore.

A study of shell shape in the dogwhelk *Nucella lapillus* was carried out at five stations on Foula (Penny, Young

& Goodman 1982), agreeing with conclusions reached by Crothers (1979) that *Nucella lapillus* in Shetland shows no correlation between shell shape and the exposure of the shore. However, the few stations sampled on Foula were from a relatively narrow band of exposures. The same workers correlated the geomorphological characteristics of the island with exposure ratings and concluded that, if oiled, the majority of Foula's coastline would be cleaned by natural processes in a matter of weeks. The only site where any problems were envisaged was the northern boulder beach at Da Ness where black guillemots *Cepphus grylle* were reported to nest between the boulders (Penny, Young & Goodman 1982). An account of a collection of molluscs listed 35 species and their habitats and noted that there were few bivalves owing to the lack of permanent littoral sand (Skene 1973). The amphipod *Gammarus duebeni* was abundant in the lower reaches of Ham Burn and occurred a considerable way up the burn into the centre of the island, almost reaching Sandvadden Loch. It was also found in a small burn at Ristie (Mooney 1971). A physical survey of Ham Voe mapped the depths, the substratum including the distribution of seaweed (*sic*) and hazards (Graham, Langley & Wallace 1974). *Chthamalus stellatus* is found on the upper shore in Foula while the congeneric *Chthamalus montagui* is apparently absent (Crisp, Southward & Southward 1981). An individual of the non-native barnacle *Elminius modestus* has also been recorded from the island (Penny, Young & Goodman 1982). Algae from Foula were included in macroalgal vegetation studies in Shetland (Irvine 1974b).

1.9.3 Sublittoral

The sublittoral environment of Foula appears to have been described only by MNCR surveys, reported by Howson (1988) and the descriptions below are based entirely on that report. Bedrock reached a depth of 30 to 35 m, where it was replaced by boulders; inshore on the east coast, the seabed consisted of shelving bedrock ridges. There was very little sediment seen. The infralittoral was dominated by kelp *Laminaria hyperborea* which was replaced by *Laminaria saccharina* in the lower infralittoral, the kelps extending to 30 m. Luxuriant foliose algae, particularly *Kallymenia reniformis, Delesseria sanguinea* and *Plocamium cartilagineum,* formed the understory, reaching 26 m at which depth the effects of grazing by sea-urchins *Echinus esculentus* became apparent and crustose algal species dominated the rock surfaces. Circalittoral rock was dominated by these coralline crusts, and the tubeworm *Pomatoceros triqueter;* species such as the soft coral *Alcyonium digitatum,* the bryozoan *Flustra foliacea,* the hydroid *Thuiaria thuja* and the anemone *Corynactis viridis* were also all important.

Massive, house-sized boulders were found at several sites. These provided horizontal and vertical surfaces, gullies, overhangs and tunnels, and vertical faces obtained some shelter from adjacent boulders. A distinct separation of communities was seen on these boulders with laminarians on the horizontal surfaces while the boulder sides were animal-dominated. In depths down to 27 m, several species of sponge, encrusting bryozoans and tubeworms were found, with the anemone *Urticina felina* in crevices. Below this depth, species such as the bryozoans *Flustra foliacea* and *Bugula plumosa,* hydroids *Nemertesia* spp., the amphipod *Dyopedos porrectus* and *Alcyonium digitatum* were frequent, and a great variety of echinoderms was found. Several caves and gullies were surveyed. These supported similar communities to those described from Fair Isle, with caves showing both horizontal and vertical zonation. The walls in these situations had algae and the barnacle *Balanus crenatus* in shallow water, *Alcyonium digitatum* and dwarf individuals of the anemone *Metridium senile* deeper, a rich turf below this with sponges such as *Clathrina coriacea,* ascidians including didemnids and *Dendrodoa grossularia* and the anemones *Phellia gausapata* and *Corynactis viridis.* The abraded lowest part of the wall was dominated by bryozoan crusts, particularly *Parasmittina trispinosa* and *Escharoides coccinea* while the boulder floor in gullies usually supported a dense forest of *Laminaria hyperborea* (Howson 1988).

Extensive pebble, cobble and gravel beds were found on the east coast of Foula. These were tide-swept and very rich in species, being dominated by echinoderms. Several interesting species were found here including the brittlestars *Amphiura securigera* and *Ophiura robusta,* the holothurian *Neopentadactyla mixta,* and the gastropod *Melanella alba.* A sand-plain with bedrock outcrops was found beyond these gravel beds. This was fairly barren but there were sand-eels present which are fished commercially (Gammack & Richardson 1980). Where boulders were mixed with patches of shell-gravel, sparse beds of the brittlestar *Ophiocomina nigra* occurred and scour-tolerant species such as the hydroid *Abietinaria abietina* and the bryozoans *Securiflustra securifrons* and *Flustra foliacea* were common (Howson 1988).

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Chapter 2: Orkney (MNCR Sector 2)*

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Synopsis

The Orkney islands are situated a short distance across the Pentland Firth from the mainland of Scotland and consist of a few large and many small islands enclosing some extensive sheltered areas. The coast is predominantly rocky and supports intertidal communities ranging from those characteristic of extreme exposure to wave action to some extensive algal-dominated shores which are extremely sheltered. However, there are some extensive sandy beaches, some with a rich sediment fauna. The Loch of Stenness and Loch of Harray are very large lagoonal habitats and there are several smaller lagoonal habitats in Orkney. Subtidal habitats on the open coast include extensive shallow rocky areas dominated by kelp forests as well as deeper, usually tide-swept, animal-dominated habitats. In wave-sheltered areas, silted rocks are more restricted to shallow depths where they support sparse, often grazed, kelp forest. There are many deep caves especially on the west coast of Hoy and these contain a variety of characteristic biotopes. The tide-swept Wyre and Rousay Sounds include rich maerl communities. Scapa Flow has sheltered sediment communities and a large amount of artificial substrata in the form of sunken warships.

2.1 Introduction

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

A general review and description of the climate and marine environment of the Orkney Islands was provided by Jones (1975). The climate is temperate, with average air temperatures ranging from –4.5 °C in winter to 20 °C in summer, and sea surface temperatures ranging from a minimum of 5 °C in February to a maximum of 13 °C in July. The average annual rainfall is 90 to 100 cm and humidity is the highest in the UK, being 80% to 90% for most of the year. The prevailing winds vary from the west to south-east. The lack of extreme temperature fluctuations and the relatively damp atmosphere allows the development of diverse littoral communities Jones (1975).

The Orkney Islands are influenced by the North-East Atlantic Drift which carries warm water northwards along the west coast of Britain. Tidal streams flow clockwise around the islands. The depth of water around and between the islands is less than 50 m except off the west coast of the mainland where the seabed shelves steeply. The seabed between the islands consists of rock, boulders, gravel, sand and occasional deposits of mud, while the substrata of tide-scoured sounds are rock, shell-gravel or sand (Jones 1975). Shores are predominantly composed of bedrock or boulders with sand in the bays. The configuration of the islands and inlets gives rise to a range of wave exposure on the shores and shallow sublittoral, varying from very sheltered between the islands to very exposed on the west coast. Strong tidal streams occur around the Pentland Firth, and around the northern islands, with speeds of up to of 9 knots (4.5 m s^{-1}) on the flood tide in Pentland Firth (Jones 1975).

Scapa Flow is an expanse of sea almost completely enclosed by islands. It has been valued as a sheltered anchorage for centuries, and was further enclosed

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

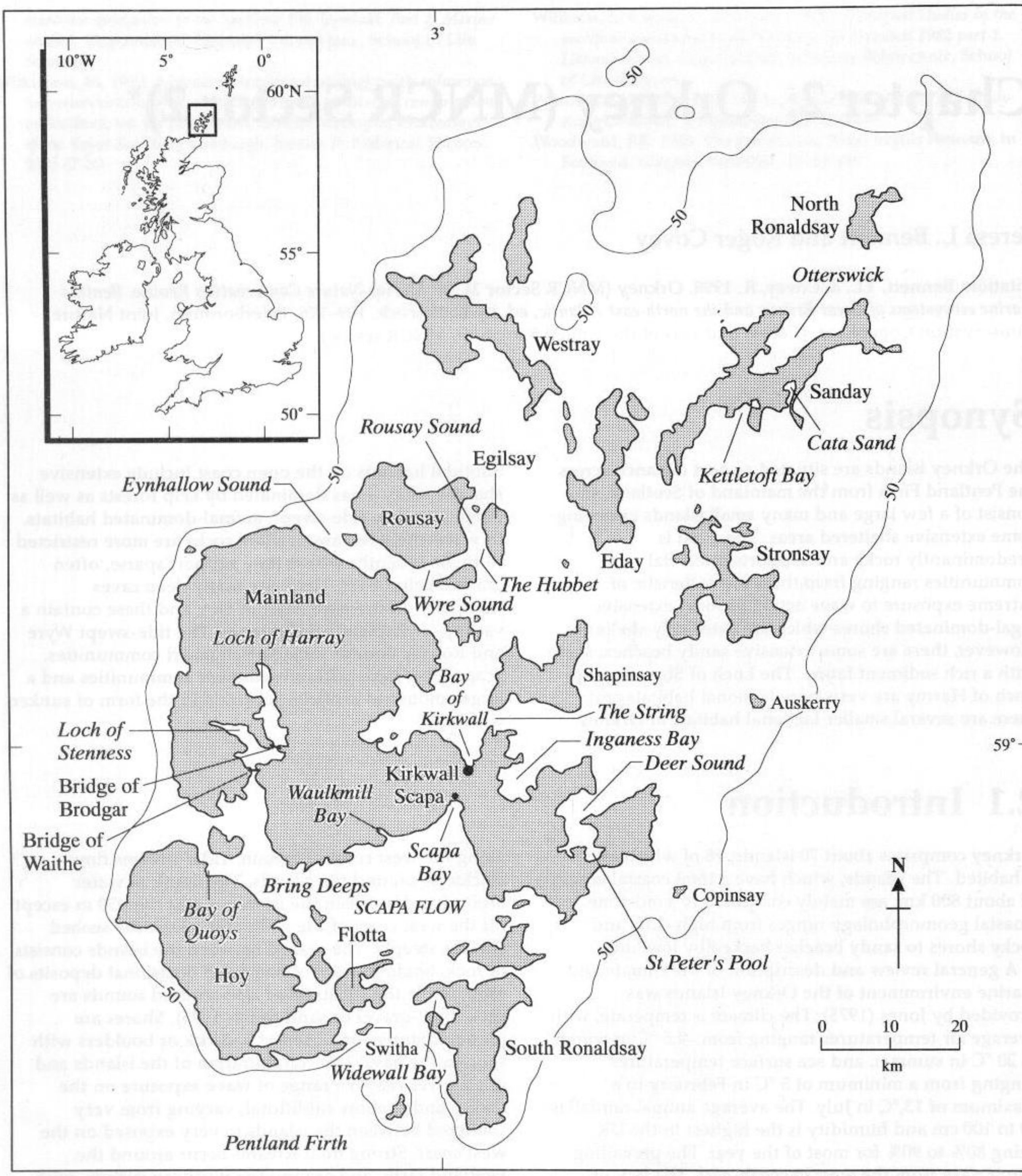

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Figure 2.1. The Orkney islands showing location of places mentioned in the text.

during World War II by the construction of the Churchill Barriers, causeways linking Orkney Mainland to South Ronaldsay.

There are two brackish-water lochs on the mainland of Orkney, Loch of Stenness and Loch of Harray, although tidal flap valves prevent saline incursion to Loch of Harray at present. A number of other smaller saline lagoons, known locally as Oyces, or Ayres, are present.

Most surveys undertaken in Orkney have been of a range of coastal areas and the following section is not therefore subdivided into areas.

2.2 Studies of the marine environment and communities

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

Orkney was rather less affected than Shetland by developments associated with the North Sea oil industry in the 1970s. However, the siting of an oil terminal at Flotta in Scapa Flow resulted in the establishment of the Orkney Marine Biology Unit (OMBU) at Scapa by the University of Dundee in 1974. This provided the impetus for many of the more recent studies of marine ecology, monitoring projects and impact studies. Following the proposal for an oil terminal at Flotta, an environmental assessment of the littoral fauna and flora and benthic sediments and fauna was undertaken (Jones & Stewart 1974). Subsequently, the Orkney Islands Council commissioned the University of Dundee to initiate an independent monitoring programme of Scapa Flow and its approaches in order to detect any deterioration in the marine environment owing to industrial development, particularly from the oil industry.

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

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

A Royal Society of Edinburgh symposium on the Marine Biology of Orkney in 1984 summarised all environmental studies at the time (Jones 1985). Most marine studies were related to commercial ventures in the area. Johnston (1985) outlined the potential for revitalising the seaweed industry and harvesting seaweeds (predominantly *Laminaria hyperborea*). The fisheries were described by Mason *et al.* (1985), who reported that local vessels tended to be small and fished mainly for inshore shellfish. Seals formed an important resource for both domestic use and export in past centuries, and the grey and common seal populations around Orkney were described by McConnell (1985). Other papers relating to the marine environment covered seabirds and otters (Reynolds 1985) and pollution (Davies 1985).

The conservation status of four estuarine bays (Otterswick, Cata Sand and Kettletoft Bay on Sanday, and Deer Sound/Peter's Pool on Orkney Mainland) was reviewed by Buck (1993), while 17 enclosed lagoons were surveyed in 1994 as part of the MNCR's survey of isolated saline waters in Scotland (Thorpe in prep.).

The volume on *The islands of Scotland: a living marine heritage* (Baxter & Usher 1994) includes Orkney in descriptions of the physical environment, benthic marine biology, marine mammals and fisheries.

Surveys of the coast of Orkney were commenced by the MNCR in 1995 and will be completed in 1997. Some of the main observations from those surveys are noted here.

Scottish Natural Heritage (SNH) commissioned a remote mapping survey of Rousay and Wyre Sounds off the north-east mainland to assess the extent and nature of maerl communities in that area (Foster-Smith & Davies 1993). In 1996, quantitative sampling was undertaken by SNH of maerl communities in Wyre Sound to assess the impact of maerl extraction.

2.2.1 Fauna

The earliest published marine biological records for the Orkney Islands were made by the Rev. James Wallace in 1693 and his son Dr James Wallace in 1700. They produced descriptions of the Orkney Islands including observations on the marine life. The nomenclature for the list of Mollusca prepared by Dr James Wallace was updated and republished by Rendall (1948). Low (1813) published a book on the fauna of Orkney which included descriptions of seals and fish. In 1830 Thomas Stewart Traill published a paper on the Orkney Islands which also contained a catalogue of marine fauna including a list of 58 molluscs. This list was updated and republished by Rendall (1953). Later, all records on the Mollusca of Orkney from shore surveys and dredging were brought together by Rendall (1956).

2.2.2 Flora

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

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

The marine algal flora of Orkney was reviewed by Maggs (1986) and was found to include elements of northern, east and west coast floras, with a number of species reaching their limit of distribution on the islands. Algal communities on Orkney were considered to be well developed for the Northern Isles compared with the Shetland Islands (Irvine 1974).

The Orkney Islands have a history of making 'kelp' (Thompson 1983). In the past, washed up *Laminaria* stipes and fucoids were collected from the beaches and then burnt in pits to make 'kelp' which was then used as a fertiliser. The seaweed industry, which started in 1719 for the production of soda, potash and iodine, ended in 1935 when iodine became cheaply available elsewhere (Johnston 1985). After World War II, a factory (since closed) was established at Kirkwall for the production of fertilisers and seaweed meal for animal feedstuffs (Jones 1975). Small-scale collection of beached seaweed for the alginate industry continues. This amounts to several hundred tonnes (dry weight) of *Laminaria* per annum, gathered by about 150 people working part-time (R. Searle pers. comm.). The potential for revitalising the seaweed industry has been considered by several authors (Walker 1981; Thompson 1983; Johnston 1985). The dense laminarian beds which occurred in fairly sheltered water were considered suitable for harvesting (Walker 1947, 1950), with the sublittoral fringe and upper infralittoral supporting abundant kelp species including *Alaria esculenta, Laminaria digitata, Laminaria hyperborea, Laminaria saccharina* and *Saccorhiza polyschides*. Walker (1950) was mainly concerned with quantifying laminarians in relation to depth to determine their productivity. The viability of harvesting kelp around the Orkney Islands was further assessed by Walker (1981). It was estimated that Orkney could supply one million tonnes of raw seaweed per year, allowing a seven-year regrowth period if all areas were exploited in rotation. The seaweed resource of the Orkneys was also described by Johnston (1985), who considered *Laminaria hyperborea* to be the main seaweed with commercial potential in Orkney. The shelf on which the Orkney Islands sit was thought to provide the appropriate substratum and to be of suitable depth for the growth of laminarians (Figure 2.2). Proposals have been put forward to redevelop the seaweed industry in Orkney (Institute of Offshore Engineering 1986), and research is continuing.

2.2.3 Littoral habitats

Shores of Orkney range from those exposed to extreme wave action on the west coast to very sheltered conditions between the islands. Table 2.1 shows the composition of different shore types calculated for the Orkney Islands (Baxter, Jones & Simpson 1985). Fuller & Baxter (1994) described the general nature of shores on Orkney and have compared and contrasted the communities found there with those found on Shetland and the Outer Hebrides.

Table 2.1 The proportion of different shore types found in Orkney (data extracted from Baxter, Jones & Simpson 1985)

Shore type	Percentage
Very exposed shores	14
Barnacle-dominated shores	17
Barnacle/fucoid-dominated shores	8
Fucoid-dominated shores	24
Ascophyllum-dominated shores	21
Sandy shores	12
Shingle shores	4

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

The sandy beaches of Orkney were surveyed by Mather, Smith & Ritchie (1974). The aim of this study was to examine the physical characteristics of sediment shores with regard to their stability and the effect of human impacts on them. Each beach on each island was described in terms of topography, habitats, land use, access and recreation.

The fauna of 14 sandy shores located throughout the Orkney Islands (seven of which were in Scapa Flow) was surveyed by Atkins, Jones & Simpson (1985). The beaches consisted of clean, fine to medium grade sand. All were dominated numerically by polychaetes and amphipods. The main species recorded were the polychaetes *Pygospio elegans* and *Capitella capitata* and the amphipod *Bathyporeia* spp. The Bay of Quoys, Hoy, was found to be the most interesting site sampled. The shore was unique in being dominated by the polychaetes *Leiochone* (now *Clymenura*) *johnstoni* and *Euclymene* (now *Praxillella*) *affinis* with the occurrence of the normally sublittoral *Polydora* (now *Pseudopolydora*) *antennata* and a diverse assemblage of amphipods. Scapa Bay and Waulkmill Bay were sampled at four- to eight-week intervals over a four-year period between 1982 and 1986 to detect seasonal fluctuations in faunal

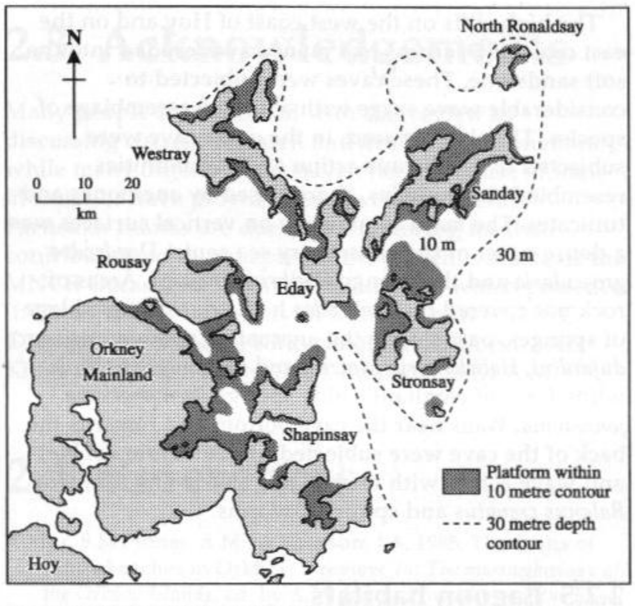

Figure 2.2. The northern islands of Orkney showing the platform suitable for laminarian growth with 10 m and 30 m contours (Johnston 1985). (Reproduced by permission of the Royal Society of Edinburgh and C.S. Johnston from *Proceedings of the Royal Society of Edinburgh*, 87B.)

composition (Atkins, Simpson & Jones 1989). They described major fluctuations in the faunal density throughout the year, owing to seasonal recruitment and mortality. A protocol for benthic monitoring was suggested, involving a monthly sampling programme in the initial year of study, followed by annual sampling at the time of year when the fauna is at a baseline state, i.e. between mortality and recruitment.

Monitoring by the Orkney Marine Biology Unit in and around Scapa Flow has involved studying transects on both rocky and sedimentary shores to record the distribution and abundance of species, as well as single-species investigations. Communities on rocky shores were found to be stable. However, faunal population changes were detected in sediment shores (Jones *et al.* 1982).

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

A few studies have been made on other islands including the molluscs of Copinsay (Smith 1973) and a description of the Hubbet on the west coast of Egilsay (McMillan 1972). The Hubbet is a long, almost land-locked inlet of the sea with a saltmarsh at its head and a muddy sandy beach towards its seaward end. Saltmarsh vegetation and algae were recorded and the green alga *Codium* sp. was found to occur in profusion.

The MNCR surveyed 36 sites on the Orkney mainland and Hoy, sampling sites from the very exposed cliffs of Hoy and west Rousay to the very sheltered embayments of Deer Sound (Murray *et al.* in prep.). Cliffs very exposed to wave action were found to be species poor, with only a few species adapted to such harsh conditions. These shores were predominantly mussel and barnacle dominated with the fucoid *Fucus distichus* occurring at some sites. The sounds and embayments had horizontal, stepped bedrock shores with rich fucoid growth and sublittoral fringe communities dominated by *Laminaria digitata*, which were species-rich in areas where there was increased tidal movement. Very sheltered sediment communities in Deer Sound had a rich infauna dominated by polychaetes and the cockle *Cerastoderma edule*, with the seagrass *Zostera marina* occurring on the lower shore at St Peter's Pool.

2.2.4 Sublittoral habitats

Sublittoral surveys of the Orkney Islands by SCUBA diving were carried out in 1978 and 1979 by members of the Underwater Conservation Society (Dipper 1984). Sites were surveyed on the west coast of Orkney Mainland and Hoy, with more extensive coverage in Scapa Flow. The substrata of the exposed west coast sites was predominantly bedrock. In the more sheltered conditions of Scapa Flow there were boulder slopes leading onto sediment plains. Sites south of Scapa Flow, off the islands of Flotta and Switha, consisted of large boulders or bedrock subject to strong tidal flow. Kelp forests of *Laminaria hyperborea* with well developed growths of epiphytes and a red algal understory occurred to a depth of 20 m off the west and south coasts. Dense growths of hydroids and bryozoans were characteristic of the south coast sites in the strong currents. Within Scapa Flow, the kelp forest, where it occurred, only extended down to 10 m and there were few epiphytes on the stipes. The common sea-urchin *Echinus esculentus* was found to graze algal populations below the kelp forest, leaving extensive areas of encrusting coralline algae. Horse mussel *Modiolus modiolus* beds with an associated faunal community were recorded in Scapa Flow. Several of the species noted were new records for Orkney: the boring sponge *Cliona celata*, the jewel anemone *Corynactis viridis*, the Devonshire cup coral *Caryophyllia smithii*, the anemone *Actinothoë sphyrodeta* and the starfish *Stichastrella rosea*.

As part of a benthic survey of the north Scottish coast and Orkney, the Department of Agriculture and Fisheries for Scotland undertook a survey of Scapa Flow in 1975 (D. Muirison & D. Moore pers. comm.). Samples of the benthos were taken from 22 stations, trawls were made across Scapa Flow and video recordings were made of the seabed. The sampling procedure was repeated by the University of Dundee in 1986 (Jones *et al.* 1988) and the sediment characteristics and fauna described. For most of the seabed the sediments were found to be variable with an uneven distribution of species. However, the north-eastern area of Scapa Flow (stations 20 to 23, and 11) was characterised by fine sediment supporting fewer species and individuals compared with other parts of the basin. In the east (stations 9 and 9A) the sediments were very coarse and had the greatest species diversity. Abundant populations of the mollusc *Chaetoderma nitidulum* and several species not previously recorded from Orkney were found.

In 1990, de Kluijver (1993) investigated the sublittoral hard substratum communities at 18 sites around Orkney, and identified seven community types. These were classified on the basis of their sessile marine biota, which reflected differences in tidal streams, wave exposure and light intensity. On wave-exposed coasts, *Laminaria hyperborea* dominated the photic zone, while with increasing shelter it was replaced by *Laminaria saccharina* and a range of green algae. Below the photic zone, communities were dominated by suspension-feeders in areas with water movement, and by encrusting red algae in sheltered areas with little or no water movement.

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

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

One hundred and thirty-one sublittoral sites have been surveyed by the MNCR on the Orkney mainland and Hoy (Murray *et al.* in prep.). The West coast of Hoy and Rousay are very exposed to wave action and kelp forests are generally species-rich with an understory rich in anemones and ascidians. Vertical faces in the kelp forests had a rich mosaic of colonial ascidians, encrusting sponges and the anemones *Corynactis viridis* and *Actinothoë sphyrodeta*. Rocky habitats in deep water on the west coast supported circalittoral communities of *Flustra foliacea* and *Alcyonium digitatum*.

Tide-swept sounds of the Bring Deeps, Eynhallow, Rousay and Wyre Sounds and The String are relatively shallow and moderately exposed to sheltered from wave action. Communities on rock were characterised by tide-swept mixed kelp forests rich in red algae, ascidians and sponges. Areas of rock adjacent to sediments and areas of mixed sediment experienced a large degree of sand scour and supported a sparse mixed kelp forest with the more opportunistic kelp species *Laminaria saccharina* and *Saccorhiza polyschides* and scour-tolerant red algae. Maerl communities in Wyre and Rousay Sounds had a high abundance of maerl *Phymatolithon calcareum*, with an associated community of brown algae and infauna of bivalves. Coarse sand and gravel supported dense beds of sabellid fanworms and the bivalves *Ensis* spp.

Deer Sound on the south-east mainland was predominantly of shallow sublittoral sediment experiencing a wide range of wave exposures owing to the complexity of the coastline. Coarse sand in the outer basin was relatively species-poor with sand-eels dominating the infauna. Fine sand and mud in the inner basin had a rich infauna dominated by polychaetes, particularly *Arenicola marina*. St Peter's Pool at the very southern end of the sound had an extensive area of shallow mud with very dense *Zostera marina* beds and a large number of the ascidians *Ascidiella aspersa*, *Ascidia mentula* and *Ciona intestinalis* attached to the blades. Small areas of shallow, silted rocky reef in the Sound supported sparse kelp forests, often of the caped forms of *Laminaria hyperborea* and *Laminaria saccharina*, and ephemeral brown algae such as *Desmarestia* spp. These areas were generally species-poor and often grazed by *Echinus esculentus*.

The high cliffs on the west coast of Hoy and on the east coast of Deerness had many caves eroded into the soft sandstone. These caves were subjected to considerable wave surge with a unique assemblage of species. The shallow areas in the outer cave were subjected to some wave action and communities resembled surge gullies, charcterised by anemones and tunicates. The main community on vertical surfaces was a dense cover of the gooseberry sea squirt *Dendrodoa grossularia* and the sponge *Clathrina coriacea*. Areas of rock not covered by *Dendrodoa* had a dense assemblage of sponges, particularly the encrusting sponges *Halisarca dujardini*, *Halichondria panicea*, and the cave-dwelling white form of elephant's hide sponge *Pachymatisma johnstonia*. Walls near the cave bottom and towards the back of the cave were subjected to scour from cobbles and wave action with very sparse encrusting fauna of *Balanus crenatus* and spirorbid worms.

2.2.5 Lagoon habitats

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

Following fish-kills in Loch of Harray caused by blooms of blue-green algae, in 1968 tidal flap valves were fitted to the Bridge of Brodgar sluices, which separate the Lochs of Harray and Stenness (Birkenshaw 1994). This resulted in a complete cessation of saline water entering Loch of Harray, with a consequent shift in species composition to those more typical of freshwater (Palmer & Reynolds 1983).

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

Surveys of 17 lagoonal sites in Orkney were carried out in.1994 as part of the MNCR's survey of isolated saline waters in Scotland and results are currently being prepared for publication as area summaries (Thorpe in prep.).

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Chapter 3: North Scotland (MNCR Sector 3)*

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Synopsis

The north coast of Scotland includes open rocky coast and some deep inlets. Loch Eriboll is the only sea loch on the north coast and the other inlets are sandy and include extensive sediment flats. There are also sandy beaches on the open coast. The limited marine biological surveys undertaken along this coast reveal a variety of rocky shore biotopes and the suggestion of some extensive tide-swept rocky habitats underwater at wave-exposed locations.

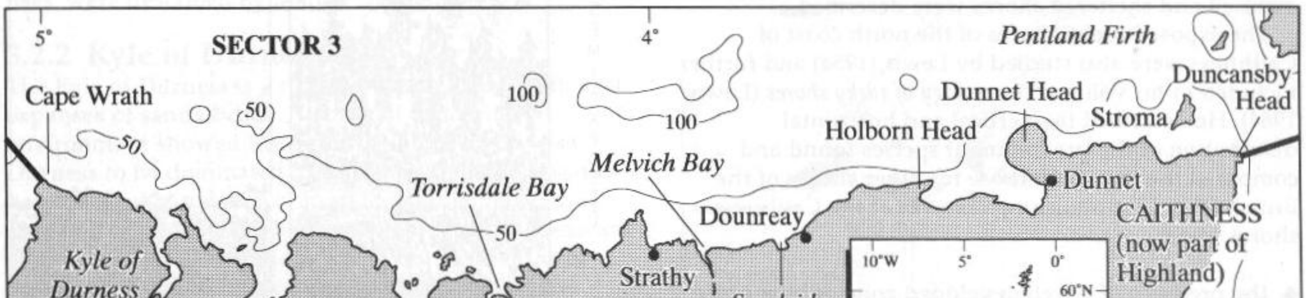

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Figure 3.1. The north coast of Scotland showing location of places mentioned in the text.

* This review was completed from published sources of information on benthic habitats and communities as well as interviews with relevant workers undertaken up to 1991 and published in Bennett (1991). It has been further revised to take account of major additional studies published 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 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.

3.1 Introduction

The north coast of Scotland, extending from Cape Wrath in the west to Duncansby Head in the east, is approximately 200 km in length. The coastline consists of predominantly rocky shores backed by cliffs, interrupted by the occasional sandy beach. Some of the highest cliffs on mainland Britain, at 91 m, occur at Cape Wrath. Much of the coastline experiences a tidal rise and fall of around 1.7 m, with tidal streams up to 9 knots (4.5 m s^{-1}) in the Pentland Firth between John O'Groats and Orkney (Jones 1975c).

Three major indentations are located in the western half of Sector 3, namely (from west to east) the Kyle of Durness, Loch Eriboll and the Kyle of Tongue. This is a wild and sparsely populated area, with only one major town, Thurso, and one major industrial establishment, the nuclear plant at Dounreay. Numerous streams and rivers meet the sea along this coastline, but its rocky nature means that estuarine conditions seldom occur. Buck (1993) reviewed the conservation status of four such habitats along this coast: the Kyle of Durness, Kyle of Tongue, Torrisdale Bay and Melvich Bay.

North Scotland has received little attention from marine biologists. The Natural Environment Research Council's Rocky Shore Surveillance Group carried out studies in the area from the mid-1970s to late 1980s, but these autecological investigations have focused on single species, rather than habitats or communities.

3.2 Studies of the marine environment and communities

3.2.1 Open coast

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

The exposed rocky shores of the north coast of Caithness were also studied by Lewis (1954) and further included in his volume *The ecology of rocky shores* (Lewis 1964). He described the vertical and horizontal distribution of the predominant species found and compared the data with those for other shores of the British Isles. Distinguishing features of the Caithness shores were:

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

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

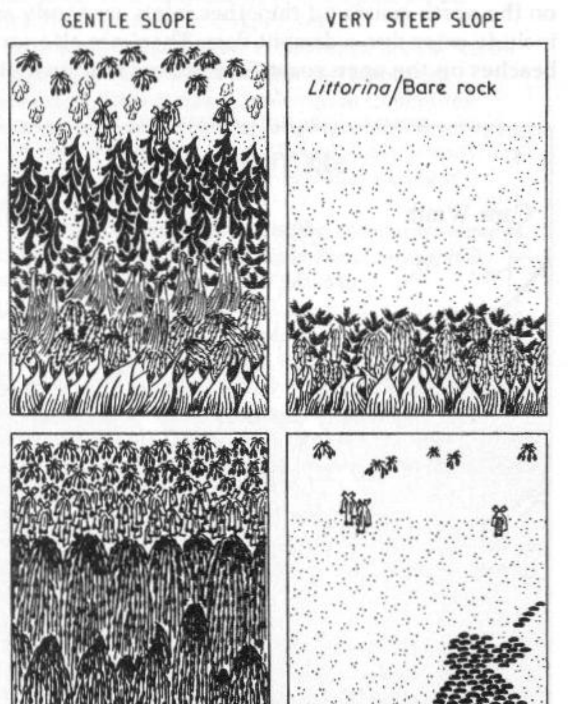

Figure 3.2. Contrasting communities on adjacent gentle and steep slopes at Baligill Point, North Sutherland. (From Lewis 1964.) In addition to the keyed species, mussels *Mytilus edulis* are shown bottom right.

Since 1971 the rocky shores at Dounreay have been part of a monitoring programme to study the annual differences in recruitment of limpets and barnacles around Great Britain (Bowman 1978). In 1977 an oil spill from an outfall at mid-tide level occurred at Dounreay. Observations were made of the shore at the time of the spill and at intervals afterwards. Similar mortalities to those recorded at Dounreay occurred at monitoring sites elsewhere. It was therefore deduced that the mortality to shore life noted at Dounreay was due to the hot summer of 1976 rather than the oil spill. The effect of Dounreay on the environment of the area was further considered as part of the proposal to build the European Demonstration Reprocessing Plant (Scott *et al.* 1985). Existing information on the coastal habitats of north Caithness was reviewed, including that for the sublittoral zone, though no new surveys were conducted.

A few studies have been carried out on the sandy shores of north Scotland. The intertidal fauna of sandy beaches at Strathy, Sandside and Dunnet was documented by Eleftheriou & McIntyre (1976). The three beaches were classified as 'exposed'; the communities and physico-chemical characteristics of the sediments were described. Dunnet, the largest beach, had a total of ten species; Sandside supported 16 species and Strathy nine species. The physical nature of beaches throughout the Highlands and Islands, together with their human uses, were described by Mather & Ritchie (1977).

3.2.2 Kyle of Durness

The Kyle of Durness is a twisting shallow inlet with vast expanses of sandy beach. A study of its marine environment showed the inner region of the Kyle of Durness to be dominated by well sorted medium sand deposits with a mixture of shingle boulder and gravel shores around the periphery and bedrock at the seaward end (Jones 1975a). In muddy shores at the mouths of rivers entering the Kyle of Durness the main species found were the amphipod *Corophium volutator,* and the polychaete worms *Nereis* (now *Hediste*) *diversicolor* and *Nerine cirratulus* (now *Scolelepis squamata*). The fucoid alga *Fucus ceranoides* was also found here and in the river channels. At the entrance to the inner Kyle well developed beds of large mussels *Mytilus edulis* were found (Figure 3.3). Salinity variation within the Kyle of Durness was considered to affect the penetration of stenohaline species. The absence of the limpet *Patella vulgata* and the dogwhelk *Nucella lapillus* and the restricted distribution of the periwinkle *Littorina littorea* in the inner Kyle was attributed to reduced salinity. In general the littoral zone was considered to be poor in terms of sediment infauna; the epifauna of exposed rocky shores was typically of high density and low diversity.

The sublittoral zone has been described from eight sites where the substratum, the extent of kelp cover and the common fauna were recorded (Glasgow University Exploration Society 1975). Bedrock with crevices, gullies, overhangs and caves and large boulders occurred at most sites, giving way to pebbles, clean sand or mud with increasing depth. In general the bedrock extended into greater depths where there was increased exposure

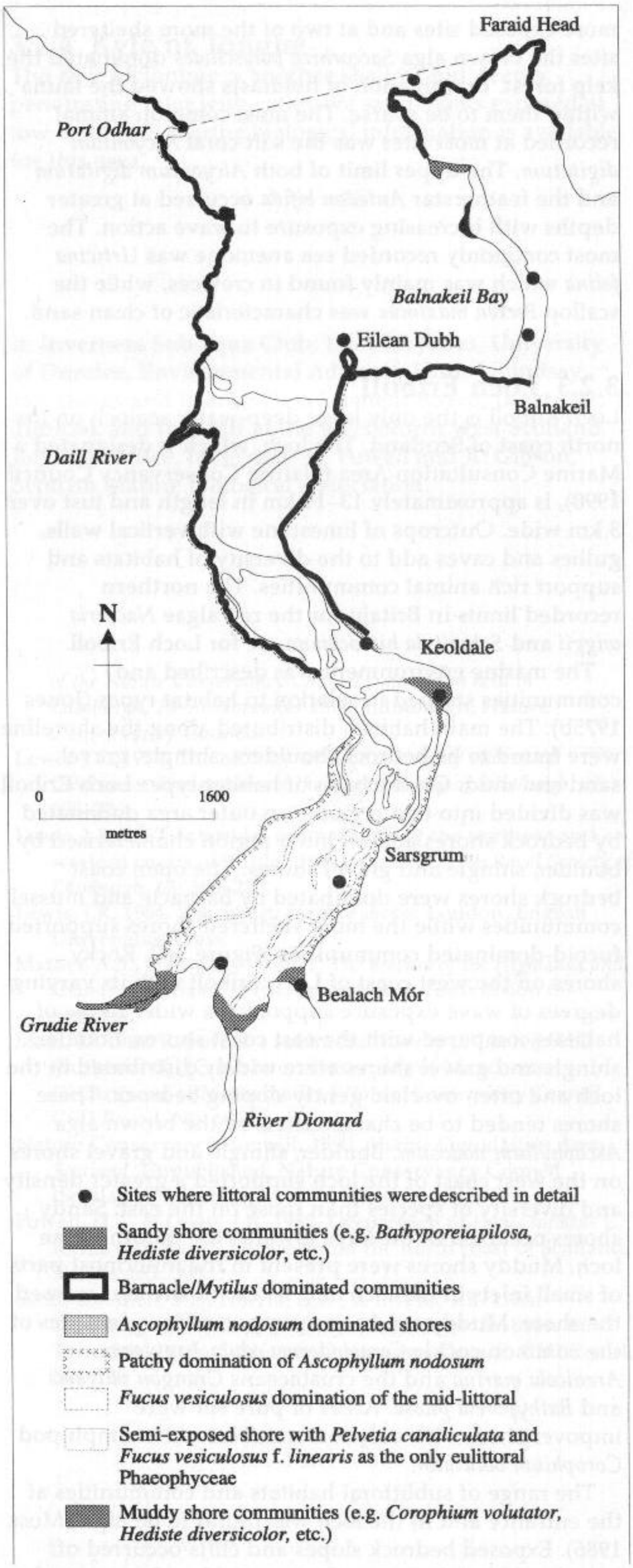

Figure 3.3. The distribution of littoral community types within the Kyle of Durness (re-drawn from Jones 1975a).

to wave action. At most sites laminarians extended from chart datum down to the limit of the rocks, with the deepest occurring at a depth of 23 m. The brown alga *Alaria esculenta* occurred down to about 3 m bcd at the more exposed sites and at two of the more sheltered sites the brown alga *Saccorhiza polyschides* dominated the kelp forest. Examination of holdfasts showed the fauna within them to be sparse. The most common animal recorded at most sites was the soft coral *Alcyonium digitatum*. The upper limit of both *Alcyonium digitatum* and the featherstar *Antedon bifida* occurred at greater depths with increasing exposure to wave action. The most commonly recorded sea anemone was *Urticina felina* which was mainly found in crevices, while the scallop *Pecten maximus* was characteristic of clean sand.

3.2.3 Loch Eriboll

Loch Eriboll is the only large deep-water sealoch on the north coast of Scotland. The loch, which is designated a Marine Consultation Area (Nature Conservancy Council 1990), is approximately 13–14 km in length and just over 3 km wide. Outcrops of limestone with vertical walls, gullies and caves add to the diversity of habitats and support rich animal communities. The northern recorded limits in Britain for the red algae *Naccaria wiggii* and *Schmitzia hiscockiana* are for Loch Eriboll.

The marine environment was described and communities studied in relation to habitat types (Jones 1975b). The main habitats distributed along the shoreline were found to be bedrock, boulders, shingle, gravel, sand and mud. On the basis of habitat types Loch Eriboll was divided into two regions: an outer area dominated by bedrock shores and an inner region characterised by boulder, shingle and gravel shores. The open coast bedrock shores were dominated by barnacle and mussel communities while the more sheltered shores supported fucoid-dominated communities (Figure 3.4). Rocky shores on the west coast of Loch Eriboll with its varying degrees of wave exposure supported a wider range of habitats compared with the east coast shores. Boulder, shingle and gravel shores were widely distributed in the loch and often overlaid gently sloping bedrock. These shores tended to be characterised by the brown alga *Ascophyllum nodosum*. Boulder, shingle and gravel shores on the west coast of the loch supported a greater density and diversity of species than those on the east. Sandy shores occurred in the bays towards the mouth of the loch. Muddy shores were present in the innermost parts of small inlets in the loch and where freshwater crossed the shore. Muddy sand areas supported low densities of the common cockle *Cerastoderma edule*, lugworm *Arenicola marina* and the crustaceans *Crangon vulgaris* and *Bathyporeia pilosa*. Areas of pure silt were impoverished, with only low numbers of the amphipod *Corophium volutator*.

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

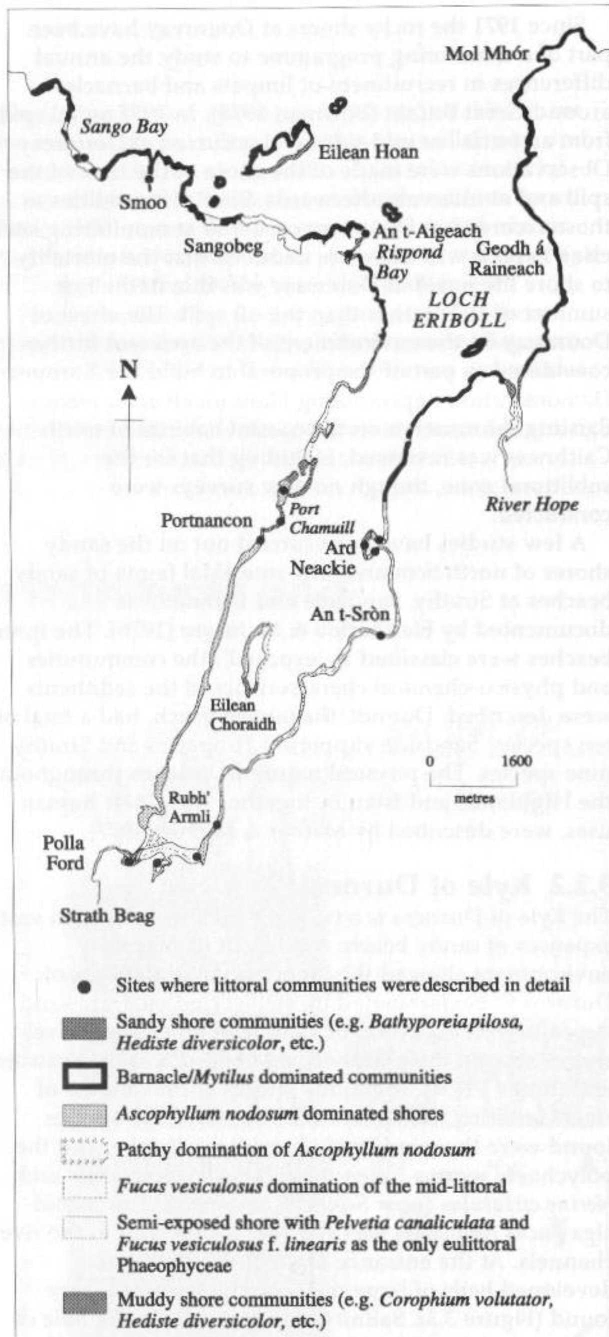

Figure 3.4. The distribution of littoral community types within Loch Eriboll. (Re-drawn from Jones 1975b.)

middle part of the loch and supported species including the anemone *Cerianthus lloydii*, the lugworm *Arenicola marina*, the bivalves *Pecten maximus*, *Chlamys opercularis* and brittlestar beds. Sparse patches of maerl occurred in hollows in muddy sand. Soft mud was found in deeper parts of the loch supporting the sea pen *Virgularia mirabilis* and the Norway lobster *Nephrops norvegicus*.

Lochan Havurn, a small brackish loch at the head of Loch Eriboll, was surveyed in 1994 as part of the MNCR's survey of isolated saline waters in Scotland. It was found to have two basins, one muddy with fully saline communities of *Halidrys siliquosa* and *Metridium senile*, and the other with a soft peat substratum with brackish-water communities of the seagrass *Ruppia* sp. and the isopod *Corophium volutator.*

3.2.4 Kyle of Tongue

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

3.3 Acknowledgements

Many people have assisted with this review by discussing current research and available information, while many organisations have offered the use of their libraries or have provided copies of documents. Particular thanks are due to the following for their contribution to this chapter of the present volume or the MNCR Occasional report (Bennett 1991) which preceded it: Inverness Sub-aqua Club; Dr A.M. Jones, University of Dundee, Environmental Advisory Unit; J. Lindsay, Highlands and Islands Development Board, Inverness; P. Tilbrook and the staff at the SNH North west Scotland Regional office, Inverness; H. Powell and R. Gibson, Scottish Marine Biological Association.

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